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Review article

Organic manures enhance biomass and improve content, chemical compounds of essential oil and antioxidant capacity of medicinal plants: A review

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ABSTRACT

The current farming systems strongly depend on chemical fertilizers (CF), which are widely applied to increase crop yield worldwide. However, although CF enhance crop yield in the short term, their excessive and long-term application can have adverse effects on environmental and human health. One of the most important goals of sustainable agriculture is substituting CF with organic manures. Organic manures can be used as a low-cost and safe alternative for CF. They contain essential nutrients for crop growth, improve soil conditions and nutrient availability, increase plant growth, and ultimately enhance yield. The application of organic manures to medicinal plants (MP) is more critical than to other plants, because organic manures not only enhance the growth and productivity of MP but also modify quality of their products. In this review, the effect of different types of organic manures on the biomass, content and chemical compositions of essential oil and antioxidant activity of various MP has been investigated. The included information was gathered from scientific databases such as Science Direct, Google Scholar, PubMed, and Scopus. Many of the collected studies showed that organic manures increase biomass and improve the quality of these plants. The findings of this review indicate that broiler litter (BL) and compost (C) are highly recommended as organic manures to promote biomass. Moreover, C, sheep manure, and vermicompost (VC) are suggested as the optimal organic manures for enhancing the essential oil content. Organic manures significantly changed the aroma profile of the essential oils and in many cases, they enhanced major chemical compositions. The usage of VC raised the content of the linalool of studied MP. Most of the organic manures, especially BL, VC, farmyard manure, and poultry manure increased the antioxidant activity of these plants. Hence, the utilization of organic manures can be recommended for productivity enhancement and quality improvement of MP.

1. Introduction

Nowadays, fulfilling the global demand for healthy and safe food for the ever-enhancing population now and into the future is a crucial challenge [1]. Modern farming systems produce high yields via the massive use of chemical fertilizers (CF) [2]. Extensive

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Abbreviations:

BL	broiler litter
C	carbon
C	compost
CAM	cattle manure
CF	chemical fertilizers
CM	chicken manure
COM	cow manure
Cu	copper
DDPH	2,2-diphenyl-1-picrylhydrazil
EC	electrical conductivity
Fe	iron
FM	farmyard manure
K	potassium
Mn	manganese
MP	medicinal plants
N	nitrogen
OC	organic carbon
P	phosphorus
PM	poultry manure
SM	sheep manure
VC	vermicompost
Zn	zinc.

utilization of CF enhance crop yield but increase the decomposition of soil organic matter, decrease soil microbial biomass, can cause soil acidification and deterioration, loss of nutrients via leaching, greenhouse gases emission, and pollution of water, air, and soil and ultimately threatening human, animal and plant health [1,3–7]. Therefore, excessive use of CF for crop production is not sustainable and more environment-friendly methods of food production are essential to meet the increasing food requirements.

In recent decades, organic farming has been advocated as an alternative form of agriculture for sustainable food production by removing the impact of CF on the environment [1]. Organic farming is supportive of the environment, health, and sustainability [8] and produces food without the use of any chemical inputs such as CF. This agriculture system makes use of eco-friendly fertilizers such as organic manures instead of CF. Organic farming preserves biodiversity, decreases the environmental pollution of soil, water, and air [9] and increases soil organic carbon, essential nutrients content, microbial population, and enzymatic activity of soil [10]. Thus, this farming system has become a great choice for organic production [10] and is a method for making available safe and healthy food and a clean environment [11]. On the other hand, consumers are paying more attention to the quality of products for human consumption and their pro-health qualities [12], and food consumption patterns are also altering as a result of health and environmental issues; hence, interest in organically produced food is enhancing around the world [13,14]. A variety of factors can potentially affect organic food consumption. Concerns for health and the chemical residues in conventional food products, nutritional concerns, environmental protection, as well as improved taste and flavor in organic products are some of the factors identified [15,16].

As mentioned above, in organic farming, CF substitutes with organic manures. Organic fertilizers have the potential to harbor pathogens [17] and soluble salts [18]. Additionally, they may contain relatively low levels of nutrients, necessitating higher quantities to adequately supply the necessary nutrients for optimal plant growth and development [17]. Due to the slow release rate of nutrients, there is a possibility of nutrient deficiency occurring as the crop's requirements may not be met within a short time [19]. The decomposition of organic matter is greatly influenced by soil moisture and temperature, resulting in the release of nutrients even when the plant does not require those [17]. However, despite these drawbacks, the advantages of utilizing organic manures outweigh their disadvantages [20]. Agriculture systems under the use of organic manure can produce more sustainable, healthier, and cleaner plant products [21]. Organic manures can be used as a safe and environmentally friendly alternative for CF [22], and have apparent advantages over CF in many aspects. First, they are primarily cost-effective, and more readily available in small-scale local productions than CF [23]. Second, organic manures have a higher content of organic matter and essential nutrients (macro and micro) [24–26]. Furthermore, it has been observed that organic manures exhibit a lower nutrient loss, particularly nitrogen (N), through leaching compared to CF [27,28]. This can be attributed to the organic matter's ability to bind with soil particles, thereby making it accessible to plant roots [29]. They improve soil's physical, chemical, and biological properties [30,31], and increase anion and cation exchange capability and water holding capacity [32]. Finally, organic manures create a suitable environment for better growth and higher productivity of crops [33].

The medicinal plants (MP) refer to a variety of that have medicinal value and properties [34]. Thyme, peppermint, rosemary, lavender, dill and basil are the most important of MP. In the body of MP, bioactive compounds like alkaloids, flavonoids, terpenoids, phenolics, and essential oils are produced and stored [34,35]. These bioactive compounds have pharmacological characteristics, such as antibacterial, antiviral, antifungal, antioxidant, anti-inflammatory, anticancer [35]. The composition and concentration of bioactive compounds in MP are indicators of quality [36,37]. In these plants, the quality of the end product is a crucial issue; indeed, their actual value originates from their quality, while yield quantity comes in the second step of importance [10]. The potential uses of MP depend on their quality and MP containing higher quality are more valuable [38]. Ensuring the quality of MP recently became a key issue, both in developing and industrialized countries [34]. Quality of MP may be highly affected by agronomic management practices such as nutrient management [39,40]. Proper nutrients management in cultivation of MP is essential to obtain a high quality of products [41]. During recent decades, the demand for organic MP has also been raised [42,43] and cultivation of MP with the utilization of organic manures is therefore enhancing [10,44]. The positive interaction between organic manures and the quality of MP has caused many researchers to investigate the effects of organic manures on the quality of these plants [45]. Many scholars believe that MP cultivated in organic farming systems mostly have higher quality than those cultivated in conventional agricultural systems [22,40,43,46–49]. Essential oils are one of the most important bioactive compounds and indicator of quality of MP. They are widely used in various fields and industries like aromatherapy, cosmetics, perfume and fragrance, incense, food preservative, biopesticides, and insecticides industries [50]. Among various pharmaceutical and biological activities that are assigned to MP, antioxidant activity is one of the most important to them. MP produce a wide variety of bioactive compounds having strong antioxidant effects. Antioxidants have the ability to protect cells from free radicals damage and act as chemopreventive agents by inhibiting the generation of free radicals and play a key role in neutralizing oxidative damage caused by these free radicals and to be very important in the prevention of many diseases [51]. Much research has been addressed worldwide to investigate the impact of the usage of organic manures on the productivity, content and chemical constituents of essential oil, antioxidant activity of MP, and there is a need for a comprehensive review of these results. Therefore, this review presents a comprehensive survey of the literature about the influence of various types of organic manures on yield, essential oil (content and chemical compounds) and antioxidant capacity of different MP. The primary objective was to examine the potential impact, whether positive, negative, or both, of organic manures on the biomass, content and chemical compositions of essential oil, as well as the antioxidant activity of these plants. This review was conducted to confirm whether organic manures can be used as a safe and effective method for enhancing the yield and quality of MP and to provide information to help in future research and development in the organic cultivation of MP.

2. Methods

This review paper was carried out through a literature search performed in November 2022 and included articles published over 20 years (2002–2022). The databases of Science Direct, Google Scholar, PubMed and, Scopus were used as a basis for the literature search. Medicinal plant(s), aromatic plant(s), essential oil(s), chemical composition(s), oil composition(s), antioxidant activity, organic manure(s), organic fertilizer(s), organic fertilization, organic farming, animal manure, broiler litter (BL), poultry manure (PM), chicken manure (CM), sheep manure (SM), cattle manure (CAM), cow manure (COM), farmyard manure (FM), vermicompost (VC), and compost (C) were used as keywords. The manuscript selection was based on papers published in English and dealing with the above keywords in the title, abstract or, full text (some articles were indexed in two or more databases or contained two or more keywords). After that, the documents obtained through the initial search (420 papers) were checked and the papers in non-English language, review papers, papers without available abstracts or full texts, papers published in conferences, book and chapters of books, were discarded and finally were selected 80 papers. The resulting selected documents are presented in Table S1. The effect of organic manures on the biomass and quality of various medicinal plants in ten families, namely Apiaceae (Umbelliferae), Asteraceae (Compositae), Fabaceae (Leguminosae), Geraniaceae, Lamiaceae (Labiatae), Myrsinaceae, Passifloraceae, Plantaginaceae, Polygonaceae and Ranunculaceae was investigated. Most studies were devoted to the family Lamiaceae, followed by Apiaceae and Asteraceae. Among MP, the effect of organic manures on fennel, coriander and dill (Apiaceae), chamomile and marigold (Asteraceae), basil, dragonhead, lavender, rosemary, peppermint, savory, and thyme (Lamiaceae), endowed with a high medicinal value and a strong industrial interest, was in-depth evaluated. The Apiaceae represent one of the largest herbal families, whose members are well-known as vegetables, culinary, and MP [52]. The Asteraceae form the biggest family of flowering plants; many members of this family have potential medicine and pharmaceutical applications and are used in the cosmetic and food industries [53]. Lastly, the Lamiaceae include a wide variety of MP [54] that are the basic source of phytochemical formulations which, besides having a beneficial effect on health or playing an active role in the treatment of diseases, are widely used to improve the flavor and aroma of foods, hence the quality of food products [55].

60% of the studies related to the impact of organic manures on the quantity and quality of MP were conducted in Iran, followed by Egypt, India, Turkey, Brazil, and Malaysia (Table S1). Eleven authors, among which two authors of this review, have published 2 or 3 articles related to the effect of organic manures on the quantity and quality of MP (Table S2). The journal “Industrial crops and products” was the dominant source title, followed by the “Journal of Medicinal Plants and By-products” and the “Journal of Essential Oil Bearing Plants” and a variety of journals that published two or three papers (Table S3). After selecting the articles, we examined the effects of organic manures reported on biomass, the content and chemical compositions of the essential oils, as well as the antioxidant capacity of the studied MP.

3. The effect of organic manures on the biomass of medicinal plants

Challenges with the use of organic manures include erratic nutrient content, a low speed of their release, and therefore the need to synchronize nutrient mineralization and crop nutrient demand [56,57]. The nutrients composition of organic manures varies widely with the species, age, and sex of the animal and its diet, management system, water intake, the amount of any added bedding material included in the manure, as well as the losses that occur during storage [58,59]. CF can directly supply nutrients to plants after mixing with soil, whereas organic manures release nutrients slowly and gradually [19]. Nutrients released by organic manures are stored for a longer period in the soil without significant loss and are efficiently used during the later growth stages of plants, but sometimes this slow and gradual release of nutrients is not able to fulfill the nutritional requirements of crops [19]. Additionally, to utilize organic manure to efficiently meet the nutrient requirements of plants, knowledge of the amount of nutrients mineralized after distribution is required [60], and to effectively apply the nutrients in organic manures, their mineralization potential should be considered when determining utilization rates [60]. Nutrients mineralization from organic manures depends on chemical and physical properties of the soil, such as pH, temperature, moisture, microbial activity, and total N and organic carbon (OC) content, as well as on organic manures characteristics like N content, C/N ratio, water-soluble compounds and recalcitrant components [59]. Since most of these factors cannot be accurately predicted, only an approximated estimate of organic manure nutrient mineralization after usage is possible [60]. Recommendations on organic manures are usually based on the plant's N requirement [61]. Typically, the assumption is that N release is the same for all organic manures, even though large variability in organic manure properties was demonstrated even among the same animal species [62,63]. N mineralization differs for various types of organic manures due to differences in their properties. Among the factors affecting N mineralization, usually the amount of N and C, and their ratio (C/N) in soil and organic manure are determined, and the mineralization potential is evaluated based on them. However, organic manures with the same the C/N ratios may mineralize various contents of N because of differences in composition that are not reflected by the C/N ratio itself. Thus, C/N ratio alone cannot explain all differences in N mineralization [64]. Some studies have identified groups such as proteins, polyphenols, soluble carbohydrates, cellulose-like, hemicellulose-like compounds, and lignin-like and have related them to organic residue decomposition [64–66]. Overall, the N mineralization rate of non-composted manures is higher than composted ones. Lower N mineralization from compost over non-composted organic manures reflects the loss of readily convertible N and C compounds during composting and the presence of stable N compounds [60,61]. Various studies indicated that PM has higher N mineralization (because of higher N and lower C/N ratio) compared to other studied organic manures in the same experiment [59,67–69].

On the other hand, there must be a balance between the supply of nutrients (especially N) and the demand for nutrients by the plants (synchrony). Given that synchrony is defined as a close balance between nutrient supply and demand, there are two types of asynchrony. The first type (excess asynchrony) takes place when nutrient availability exceeds crop requirements, often because the release occurs at a time when crop demand is restricted or non-existent. The second type (insufficient asynchrony) takes place when the nutrient supply is insufficient to fulfill crop needs at certain times [70]. Excess-nutrient asynchrony is likely to happen in organic farming systems due to the continuous release of nutrients from organic manures and soil organic matter, and nutrients deficiencies may take place during periods of nutrients immobilization [70,71]. In general, biomass and yield of MP under the application of organic manure are highly affected by the availability of nutrients, nutrients-release rate, balance between nutrients supply and plants' demand, amount of organic manure supply, and soluble salts content in applied organic manures.

Considerable research has focused on the influence of organic manures on the biomass and yield of MP. Organic manures contain significant nutrients (macro and micro) [32]. Compared to CF, macro- and micronutrients from organic manure are released more slowly and gradually, and stored for a longer time in the soil [19,72]. When organic manure is applied to soil, it improves its chemical, physical, and biological properties [73], and increases organic matter and carbon content, microorganism activity in the soil, anion and cation exchange capability, water holding capacity, and ultimately crop yield [24,32]. Organic manures play an important role in the growth and biomass accumulation of MP, eventually leading to cleaner and healthier production [48]. In the majority of surveyed cases (Table 1), MP amended with organic manures produced higher biomass than unsupplied plants. In some cases, this response was evident only after the second cultivation year, or when organic manures were supplied at a high dose. For example, in two separate studies by Emami Bistgani et al. [74] on Denaian thyme (*Thymus daenensis* Celak) and Hosseini et al. [75] on Sahandi savory (*Satureja sahendica* Bornm.), the biomass of Denaian thyme treated with VC and Sahandi savory nourished with CAM were similar after organic manure distribution and in the controls in the first cultivation year, whereas biomass of both species after the usage of organic manure, compared to control plants, raised in the second cultivation year. Dashti et al. [76] and Moghaddam et al. [77] stated that *Salvia leriifolia* (Benth.) amended with 10 t h^{-1} of C, and agastache (*Agastache foeniculum)* supplied with 20 t h^{-1} of COM, did not exhibit any significant difference in biomass over the control plants; in both species, however, the biomass raised with a higher administration of C (20 t h^{-1}) and COM (25 t ha^{-1}) compared to the controls. In another study, the fresh weight yield of *Satureja mutica* under grown the application of CAM and control treatment was alike in the first year, while it was enhanced by the addition of CAM in the second year. The dry weight of this plant was boosted after CAM in both years over control plants [78]. Gholami et al. [46] reported that the usage of various levels of VC (5, 7.5, and 10 t h^{-1}) caused the fresh weight of chicory (*Cichorium intybus* L.) to increase than control conditions; in this case, only plants treated with a high level of VC (10 t h^{-1}) had higher dry weight compared to untreated plants.

As indicated in Table 1, different results were obtained when organic manures application was compared to CF. Among the various types of organic manures, BL and C were found to increase the biomass or grain yield of most of the studied MP compared with CF [22,43,47,48,79,122,125,127]. Salehi et al. [79] reported that the usage of BL enhanced above-ground dry matter of fenugreek (*Trigonella foenum-graecum*) in the first year and its seed yield in the second year more than CF. In the same work, the addition of BL did not bring any significant difference over CF in above ground dry matter in the second year (except in one cropping pattern) and seed yield in the first year. These authors also claimed that the common buckwheat (*Fagopyrum esculentum* Moench) treated with BL produced the highest above-ground dry matter in first and second year and the application of BL boosted seed yield of this plant in both years compared to CF. Forouzandeh et al. [121] stated that basil (*Ocimum basilicum* L.) fertilized with CF produced a higher biomass compared with plants grown with the usage of C. The result by Gharib et al. [124] indicated a low level of C increased the fresh and dry weight of Sweet marjoram (*Majorana hortensis*) in the first, second, and third cutting, while the high level of C only boosted the fresh and dry weight of this plant in third cutting. BL has a higher content of essential nutrients (especially N) and a lower C/N ratio, and experiences faster decomposition than other organic manures, therefore providing a larger amount of essential nutrients for plant

Table 1
Summary of results from the literature about the effects of the administration of different types of organic manures on biomass or seed yield or both in several medicinal plants.

Medicinal plant (s)	Organic manure	Control	CF	Results (organic manure vs. control or CF or both)	Reference (s)
Dracocephalum kotschyi[c]	BL	+	+	Control and CF: increased	[48]
Dragonhead	BL	–	+	CF: increased	[22]
Dill	BL	–	+	CF: increased	[47]
Black cumin	BL	–	+	CF: increased	[43]
Fenugreek[d]	BL	–	+	CF: increased above ground dry matter in the first year and seed yield in the second year[a]	[79]
Common buckwheat[d]				CF: produced the highest above ground dry matter and increased seed yielda	
Japanese mint	PM	+	–	Control: increased	[44]
Basil and marigold	PM	+	+	Control: increased; CF: decreased	[32,80]
Pelargonium graveolens L'Hér.	PM	+	+	Control: increased; CF: decreased	[81]
Sweet fennel[d]	PM	+	–	Control: increased	[82]
Chamomile[d]	CM[b]	+	–	Control: increased	[83]
Dill[d]	CM	–	+	CF: increased fresh and dry weighta	[84]
D. kotschyi[c]	SM	+	+	Control: increased	[48]
Rosemary	SM	+	+[b]	Control and CF: increased	[85]
Thyme[c],[d]	SM	+	–	Control: increased	[86]
Bakhtiari savory[d]	CAM	+	–	Control: increased	[87]
Sahandi savory[d]	CAM	+	–	Control: increased in the second year	[75]
Ducrosia anethifolia	CAM	+	+	Control: increaseda	[88]
Lemon balm	CAM	+	–	Control: increased	[89]
Satureja mutica[d]	CAM	+	–	Control: increased fresh weight in the second year and increased dry weight	[78]
Khella[d]	CAM[b]	+	–	Control: increased	[90]
Sweet basil[c],[d]	CAM[b]	+	–	Control: increased	[91]
Dragonhead	CAM[b]	+	–	Control: increased	[92]
Basil (cv. green and purple)	CAM[b]	+	–	Control: increased	[93]
Marigold	CAM[b]	–	+	CF: increased	[94]
Caraway[d]	CAM[b]	+	–	Control: increased	[95]
S. macrantha C.A.Mey.[d]	COM	+	+	Control: increased; CF: increased in the second year	[96]
Lavender	COM[b]	+	–	Control: increased	[97]
Coriander	COM	+	+	Control: increased shoot and root dry weight; CF: decreased shoot dry weight	[98]
D. kotschyi[c]	COM	+	+	Control: increased; CF: decreased in the first cutting	[48]
Fennel	COM[b]	+	–	Control: increased	[99]
Thymus daenensis[d]	COM	+	–	Control: increased	[100]
Denaian thyme[d]	COM	+	+	CF: decreased in the second year	[74]
Lavender	COM[b]	+	–	Control: increased leaf yield	[101]
Agastache	COM[b]	+	+	Control: increased at high level; CF: increased	[77]
Digitalis purpurea L.[d]	FM	+	–	Control: increased	[102]
Coriander	FM[b]	+	–	Control: increased	[33]
Chamomile[d]	FM[b]	+	–	Control: increased	[83]
Japanese mint	FM	+	–	Control: increased	[44]
Basil and marigold	FM	+	+	Control: increased; CF: decreased	[32,80]
P. graveolens L'Hér	FM	+	+	Control: increased; CF: decreased	[81]
Indian basil[d]	FM	+	+	Control and CF: increased	[103]
French basil	FM	+	+	Control: increased; CF: decreased	[104]
Lavender	VC[b]	+	–	Control: increased	[45]
Peppermint	VC	+	–	Control: increased	[49]
D. purpurea L.[d]	VC	+	–	Control: increased	[102]
Fenugreek	VC	–	+	CF: decreased seed yielda	[105]
Lavender	VC[b]	+	–	Control: increased	[97]
Dragonhead	VC	+	+	Control: increased; CF: produced the lowest	[106]
Black cumin[d]	VC	+	+	Control and CF: increased	[107]
Coriander (vr. Arslan)	VC	+	+	Control: increased; CF: decreaseda	[108]
Coriander (vr. Erbaa)				Control: increased seed yield; CF: decreaseda	
D. anethifolia	VC	+	+	Control: increased; CF: increased seed yielda	[88])
Sweet basil[c]	VC	+	–	Control: increased	[109]
Marigold	VC	+	–	Control: increased	[110]
Moldavian balm	VC	–	+	CF: decreased	[111]
Denaian thyme[d]	VC	+	+	Control: increased in the second year; CF: decreased in the first year	[74]

(continued on next page)

Table 1 (*continued*)

Medicinal plant (s)	Organic manure	Control	CF	Results (organic manure vs. control or CF or both)	Reference (s)
Chicory	VC[b]	+	–	Control: increased fresh weight and dry weight at high level	[46]
Chamomile[d]	VC[b]	+	–	Control: increased	[112]
Salvia Leriifolia Benth.	VC	+	–	Control: increased	[113]
Lavender	VC[b]	+	–	Control: increased stem and shoot yield	[101]
Japanese mint	VC	+	–	Control: increased	[44]
Basil and marigold	VC	+	+	Control: increased; CF: decreased	[32,80]
P. graveolens L'Hér	VC	+	+	Control: increased; CF: decreased	[81]
Agastache	VC	+	+	Control and CF: increased	[77]
Rosemary	VC	+	+[b]	Control and CF: increased	[85]
Fennel	VC[b]	+	+	Control and CF: increased	[114]
Peppermint	VC	+	+	Control and CF: increased	[115]
Indian basil[d]	VC	+	+	Control: increased	[103]
Rosemary	VC	+	+	Control: increased; CF: decreased	[116]
Chamomile	VC[b]	+	–	Control: increased	[117]
French basil	VC	+	+	Control: increased	[104]
S. leriifolia Benth.[d]	C[b]	+	–	Control: increased at high level	[76]
Coriander	C[b]	+	–	Control: increased	[118]
Fennel[d]	C[b]	+	–	Control: increased	[119]
S. Leriifolia Benth.	C	+	–	Control: increased	[113]
Khella[d]	C[b]	+	–	Control: increased	[90]
Medicinal plant (s)	**Organic manure**	**Control**	**CF**	**Results (organic manure vs. control or CF or both)**	**Reference (s)**
Cumin	C	+	–	Control: increased	[120]
Basil	C	+	+	Control: increased; CF: decreased	[121]
Chamomile	C[b]	+	+[b]	Control and CF: increased	[122]
Thyme[c],[d]	C	+	–	Control: increased	[86]
Thyme[c]	C[b]	+	–	Control: increased	[123]
Sweet marjoram[c]	C[b]	–	+	CF: increased at low level	[124]
Bitter fennel and sage[c]	C[b]	–	+	CF: increased	[125]
Dragonhead	C[b]	+	–	Control: increased	[126]
Basil[d]	C[b]	–	+	CF: increased	[127]

CF: chemical fertilizer, BL: broiler litter, PM: poultry manure, CM: chicken manure, SM: sheep manure, CAM: cattle manure, COM: cow manure, FM: farmyard manure, VC: vermicompost and C: compost.

[a] Both biomass and seed yield measured.

[b] Organic manure or CF used at more than one level.

[c] Biomass or seed or yield or both measured in two or more cuttings.

[d] Biomass or seed yield or both measured in two years or two seasons. When not otherwise specified, changes of biomass or seed yield have occurred in all cutting or seasons or years or levels of organic manure or CF or both.

growth [48,79]. On the other hand, BL contains smaller particles compared with other organic manures. Smaller particle size would have a larger surface-to-volume ratio and may release nutrients faster [57]. C is characterized by high macro-micronutrients and organic matter content. Besides playing a role in plant yield increase, C improves the physical and chemical properties of soil, such as structure, aggregation, porosity, air exchange, hydraulic conductivity, water holding capacity, microbial activity, and pH of soil [128,129].

In a few cases, such as *Pelargonium graveolens* L'Hér., marigold (*Tagetes minuta* L.) and basil, plant biomass obtained by applying PM was lower than using CF [32,81,80]. It seems that the reduction in biomass of plants treated with PM may be due to slow release or high soluble salts in this manure.

Khalid and Shafei, [84] stated that the supply of CM raised the fresh and dry weight of dill (*Anethum graveolens* L.) during two continuous seasons compared with CF. Hosseini Valiki et al. [85] noted that the addition of SM boosted the biomass of rosemary (*Rosmarinus officinalis* L.) by 15%–95% than various rates of CF. SM and CM are rich in macro-micronutrients. They also maintain the content of organic matter in soil and improve soil physicochemical properties including structure, aeration, water holding capacity, also reducing bulk density [84,130–132].

The usage of COM and FM often reduced the biomass of MP compared to CF. Serri et al. [98] found that the biomass of coriander (*Coriandrum sativum* L.) reduced after the administration of COM over CF. The result of Fallah et al. [48] indicated that usage of COM led to a biomass decrease in *Dracocephalum kotschyi* in the first cutting than CF. At the second cutting, harvested biomass was alike in COM and CF treatments. Emami Bistgani et al. [74] demonstrated that in the first cultivation year, the biomass of Denaian thyme was similar in plants grown using COM and CF; however, in the second cultivation year, the utilization of COM reduced the biomass over CF. In contrast, Moghaddam et al. [77] noted that the application of 20 and 25 t ha^{-1} of COM enhanced more than CF the biomass of agastache. Baniyaghoub Abkenar et al. [96] claimed that the biomass of *Satureja macrantha* (C.A.Mey.) was alike in CF and COM treatments in the first year, otherwise in the second year, biomass boosted after the distribution of COM compared to CF. Anwar et al. [104]; Pandey and Patra, [81]; Pandey et al. [32,80] stated that French basil, *P. graveolens* L'Hér., basil and marigold amended with FM had lower biomass over CF. Oppositely, Singh et al. [103] demonstrated that the addition of FM boosted Indian basil more than CF. The lower biomass obtained from the FM and COM treatments may be due to the slow decomposition of these manures [48,103]. COM and

FM have a high C/N ratio and release low nutrients in the plant's rhizosphere [48,59].

VC is one of the most common organic manures. In this review, most studies were devoted to VC (Table 1). Vermiculture is a process by which various types of waste such as wastes from kitchens, markets, livestock, and farms, as well as bio-wastes from agro-based industries, are converted while passing through the worm-gut to nutrient-rich VC [133]. Many scholars all over the world have reported that the nutrients in VC are generally higher than in C. This manure can raise soil fertility physically, chemically, and biologically. Physically, VC-amended soil has better porosity, aeration, water retention, and bulk density. Chemical properties such as organic matter content, electrical conductivity (EC), and pH are also improved, eventually increasing crop yields [134]. Ayyobi et al. [115]; Moghaddam et al. [77]; Hosseini Valiki et al. [85,114]; Sadat Darakeh et al. [107]; Yousefi Rad and Radbakht, [88] claimed that the consumption of VC led to increased biomass of peppermint (*Mentha piperita* L.), agastache, rosemary, fennel (*Foeniculum vulgare*), black cumin (*Nigella sativa* L.) and *Ducrosia anethifolia* compared with CF. In contrast, Singh and Guleria, [116]; Pandey and Patra, [81]; Pandey et al. [32,80]; Vafadar-Yengeje et al. [111]; Garshasbi et al. [105]; Özyazici, [108], found that the utilization of VC decreased the biomass of rosemary, *P. graveolens* L'Hér., basil, marigold, moldavian balm (*Dracocephalum moldavica* L.), fenugreek and two varieties of coriander (Coriander (*Coriandrum sativum* L.) over CF. Emami Bistgani et al. [74] demonstrated that Denaian thyme fertilized with CF had higher biomass compared to VC in the first year. Otherwise, in the second year, biomass was similar in CF and VC treatments. Rezaei-Chiyaneh et al. [106] reported that although biomass of dragonhead supplied with CF and VC was alike in most cropping patterns, the lowest biomass was obtained in VC treatment. The major problem of extensive usage of VC is plant toxicity via high soluble salts content [134,115,135]. High salt concentration can be reduced with leaching [115], or VC should be utilized at a moderate dose to achieve maximum plant yield [134]. Moreover, the slow release of nutrients in VC can reduce the biomass of MP [103].

As presented in Table 1, the biomass of common buckwheat, *Ducrosia anethifolia,* chamomile (*Matricaria chamomilla* L.), sweet marjoram, sage, bitter fennel, peppermint, and fennel was enhanced by the application of one organic manure compared to CF. The usage of two organic manures boosted the biomass of agastache, black cumin, and dill in comparison with CF. The supply of more than one organic manure marigold, *P. graveolens* L'Hér, coriander, and Denaian thyme gave lower biomass over CF. Biomass of dragonhead, rosemary, *D. kotschyi,* fenugreek, and basil genotypes had contrasting responses (both positive and negative) to the usage of organic manures. This information could be helpful in future research into the influence of organic manures on the biomass of these MP.

4. The effect of organic manure on the quality of medicinal plants

4.1. Essential oil content

Essential oils are complex mixtures of volatile compounds, with various functional group classes, that are produced as secondary metabolites by many MP [136]. They are usually stored in specialized plant cells, such as oil cells or ducts, resin ducts, glands or trichomes (glandular hairs) [137], located in leaves, buds, flowers, seeds, fruits, roots, wood and bark, from which they can be extracted [138]. Different pharmaceutical and biological activities, such as antibacterial, antiviral, antifungal, antimutagenic, antiprotozoal, anticancer, antiinflammatory, and antidiabetic properties, are assigned to them [39]. Essential oils are widely used in the food, agricultural, sanitary, cosmetic, and pharmaceutical industries [139] and are added to foods as spices or herbs.

The production of plant secondary metabolites, including essential oils, is very much related to fertilization management [48,140,141], and fertilizers, including organic manures, can affect the essential oil content of MP. As reported by the literature (Table 2), plants grown under the application of organic manure often have higher essential oil content over control plants. The results of some studies indicated that the increase in the essential oil of MP grown under organic fertilization was not observed at all levels or in two consecutive years. For instance, Daneshian et al. [93] stated that a high level of CAM led to an increase in the essential oil of basil (cv. green) compared with untreated plants. The essential oil content of this plant was similar at a low level of CAM and control. Similar results were observed on chamomile amended with FM [83]. In a study by Mirjalili et al. [87] on Bakhtiari savory (*Satureja bachtiarica* Bunge.), the addition of CAM boosted the synthesis of essential oil than control conditions in the first year, whereas in the second year, the essential oil content was alike in plants nourished with CAM and control plants. In two various studies, Baniyaghoub Abkenar et al. [96] and Keshavarz Mirzamohammadi et al. [142] stated that *S. macrantha* (C.A.Mey.) amended with COM and peppermint supplied with VC, did not exhibit any significant difference in essential oil compared to the control plants in first cultivation year; while the addition of organic manures raised essential oil in both species more than in the control plants in the second cultivation year. Emami Bistgani et al. [74] in Denaian thyme revealed that the essential oil content of this plant in the first year was lower in plants supplied with VC compared to the controls, whereas in the second year, the plants amended with VC had a higher essential oil content than unfertilized plants.

Several studies have also been addressed to compare the effect of organic manures with CF. As shown in Table 2, the usage of several organic manures (SM, C, and VC) increased the essential oil content of most of the studied MP compared with CF [122,125,127,124,84,85,104,115,88]. In some cases, this response was not always linear, and some researchers have reported enhancement of essential oil content in MP supplied with organic manures at only one level, or in one harvest, or in one year or in some cropping patterns. For example, the result of Moghaddam et al. [77] on agastache indicated no significant difference in the essential oil content between plants amended with COM (20 t ha^{-1}) and CF; however, essential oil content of the same species increased by 27% over CF after a slightly higher administration of COM (25 t ha^{-1}). In the study by Hosseini Valiki et al. [114], the utilization of 15 t h^{-1} of VC enhanced the essential oil content of fennel by 58% in comparison with CF, while the application of 5, 10, and 20 t h^{-1} of VC did not cause any significant difference. Baniyaghoub Abkenar et al. [96] reported that the essential oil of *S. macrantha* (C.A.Mey.) was similar in COM and CF treatments in the first cultivation year, whereas in the second year, plants supplied with COM had higher essential oil

Table 2
Summary of results from the literature about the effects of the administration of different types of organic manures on essential oil content in several medicinal plants.

Medicinal plant (s)	Organic manure	Control	CF	Results (organic manure vs. control or CF or both)	Reference (s)
D. kotschyi[b]	BL	+	+	Control: increased; CF: increased in the second cutting	[48]
Artemisia annua L.	PM	+	+	Control: increased; CF: decreased	[143]
Coriander	PM[a]	+	–	Control: increased	[144]
Turkish sage	PM	+	–	Control: increased	[145]
Chamomile[c]	CM[a]	+	–	Control: increased	[83]
Dill[c]	CM	–	+	CF: increased in the first season and decreased in the second season†	[84]
D. kotschyi[b]	SM	+	+	Control: increased; CF: increased in the second cutting	[48]
Rosemary	SM	+	+[a]	Control and CF: increased	[85]
Thyme	SM	+	–	Control: increased	[86]
Turkish sage	SM	+	–	Control: increased	[145]
Dill[c]	SM	–	+	CF: increased†	[84]
Bakhtiari savory[c]	CAM	+	–	Control: increased in the first year	[87]
D. anethifolia	CAM	+	+	Control: decreased; CF: increased	[88]
Sweet basil[b,c]	CAM[a]	+	–	Control: increased	[91]
Basil (cv. green)	CAM[a]	+	–	Control: increased at high level	[93]
Basil (cv. purple)				Control: increased	
Thyme	CAM	+	–	Control: increased	[86]
Turkish sage	CAM	+	–	Control: increased	[145]
S. macrantha C.A. Mey.[c]	COM	+	+	Control and CF: increased in the second year	[96]
D. kotschyi[b]	COM	+	+	Control: increased in the second cutting; CF: decreased in the first cutting and increased in the second cutting	[48]
Lavender	COM[a]	+	–	Control: increased	[97]
Medicinal plant (s)	**Organic manure**	**Control**	**CF**	**Results (organic manure vs. control or CF or both)**	**Reference (s)**
Denaian thyme[c]	COM	+	+	Control: increased; CF: increased in the first year and decreased in the second year	[74]
Agastache	COM[a]	+	+	Control: decreased at low level; CF: increased at high level	[77]
A. annua L.	FM	+	+	Control: increased; CF: decreased	[143]
Chamomile[c]	FM[a]	+	–	Control: increased at high level	[83]
Dragonhead	FM	+	–	Control: increased	[146]
Lavender	VC[a]	+	–	Control: increased	[45]
Peppermint[c]	VC	+	+	Control: increased in the second year	[142]
Dragonhead	VC	+	+	Control: increased; CF: produced the highest	[106]
Coriander (var. Arslan)	VC	+	+	Control: increased	[108]
Coriander (var. Ebraa)				Control: increased; CF: decreased	
D. anethifolia	VC	+	+	Control: decreased; CF: increased	[88]
Sweet basil[b]	VC	+	–	Control: increased	[109]
A. annua L.	VC	+	+	Control: increased; CF: decreased	[143]
Moldavian balm	VC	–	+	CF: decreased	[111]
Denaian thyme[c]	VC	+	+	Control and CF: decreased in the first year and increased in the second year	[74]
Chamomile[c]	VC	+	–	Control: increased	[112]
S. Leriifolia Benth.	VC	+	–	Control: increased	[113]
Agastache	VC	+	+	Control: decreased	[77]
Rosemary	VC	+	+[a]	Control and CF: increased	[85]
Fennel	VC[a]	+	+	Control: increased; CF: produced the highest	[114]
Peppermint	VC	+	+	Control and CF: increased	[115]
Cumin	VC	+	–	Control: increased	[120]
Coriander	VC[a]	+	–	Control: increased	[144]
Dill	VC[a]	+	–	Control: increased	[147]
Chamomile	VC[a]	+	–	Control: increased	[117]
French basil	VC	+	+	Control and CF: increased	[104]
Medicinal plant (s)	**Organic manure**	**Control**	**CF**	**Results (organic manure vs. control or CF or both)**	**Reference (s)**
Fennel[c]	C[a]	+	–	Control: increased	[148]
S. Leriifolia Benth.	C	+	–	Control: increased	[113]
Cumin	C	+	–	Control: increased	[120]
Basil	C	+	+	Control: increased; CF: decreased	[121]
Chamomile	C[a]	+	+[a]	Control and CF: increased	[122]
Thyme[b,c]	C	+	–	Control: increased	[86]
Sweet marjoram[b]	C[a]	–	+	CF: increased	[124]
Bitter fennel and sage[b]	C[a]	–	+	CF: increased	[125]
Dragonhead	C[a]	+	–	Control: increased	[126]
Basil[c]	C[a]	–	+	CF: increased	[127]

CF: chemical fertilizer, BL: broiler litter, PM: poultry manure, CM: chicken manure, SM: sheep manure, CAM: cattle manure, COM: cow manure, FM: farmyard manure, VC: vermicompost and C: compost. †: Essential oil content of herbal and fruit measured.

[a] Organic manure or CF used at more than one level.

[b] Essential oil content measured in two or more cuttings.

[c] Essential oil content measured in two years or two seasons. When not otherwise specified, changes of essential oil content have occurred in all cutting or seasons or years or levels of organic manure or CF.

compared with CF. Fallah et al. [48] found that the essential oil content of *D. kotschyi* in the first harvest was lower in plants supplied with COM than CF, whereas it was similar in SM, BL, and CF. At the second harvest, the essential oil content was enhanced by applying COM over CF, and even the use of BL and SM increased essential oil content compared to CF by 65% and 89%, respectively. In a study by Emami Bistgani et al. [74] on Denaian thyme, contrasting results were reported between the essential oil content achieved in the first and second years after the administration of different fertilizers. The usage of COM improved the essential oil content by 14% over CF in the first year, whereas a lower essential oil content in COM compared with CF was obtained in the second year. In the same experiment, plants fertilized with CF had higher essential oil content than VC in the first year, however in the second year, VC boosted the essential oil content of this species by 18% compared with CF. Khalid and Shafei, [84] claimed that the administration of CM boosted essential oil content of the herb and fruit of dill compared with CF during the first growing season, whereas a decrease in the essential oil content was observed in the second season over CF. Rezaei-Chiyaneh et al. [106] stated that the application of VC raised the essential oil of dragonhead in some cropping pattern over CF, so the highest essential oil was obtained in VC treatment.

In contrast with the above results, some authors found a substantial lower essential oil in several plants with the administration of organic manures, compared with CF or even with the untreated control (Table 2). For instance, in two different studies, Vafadar-Yengeje et al. [111] on moldavian balm and Özyazici, [108] on coriander (var. Ebraa) demonstrated that the application of CF increased the essential oil of both species more than VC. In another study, the essential oil of *Artemisia annua* was enhanced by the addition of CF over FM, VC, and PM [143]. Similarly, Forouzandeh et al. [121] found that basil amended with C had lower essential oil content compared with CF treatment. Moghaddam et al. [77] and Yousefi Rad and Radbakht, [88] found that *D. anethifolia* amended with VC and CAM and agastache VC and COM (20 t ha^{-1}) had lower essential oil compared with untreated plants. The decrease in essential oil content in plants grown under organic fertilization in these experiments may be due to the slow mineralization of organic manures or high soluble salts [103].

Among the studied MP, *S. khuzestanica* Jamzad, *D. anethifolia,* and rosemary demonstrated to react more significantly to the organic manures, and the distribution of two organic manures increased the essential oil content of these three species more than CF. The utilization of one organic manure raised essential oil content of sage, bitter fennel, sweet marjoram, French basil, chamomile, peppermint, fennel and agastache as compared to CF. The essential oil content of *A. annua* was reduced over CF by the application of three organic manures, namely PM, FM, and VC. Plants of *D. kotschyi.,* dill, Denaian thyme, basil, and dragonhead had contrasting responses (either negative or positive) to organic manures (Table 2). This information paves the way for further research about the effect of organic manures on the essential oil content of these MP.

It is possible to conclude that, in general, MP treated with organic manures mostly had higher essential oil content than CF, or control (unfertilized) plants, or both. The main reason for this response could rely on the peculiar composition and physico-chemical characteristics of organic manures, which not only supply essential nutrients for plant growth [48], but also affect soil structure and characteristics positively. Among the involved nutrients, N is used by plants to build many organic compounds, including nucleic acids, amino acids, proteins, and enzymes, which play a vital role in the biosynthesis of numerous constituents, among which the essential oil compounds [149,150]. This nutrient also has a significant effect on the development and division of the cells containing essential oil, including essential oil channels, secretory ducts, and glandular trichomes [47].

Besides N, other nutrients play a significant role in MP biochemistry [151]. Phosphorus (P) is a structural constituent of essential biomolecules involved in energy metabolism, like PPi and ATP, and in the formation of crucial macromolecules like phospholipids and nucleic acids [152]. Potassium (K) is involved in many plants' physiological reactions, including enzyme activation, protein synthesis, osmoregulation, and photosynthate translocation [153]. This nutrient also controls the opening and closing of stomata which affect CO_2 uptake for photosynthesis [86]. Zinc (Zn) and iron (Fe) act as metal components of different enzymes and are associated with protein synthesis, saccharide metabolism, and photosynthesis. According to Nasiri and Najafi, [154], Zn is a vital nutrient for the maintenance of membrane structure and function, cell division, and as well as synthesis of IAA. Fe has key functions in plant metabolisms, like activating catalase enzymes associated with superoxide dismutase, as well as in photorespiration, the glycolate pathway, and chlorophyll content.

Copper (Cu) is an essential element for normal plant growth and metabolism and plays a crucial role in different metabolic processes, such as cell wall metabolism; it also acts as a structural nutrient in photosynthetic electron transport, mitochondrial respiration, regulatory proteins, and biosynthesis of plant hormones, and as a cofactor for many enzymes [155,156]. Manganese (Mn) plays a key role in many physiological processes, as almost every cell compartment carries at least one enzyme whose activity is dependent on Mn. This nutrient acts as a cofactor for deoxyribonucleic acid (DNA), ribonucleic acid (RNA) polymerases, oxidases, kinases, decarboxylases, dehydrogenases, and sugar transferases [157,158].

4.2. Chemical compositions of essential oil

Essential oils are composed of 20–100 compounds belonging to a variety of chemical classes [159], being terpenoids and phenylpropanoids the most important [39]. Depending on their number of five-carbon isoprene units, the terpenoids are classified as hemiterpenes (one unit), monoterpenes (two units), sesquiterpenes (three units), diterpenes (four units), and so on. Although both monoterpenes and sesquiterpenes can be found in essential oils, the most abundant terpenoids are monoterpenes (about 90%) [160]. Terpenoids are synthesized by two pathways: 1) plastidic methyl erythritol phosphate (MEP) pathway. 2) cytosolic classical mevalonate (MVA) pathway. Both ultimately produce the intermediate universal precursors for terpene biosynthesis isopentyl pyrophosphate (IPP) and its allylic isomer dimethylallyl diphosphate (DMAPP) [161–163] (see complete details in the paper of Abdallah and Quax, [164]).

Phenylpropanoids can be divided into five groups, including phenolic acids, flavonoids, coumarins, monolignols, and stilbenes [165–167]. The phenylpropanoids are formed from shikimic acid (see complete details in the paper of Deng and Lu, [167]).

Plants producing essential oils belong to different genera distributed to around 60 families. Plant families like Lamiaceae, Apiaceae, Asteraceae, Rutaceae, Poaceae, Alliaceae, and Myrtaceae are well known for their ability to produce essential oils of medicinal and industrial value [168–170]. All essential oil-producing plant families are rich in terpenoids. Otherwise, plant families such as Lamiaceae, Apiaceae, Myrtaceae, Rutaceae, and Piperaceae, more frequently contain phenylpropanoids [171].

Increasing of selected chemical components of essential oil is one of the major challenges in the production of MP. Nurzynska-Wierdak [172] noted that fertilizers could significantly modify the chemical compounds of essential oils of MP. After the utilization of fertilizer (either synthetic or organic), a change in the chemical constituents of essential oil in MP could occur that is linked to the nutritional status of the plants [43]. As indicated in Table 3, organic manures can either increase or decrease the presence of certain chemical components of essential oil compared with control or CF, or both. The main results from the surveyed literature are as follows:

Thymol: In *S. macrantha* (C.A.Mey.), Baniyaghoub Abkenar et al. [96] demonstrated that in the first cultivation year, the supply of COM reduced thymol content in essential oil compared with CF, while the same species treated with COM achieved a higher thymol in the second year over CF. Oppositely, in Denaian thyme, the administration of COM led to an increase in thymol in comparison to CF in the first year, and reduced the thymol content in the second year. In the same experiment, plants treated with VC had lower thymol than CF in the first year, whereas in the second year, the addition of VC enhanced thymol over CF [74]. Edris et al. [123] claimed that compared to CF, the thymol content in thyme decreased after the application of C at an amount of 10 m^3 $acre^{-1}$, whereas the content of the same metabolite raised by 61% after the administration of 20 m^3 $acre^{-1}$ of C. Emami Bistgani et al. [74] and Hosseini et al. [75] stated that Denaian thyme amended with COM and VC and Sahandi savory treated with CAM had a higher thymol content than control plants in the first and second year. Hendawy et al. [86] reported that the distribution of some organic manures including SM, CAM, and C enhanced the thymol content in thyme essential oil compared with unfertilized plants. In a study by Saki et al. [78] on *S. mutica,* although thymol amount decreased over control plants in plants grown under CAM at some plant densities, the highest amount of thymol (38.2%) was achieved in plants amended with CAM. Baniyaghoub Abkenar et al. [96] in *S. macrantha* (C.A.Mey.) and Askary et al. [100] in *Thymus vulgaris* and *Thymus daenensis* found contrasting results in the thymol content of plants treated with COM and controls in the first and second year.

Linalool: Several studies found that the utilization of some organic fertilizers increased the linalool content of essential oil compared to CF; this result was obtained in two varieties of coriander amended with VC [108], and in basil after administration of C or VC [32,127] and FM and VC [104]. In contrast, decreased linalool content was found in different basil genotypes after the administration of FM [103], and PM and FM [32]. The comparison between organic manures and control (unfertilized) plants gave variable responses as well. In an experiment on sweet basil plants [91], the addition of CAM allowed the greatest content of linalool (14.89%). In different basil genotypes, the linalool content was higher than in control plants after the addition of VC [32,109] and FM and VC [104,103]. Similar results were achieved in two varieties of coriander supplied with VC [108], and in dragonhead plants after distribution of 13.2 t ha^{-1} of C [126]. Contrastingly, a decrease in linalool content of basil in comparison to control plants was observed after the administration of PM and FM [32], and under some levels of CAM [91]. In dragonhead, in contrast to what was observed at the lowest rate, higher doses of C (26.4 and 39.6 t ha^{-1}) reduced the linalool content [126].

Methyl chavicol: Panday et al. [32] found that the distribution of PM and FM raised the methyl chavicol of basil over CF. Likewise, studies by Moghaddam et al. [77] on agastache, Khalid et al. [127], Singh et al. [103], and Anwar et al. [104] on basil, indicated an increase in methyl chavicol compared to CF after the addition of COM (25 t ha^{-1}), C, VC, and (VC and FM), respectively. Also in this case, strong differences were found as different treatments were involved: according to Singh et al. [103], the distribution of FM on basil plants reduced methyl chavicol content compared to CF, and Moghaddam et al. [77] and Panday et al. [32] reported that basil and agastache supplied with VC had lower methyl chavicol compared with CF. As concerns the comparison with untreated plants, Anwar et al. [104] and Singh et al. [103] reported a higher methyl chavicol content in two basil genotypes after the usage of FM and VC. Similar results were observed on basil treated with PM and FM [32]. In contrast, basil supplied with VC decreased methyl chavicol compared with control conditions [32,109]. The application of 20 and 25 t ha^{-1} of COM and 30 t ha^{-1} of VC reduced methyl chavicol of agastache over unfertilized plants [77]. In a study by El-Naggar et al. [91] on sweet basil, although methyl chavicol decreased over control plants in plants grown under CAM at some levels, the greatest amount of methyl chavicol (75.11%) was obtained in plants amended with CAM.

***p*-Cymene**: According to Edris et al. [123], the utilization of C reduced the *p*-cymene content of thyme over CF. Baniyaghob Abkenar et al. [96] noted that *p*-cymene of *S. macrantha* (C.A.Mey.) boosted with the application of COM compared with CF in the first year. In the second year, *p*-cymene content decreased after the usage of COM than CF treatment. The administration of BL raised the content of *p*-cymene in dill in most cropping patterns over CF, so the highest *p*-cymene content (33.69%) was obtained in BL treatment [47]. In another study about black cumin, Rostaei et al. [43] reported that although in some cropping patterns, the usage of CF induced a lower *p*-cymene content compared with BL, the greatest content of *p*-cymene (62.77%) was achieved in CF. Askary et al. [100] claimed that *T. vulgaris* treated with COM had lower *p*-cymene in the first year over the controls, whereas it increased after the

Table 3
Summary of results from the literature about the effects of the administration of different types of organic manures on chemical compositions of essential oil in several medicinal plants.

Medicinal plant (s)	Organic manure	Control	CF	Results (organic manure vs. control or CF or both)	Reference (s)
D. kotschyi[b]	BL	+	+	Control: increased geranial and neral; CF: decreased neral and geranial in the first cutting, increased geranial and neral in the second cutting	[48]
Dragonhead	BL	–	+	Geranial: BL (31.74%–36.83%); CF (29.08%–41.52%) geranyl acetate: BL (28.46%–32.74%); CF (24.68%–34.8%)	[22]
Dill	BL	–	+	p-Cymene: BL (27.31%–33.69%); CF (21.66%–31.88%) carvone: BL (22.06%–49.66%); CF (41.21%–45.07%)	[47]
Black cumin	BL	–	+	p-Cymene: BL (22.12%–46 %); CF (20.51%–62.77%) carvacrol: BL (8.56%–13%); CF (2.4%–25.99%)	[43]
A. annua L.	PM	+	+	Control: increased 1,8-cineole and decreased camphor; CF: decreased 1,8-cineole and increased camphor	[143]
Basil	PM	+	+	Control and CF: decreased linalool and increased methyl chavicol	[32]
Marigold	PM	+	+	Control: decreased E-ocimenone and (Z)-tagetone CF: increased E-ocimenone and decreased (Z)-tagetone	[80]
P. graveolens L'Hér.	PM	+	+	Control: increased citronellol and decreased geraniol CF: decreased citronellol and geraniol	[81]
Sage	PM	+	–	Control: increased 1,8-cineole and decreased camphor	[145]
Chamomile	CMa	+	–	Control: increased α-bisabolol oxide A and chamazulene	[83]
Dill	CM	–	+	CF: increased limonene and carvone	[84]
D. kotschyi[b]	SM	+	+	Control: increased neral and geranial; CF: increased neral and decreased geranial in the first cutting and increased geranial in the second cutting	[48]
Rosemary	SM	+	+[a]	Control and CF: increased alpha-pinene and decreased 1,8-cineole	[85]
Medicinal plant (s)	**Organic manure**	**Control**	**CF**	**Results (organic manure vs. control or CF or both)**	**Reference (s)**
Thyme	SM	+	–	Control: increased thymol and decreased ρ-cymene	[86]
Dill	SM	–	+	CF: increased limonene and carvone	[84]
Sage	SM	+	–	Control: decreased 1,8-cineole and increased camphor	[145]
Sahandi savory[c]	CAM	+	–	Control: increased thymol and decreased p-cymene	[75]
Bakhtiari savory[c]	CAM	+	–	Control: decreased P-cymene and carvacrol	[87]
Lemon balm	CAM	+	–	Neral: CAM (29.54%–31.05%); control (30.16%–31.25%) Control: decreased geranial	[89]
S. mutica[c]	CAM	+	–	Thymol: CAM (30.07%–38.2 %); control (30.77%–34.61%) carvacrol: CAM (21.86%–29.99%); control (22.55%–25.7%)	[78]
Sweet basil	CAM	+	–	Linalool: control (12.36%); CAM (1.58%–14.89%) methyl chavicol: control (4.76%); CAM (55.97%–75.11%)	[91]
Thyme	CAM	+	–	Control: increased thymol and decreased ρ-cymene	[86]
Sage	CAM	+	–	Control: increased 1,8-cineole and decreased camphor	[145]
Marigold	CAM[a]	–	+	Control: increased delta-cadinene and alpha-cadinol	[94]
S. macrantha C.A. Mey.[c]	COM	+	+	Control and CF: decreased thymol and increased p-cymene in the first year and increased thymol and decreased p-cymene in the second year	[96]
Fennel	COM[a]	+	–	Control: increased trans-anethole and dill apiole at low and medium level and decreased dill apiole at high level	[99]
D. kotschyi[b]	COM	+	+	Control: increased neral and geranial; CF: decreased geranial and neral in the first cutting and increased neral and geranial in second cutting	[48]
Lavender	COM[a]	+	–	Control: increased 1,8-cineole and borneol	[97]
Medicinal plant (s)	**Organic manure**	**Control**	**CF**	**Results (organic manure vs. control or CF or both)**	**Reference (s)**
T. vulgaris	COM	+	–	Control: increased thymol and decreased P-cymene in the first year and decreased thymol and increased P-cymene in the second year and	[100]
T. daenensis[c]				Control: increased thymol in the first year and decreased thymol in the second year P-cymene: control (8.35%–10.82%); COM (0.15%–13.06%)	
Denaian thyme[c]	COM	+	+	Control: increased thymol; CF: increased thymol in the first year and decreased in the second year	[74]
Agastache	COM[a]	+	+	Control: decreased methyl chavicol; CF: increased methyl chavicol at high level	[77]
Sweet fennel	COM	+	+	Control and CF: increased anethole	[173]
A. annua L.	FM	+	+	Control and CF: increased 1,8-cineole and decreased camphor	[143]
Dragonhead	FM	+	–	Control: increased geranyl acetate and decreased geraniol	[146]
Basil	FM	+	+	Control and CF: decreased linalool and increased methyl chavicol	[32]
Marigold	FM	+	+	Control and CF: increased E-ocimenone and decreased (Z)-tagetone	[80]
P. graveolens L'Hér	FM	+	+	Control: increased citronellol and decreased geraniol; CF: decreased citronellol and geraniol	[81]
Indian basil	FM	+	+	Control: increased methyl chavicol and linalool; CF: decreased methyl chavicol and linalool	[103]
French basil	FM	+	+	Control and CF: increased linalool and methyl chavicol	[104]
Peppermint	VC	+	–	Control: increased menthone and menthol	[49]

(continued on next page)

Table 3 (*continued*)

Medicinal plant (s)	Organic manure	Control	CF	Results (organic manure vs. control or CF or both)	Reference (s)
Lavender	VC[a]	+	–	Control: decreased linalyl acetate and geranyl acetate	[45]
Lavender	VC[a]	+	–	Control: increased 1,8-cineole at medium and high level and decreased 1,8-cineole at low level and increased borneol	[97]
Dragonhead	VC	+	+	Control and CF: increased geranial and geranyl acetate	[106]
Medicinal plant (s)	**Organic manure**	**Control**	**CF**	**Results (organic manure vs. control or CF or both)**	**Reference (s)**
Coriander (two varieties)	VC	+	+	Control and CF: increased linalool	[108]
A. annua L.	VC	+	+	Control and CF: decreased 1,8-cineole and camphor	[143]
Basil	VC	+	–	Control: increased linalool and decreased methyl chavicol	[109]
Moldavian balm	VC	–	+	CF: decreased geranial geraniol: VC (24.75%–42.13%); CF (20.89%–36.73%)	[111]
Denaian thyme[c]	VC	+	+	Control: increased thymol; CF: decreased thymol in the first year and increased in the second year	[74]
German chamomile	VC	–	+	CF: increased α-bisabolol and α-bisabolol oxide A	[112]
Basil	VC	+	+	Control and CF: increased linalool and decreased methyl chavicol	[32]
Marigold	VC	+	+	Control: decreased E-ocimenone; CF: increased E-ocimenone and decreased (Z)-tagetone	[80]
P. graveolens L'Hér	VC	+	+	Control and CF: decreased geraniol and increased citronellol	[81]
Agastache	VC	+	+	Control and CF: decreased methyl chavicol	[77]
Rosemary	VC	+	+[a]	Control and CF: increased 1,8-cineole α-pinene: control (20.22%); VC (22%); CF (16.09%–22.53%)	[85]
Rosemary	VC	+	–	Control: increased 1,8-cineole and camphor	[174]
Indian basil	VC	+	+	Control: increased linalool and methyl chavicol; CF: increased methyl chavicol	[103]
Dill	VC[a]	+	–	Control: increased carvone and decreased limonene	[147]
Sweet fennel	VC	+	–	Control: increased anethole and decreased limonene	[175]
French basil	VC	+	+	Control and CF: increased linalool and methyl chavicol	[104]
Sweet fennel	C	+	–	Control: increased anethole and decreased limonene	[175]
Chamomile	C[a]	+	+[a]	Control: increased chamazulene and decreased bisabolol oxide A; CF: decreased chamazulene and bisabolol oxide A at low level and increased bisabolol oxide A at medium and high level	[122]
Thyme	C	+	–	Control: increased thymol and ρ-cymene	[86]
Medicinal plant (s)	**Organic manure**	**Control**	**CF**	**Results (organic manure vs. control or CF or both)**	**Reference (s)**
Thyme	C[a]	–	+[a]	CF: decreased thymol at low level and increased thymol at high level and decreased P-cymene	[123]
Sweet marjoram	C[a]	–	+	CF: decreased cis-sabinene hydrate and increased terpinen-4-ol at low level and decreased terpinen-4-ol at high level	[124]
Bitter fennel	C[a]	–	+	CF: decreased anethole and increased limonene at low level and decreased limonene at medium and high level	[125]
Sage	C[a]	–	+	CF: increased α -thujone and 1,8-cineole	[125]
Dragonhead	C[a]	+	–	Control: increased linalool at low level and decreased linalool at medium and high level and decreased geranial	[126]
Basil	C[a]	–	+	CF: increased linalool and methyl chavicol	[127]

CF: chemical fertilizer, BL: broiler litter, PM: poultry manure, CM: chicken manure, SM: sheep manure, CAM: cattle manure, COM: cow manure, FM: farmyard manure, VC: vermicompost and C: compost.

[a] Organic manure or CF used at more than one level.

[b] Chemical composition measured in two or more cuttings.

[c] Chemical composition measured in two years or two seasons. When not otherwise specified, changes of chemical compositions have occurred in all cutting or seasons or years or level of organic manure or CF; when the changes of chemical composition of the essential oil of one plant in all treatments did not have the same trend, the amount of chemical compounds is presented as a range.

administration of COM in the second year. In the same work, although the *p*-cymene of *T.* daenensis decreased in most water stress levels as compared to control conditions, the highest content of *p*-cymene was obtained in plants grown under the usage of COM. Baniyaghoub Abkenar et al. [96] concluded that the utilization of COM led to an increase in *p*-cymene of *S. macrantha* in the first cultivation year than controls, whereas in the second cultivation year, the usage of COM decreased p-cymene compared with control plants. In two different studies, Hosseini et al. [75] and Mirjalili et al. [87] stated that the consumption of CAM reduced *p*-cymene of Sahandi savory and Bakhtiari savory over control conditions in two consecutive years. In another study, thyme supplied with SM and CAM had lower *p*-cymene than untreated plants. While C enhanced the *p*-cymene content over control plants [86].

1,8-Cineole: Studies by Mona et al. [125] on sage, Hosseini Valiki et al. [85] on rosemary, and Sajwan et al. [143] on *A. annua* L., demonstrated an increase in 1,8-cineole compared to CF after the addition of C, VC and FM, respectively. Oppositely, according to Sajwan et al. [143], the usage of PM and VC on *A. annua* L. decreased 1,8-cineole content over CF. Hosseini Valiki et al. [85] reported that rosemary amended with SM had lower 1,8-cineole compared with CF. Hosseini Valiki et al. [85] and Ganjali and Kaykhaii, [174] found that the utilization of VC enhanced the 1,8-cineole content of essential oil of rosemary and lavender compared to controls. Similar results were obtained in lavender treated with COM [97], in *A. annua* L. plants after the distribution of PM and FM [143] and in sage plants treated with CAM and PM [145]. A decrease in content of 1,8-Cineole of lavender over control plants was achieved at a low level of VC (5 t h^{-1}), while medium and high levels of VC (10 and 15 t h^{-1}) led to an increase in 1,8-cineole than controls [97]. Sajwan et al. [143] stated that the utilization of VC decreased the 1,8-cineole content of essential oil of *A. annua* L. over controls. In two different studies, Hosseini Valiki et al. [85] and Kocabas et al. [145] noted that rosemary and sage supplied with SM had lower 1, 8-cineole compared with control conditions.

Carvacrol: Rostaei et al. [43] reported that although the administration of CF reduced the carvacrol of black cumin in most cropping patterns over BL, the highest amount of carvacrol (25.99%) was obtained in CF treatment. Saki et al. [78] observed that although the usage of CAM reduced the amount of carvacrol in *S. mutica* at some plant densities than control plants, the greatest content of carvacrol (29.99%) was obtained in plants grown under the utilization of CAM. Mirjalili et al. [87] found that the application of CAM decreased carvacrol of Bakhtiari savory compared with controls in two consecutive years.

Geranial: Rezaei-Chiyaneh et al. [106] reported that the addition of VC raised the geranial content oil of dragonhead over CF. In contrast, Vafadar-Yengeje et al. [111] noted that using VC decreased geranial of this plant by (2%–27%) compared to CF. In another study, *D. kotschyi* supplied with CF had higher geranial than COM, BL and SM in the first cutting. In the second cutting, the administration of organic manures increased the geranial of this plant compared with CF [48]. Fallah et al. [22] revealed that utilization of CF raised the geranial of dragonhead in most cropping patterns than CF, so the highest geranial (41.52%) was achieved in CF treatment. The increase of geranial after the application of some organic manures compared to controls was observed by Fallah et al. [48] in *D. kotschyi* after the administration of BL, SM, and COM and Rezaei-Chiyaneh et al. [106] in dragonhead after the addition of VC. Contrastingly, Hussein et al. [126] and De Assis et al. [89] stated that dragonhead treated with C and lemon balm (*Melissa officinalis* L.) nourished with CAM had lower geranial compared with untreated plants.

Neral: According to Fallah et al. [48], the neral of *D. kotschyi* was raised by adding SM, over CF and control plants in the first and second cuts. These authors also claimed that the application of CF led to an increase in neral than BL and COM in the first cutting. At the second cutting, plants supplied with BL and COM had a higher neral compared with CF. The usage of BL and COM increased the neral content of *D. kotschyi* over untreated plants in both cuttings. De Assis et al. [89] reported that lemon balms without CAM had higher neral content in conditions of nonincubation with arbuscular mycorrhizal fungi, whereas neral content was enhanced with the use of CAM and incubation of arbuscular mycorrhizal fungi.

α-Bisabolol oxide A (Bisabolol oxide A): Salehi et al. [112] stated that the utilization of VC increased α-bisabolol oxide A of chamomile by 28% compared with CF. In another study, the low level of C reduced bisaobolol oxide A of chamomile compared with CF. Oppositely, the usage of medium and high levels of C raised bisaobolol oxide A of than CF [122]. Hassan and Fahmy, [83] claimed that the administration of CM raised α-bisaobolol oxide A of chamomile by 37 % more than untreated plants. In contrast, Hendawy and Khalid, [122] revealed that chamomile supplied with C had lower bisaobolol oxide A over controls.

Geranyl acetate: In a study by Rezaei-Chiyaneh et al. [106] on dragonhead, plants supplied with VC had higher geranyl acetate over CF. Fallah et al. [22] reported that CF boosted geranyl acetate of dragonhead in most cropping patterns compared with BL, so that the highest geranyl acetate (34.8%) was obtained in CF treatment. In two separate studies, the utilization of FM or VC raised geranyl acetate of dragonhead more than control [106,146]. In contrast, Habibi Sharafabad et al. [45] claimed that the lavender amended with VC had lower geranyl acetate over control conditions.

Camphor: Sajwan et al. [143] observed that the application of PM enhanced the camphor of *A. annua* L. more than CF, whereas the same compound was reduced after the administration of FM and VC. Studies by Kocabas et al. [145] on sage and Ganjali and Kaykhaii, [174] on rosemary, showed an increase in camphor than the controls after the addition of SM and VC, respectively. Negative effects of the usage of organic manures on camphor were reported in *A. annua* L. supplied with FM, VC, and PM [143] and in sage plants treated with CAM and PM [145] over control conditions.

Geraniol: The result of Vafadar-Yengeje et al. [111] indicated that the consumption of VC raised geraniol of moldavian balm in most cropping patterns more than CF, so that the greatest geraniol (42.13%) detected in VC treatment. Oppositely, the administration of PM, FM and VC reduced the geraniol of *P. graveolens* L'Hér compared with CF [81]. The decrease of geraniol after the application of organic manures compared to controls was reported by Pandey and Patra, [81] in *P. graveolens* L'Hér amended with FM, PM, and VC and Nasiri et al. [146] in dragonhead after the administration of FM.

Limonene: Khalid and Shafei, [84] found that the consumption of CM and SM enhanced limonene of dill (*Anethum graveolens* L.) over CF. Mona et al. [125] noted that the low level of C boosted limonene of sage by 18% compared with CF. In contrast, the usage of medium and high levels of C reduced limonene than CF. Moradi et al. [175] found that limonene in sweet fennel decreased after applying C and VC over control conditions. Similar results were achieved on the dill amended with the VC [147].

Alpha-pinene: According to Hosseini Valiki et al. [85], the usage of SM raised the α-pinene content of rosemary over control plants and various rates of CF. In the same work, the addition of VC led to an increase in α-pinene compared with the controls. Although the usage of CF at most levels induced a lower α-pinene content compared with VC, the highest content of α-pinene (22.53%) was obtained in CF.

Trans-anethole and dill apiole: In a study by Punetha et al. [99] on fennel, the application of 26, 52, and 104 t ha^{-1} of COM boosted trans-anethole over control plants. These authors also reported that the usage of 26 and 52 t ha^{-1} of COM enhanced dill apiole than control conditions, while the application of 104 t h^{-1} of C led to a decrease in dill apiole compared with unfertilized plants.

Carvone: The content of carvone of dill was enhanced after the utilization of SM and CM compared with CF [84]. Rostaei et al. [47] revealed that although usage of BL reduced carvone of dill in most cropping patterns than CF, the highest amount of carvone (49.66%) was achieved in BL treatment. Darzi et al. [147] reported that the administration of various levels of VC (4, 8, and 12 t h^{-1}) led to an increase in carvone of dill over the controls.

E-ocimenone: Pandey et al. [80] found that the consumption of PM and VC increased E-ocimenone of marigold more than CF. Marigold treated with FM had higher E-ocimenone over control plants and CF. The utilization of PM and VC decreased E-ocimenone compared with untreated plants.

Anethole: The content of anethole of sweet fennel was enhanced by applying COM compared with CF [173]. Mona et al. [125] noted that bitter fennel treated with C had lower anethole than CF. In two separate studies, the utilization of (VC and C) or COM raised anethole of sweet fennel more than the controls [175,173].

Cis-sabinene hydrate and terpinen-4-ol: Gharib et al. [124] indicated that low and high levels of C decreased cis-sabinene hydrate of sweet marjoram over CF. In the same experiment, terpinen-4-ol content increased at a low level of C more than CF, whereas, at a high level, plants supplied with C had lower terpinen-4-ol.

Chamazulene: According to Hendawy and Khalid, [122] in chamomile supplied with C, chamazulene content was lower than CF, but higher when compared with control plants. Hassan and Fahmy, [83] indicated that CM boosted the chamazulene of chamomile over control conditions.

Citronellol: *P. Graveolens* L'Hér grown under the administration of VC had higher citronellol than CF. In contrast, citronellol of this plant was reduced by adding PM and FM over CF. Using FM, PM and VC enhanced citronellol compared with untreated plants [81].

(Z)-Tagetone: Pandey et al. [80] noted that the application of PM and FM reduced (Z)-tagetone of marigold compared with control conditions and CF. These Authors also reported the administration of VC led to a decrease in (Z)-tagetone over CF.

Delta-cadinene and α-cadinol: Khalid et al. [94] stated the utilization of CAM enhanced delta-cadinene and alpha-cadinol of marigold by 7% and 27% over CF, respectively.

α-Bisabolol: Results of Salehi et al. [112] indicated that the utilization of VC slightly boosted α-bisabolol of chamomile than CF.

α-Thujone: Mona et al. [125] found that sage treated with C had higher α-thujone compared with CF.

Borneol: Mavandi et al. [97] reported that using COM and VC increased the borneol of lavender over control conditions.

Menthone and menthol: According to Javanmard et al. [49], peppermint amended with VC had higher menthone and menthol than untreated plants.

Linalyl acetate: The content of linalyl acetate in the lavander was reduced by applying VC compared with control plants [45].

In general, the application of organic manure or CF significantly changed the aroma profile of the essential oils. Thymol, linalool, methyl chavicol, 1,8-cineole, geranial, *p*-cymene, and carvacrol were the most abundant chemical constituents of essential oils of studied MP. Thymol, linalool, methyl chavicol, geranial, neral, 1,8-cineole, *p*-cymene, camphor, limonene, carvacrol, geraniol and geranyl acetate were identified as the main chemical compositions of essential oil of more than one MP. α-Pinene, carvone, citronellol, E-ocimenone, (Z)-tagetone, α-bisobolol oxide A (bisobolol oxide A), α-bisabolol, chamazulene, α-thujone, cis-sabinene hydrate, terpinen-4-ol, delta-cadinene, α-cadinol, trans-anethole, dill apiole, borneol, menthone, menthol and linalyl acetate were as major chemical constituents of essential oil of one medicinal plant. Each chemical compound had different responses to organic manures or CF. They often failed to increase or decrease a specific chemical constituent in the essential oil of all MP. Various organic manures often positively affected the amount of thymol, linalool, methyl chavicol, 1,8-cineole, neral, carvone, E-ocimenone, citronellol, anethole, borneol, and α-bisobolol oxide A. Among organic manures, the usage of VC led to an increase in linalool in the essential oil of studied MP. Therefore, despite the limitations of existing research and the need for more studies, the usage of VC can be recommended as an appropriate method to increase linalool in different MP. The utilization of one organic manure led to an increase in α-pinene, α-bisabolol, delta-cadinene, α-cadinol, α-thujone, trans-anethole, menthone, and menthol. However, organic manures had contrasting effects on geranial, geranyl acetate, terpinen-4-ol, and dill apiole. Although numerous researchers reported the positive effect of organic manures on the main chemical compounds of essential oil of MP, some researchers showed the negative effect of organic manure on the major chemical compositions of MP (Table 3). Organic manures often had a negative impact on the content of P-cymene, carvacrol, camphor, geraniol, and limonene. The usage of some organic manures reduced (Z)-tagetone and cis-sabinene. These differences could be attributed to the various biosynthesis pathways of these compounds and their role in crop physiology and metabolism [111]. The type and supply rate of fertilizers directly influence the availability of plant nutrients and indirectly affect physiological and biochemical mechanisms in MP [107,176]. The chemical constituents of the essential oil could be influenced by the quantity and availability of N and P and micronutrients. N nutrient is an important compound of amino acids and enzymes, and its deficiency has an adverse effect on the biosynthesis of terpenoids. This nutrient upholds terpenoid emissions by increasing the electron transport rate and leaf photosynthesis [177]. Photosynthesis provides carbon substrate (pyruvate or glyceraldehyde-3-phosphate) and ATP for isoprene synthesis. N as NADPH is also needed in terpenoids biosynthesis [178].

P raises terpenoid biosynthesis by enhancing the content of the pyrophosphate compounds, like DMAPP and IPP [179,180] that contain high-energy phosphate bonds. The role of P is evident in the synthesis of precursors of terpenoids both by the MEP pathway (glyceraldehyde phosphate and pyruvate), as well as via the MVA pathway (acetyl-CoA, ATP, and NADPH). Moreover, when P is restricted, the reduction in the phospholipid bilayer destabilizes the cell membrane. This effect is compensated by isoprene emissions [181,182]. Micronutrients, such as Mn, Cu, and Zn act as a cofactor of several enzymes involved in the biosynthesis of terpenoids [178]. Nutrients act as cofactors for enzymes and/or precursors of the different compounds in phenylpropanoids biosynthesis [183, 184].

4.3. Antioxidant activity

In the human body, free radicals and oxidants are produced either from normal cell metabolisms in situ or from external sources, such as radiation, air pollutants, inflammation, exercise, stress, smoking, alcohol, and drugs [185,186]. Free radicals and other reactive oxygen species cause oxidation of biomolecules including DNA, amino acids, proteins, and unsaturated lipids and finally produce molecular alterations related to aging, asthma, arteriosclerosis, diabetes, Parkinson, Alzheimer, and cancer [187]. The inherent defense system of the human body can quench free radicals present in almost all cells [187]. An imbalance between free radical production and their removal by the body's antioxidant system leads to a phenomenon known as 'oxidative stress' [188]. In this situation, an external supply of antioxidants is necessary to regain a balance between free radicals and antioxidants [187].

The use of synthetic antioxidants has been limited because of their possible carcinogenic and toxic effects. Therefore, the importance of searching for and exploiting natural antioxidants has been greatly boosted in recent years [189]. MP are a source of a wide variety of natural antioxidants [190]. Several natural compounds, such as phenolic constituents, flavonoids, terpenoids and other phytochemicals, have strong antioxidant potential due to their ability to scavenge free radicals [39,191,192] and may play an important role in disease prevention caused by reactive oxygen species and free radicals [193,194]. Although the effects of organic manures on biomass, content, and chemical compositions of essential oil of MP have been well studied, there is little information regarding the action exerted by organic manures on the antioxidant activity of these plants. Recently, the antioxidant activity of MP treated with organic manures has also been surveyed.

In this review, the antioxidant capacity of the studied MP was measured using their essential oils or extracts. In most studies, the antioxidant capacity was determined using the 2,2-diphenyl-1-picrylhydrazil (DDPH) assay, and in one case only [195], this activity was tested based on DDPH and ferric reducing antioxidant power assays. As presented in Table 4, the use of organic manures enhanced the antioxidant capacity of Kacip Fatimah (*Labisia pumila* Benth), *P. graveolens* L'Hér, marigold, basil, fenugreek, *A. annua* L., and black cumin compared with control plants or CF or both [32,81,80,107,143,195,196]. According to Emami Bistgani et al. [74], the antioxidant capacity of Denaian thyme increased after the usage of COM and VC compared with CF in the first year, whereas in the second year, it was alike in COM, VC, and CF treatments. Fallah et al. [22] and Rostaei et al. [47] stated that the application of BL raised the antioxidant activity of dragonhead and dill in most cropping patterns over CF, so the greatest antioxidant activity of both plants was achieved in BL. In two different studies, coriander and marigold treated with VC had higher antioxidant activity than unfertilized plants [98,197]. Saki et al. [78] in *S. mutica* found that the supply of COM boosted the antioxidant capacity compared with the controls in the first and second cultivation years. Similar results were obtained on Denaian thyme treated with COM and VC in two consecutive years [74]. Hosseini et al. [75] noted that Sahandi savory amended with CAM and control plants had similar antioxidant capacity in the first year. In the second year, plants grown under the usage of CAM had higher antioxidant capacity over untreated plants. Pacheco et al. [198] demonstrated that the antioxidant capacity of *P. incarnata* did not express any significant difference between the plants supplied with PM and the control plants in the first harvest. In the second harvest, the application of PM enhanced the antioxidant capacity by 67% more than controls. These authors also reported that the utilization of CAM raised the antioxidant activity of

Table 4
Summary of results from the literature about the effects of the administration of different types of organic manures on antioxidant activity in several medicinal plants.

Medicinal plant (s)	Organic manure	Control	CF	Results (organic manure vs. control or CF or both)	Reference (s)
Fenugreek[b]	BL	–	+	CF: increased	[195]
Dragonhead	BL	–	+	CF: increased in most cropping patterns	[22]
Dill	BL	–	+	CF: increased in most cropping patterns	[47]
Passiflora incarnata[a]	PM	+	–	Control: increased in the second harvest	[198]
A. annua L.	PM	+	+	Control and CF: increased	[143]
Basil and marigold	PM	+	+	Control and CF: increased	[32,80]
P. graveolens L'Hér	PM	+	+	Control and CF: increased	[81]
Kacip Fatimah	CD	–	+	CF: increased	[196]
Sahandi savory[b]	CAM	+	–	Control: increased in the second year	[75]
P. incarnata[a]	CAM	+	–	Control: increased	[198]
S. mutica[b]	CAM	+	–	Control: increased	[78]
Denaian thyme[b]	COM	+	+	Control: increased; CF: increased in the first year	[74]
A. annua L.	FM	+	+	Control and CF: increased	[143]
Basil and marigold	FM	+	+	Control and CF: increased	[32,80]
P. graveolens L'Hér	FM	+	+	Control and CF: increased	[81]
Black cumin	VC	+	+	Control and CF: increased	[107]
Coriander	VC	+	+	Control: increased	[98]
Peppermint	VC	+	+	Control and CF: decreased	[142]
A. annua L.	VC	+	+	Control and CF: increased	[143]
Marigold	VC	+	–	CF: increased	[197]
Denaian thyme[b]	VC	+	+	Control: increased; CF: increased in the first year	[74]
Chicory	VC*	+	–	Control: increased at high level	[46]
Basil and marigold	VC	+	+	Control and CF: increased	[32,80]
P. graveolens L'Hér	VC	+	+	Control and CF: increased	[81]

CF: chemical fertilizer, BL: broiler litter, PM: poultry manure, CD: chicken dung, SM: sheep manure, CAM: cattle manure, COM: cow manure, FM: farmyard manure, VC: vermicompost and C: compost.
*: Organic manure or CF used at more than one level.
[a] Antioxidant activity measured in two or more cuttings.
[b] Antioxidant activity measured in two years or two seasons. When not otherwise specified, changes of antioxidant activity have occurred in all cuttings or seasons or years or levels of organic manure or CF.

P. incarnata by 33% and 25% compared with untreated plants in the first harvest and second harvests, respectively. In another study, Gholami et al. [46] demonstrated that chicory treated with 5 and 7.5 t h^{-1} of VC did not have any significant differences in antioxidant capacity over control plants, whereas it increased after the administration of 10 t h^{-1} of VC. In contrast with the above results, Keshavarz Mirzamohammadi et al. [142] claimed that peppermint nourished with VC had lower antioxidant capacity than plants fertilized with CF and control plants. Apart from the studies listed in Table 4, only one other article [115] has been conducted on the effect of organic manure and CF on the antioxidant capacity of MP. Ayyobi et al. [115] stated that peppermint treated with CF and VC and unfertilized plants did not show any significant differences in antioxidant capacity.

In general, plants supplied with organic manure often possessed a higher capability to scavenge free radicals than control plants and CF. Among organic manures, the effect of BL, PM, FM, and VC on antioxidant capacity has been studied more than other organic manures, and usage of these organic manures raised the antioxidant capacity of most of MP compared with control or CF, or both. Some MP such as basil, marigold, *P. graveolens* L'Hér, *A. annua* L., Denaian thyme and *P. incarnata* were treated with more than one organic manure and the application of organic manures often led to an increase in the antioxidant capacity of their extracts. Therefore, despite the limitations in existing studies and the need for further research, the results of the current review support evidence that the usage of organic manure is an effective way to increase the antioxidant capacity of several MP. The enhancement of antioxidant activity in MP amended with organic manures may have been caused by the availability of various macro and micro nutrients, whereas the CF supplied only the three principal nutrients, i.e., N, P, and K. This could improve the nutrients accessibility and physiological functions that may enhance the metabolic pathways, including ones which synthesise secondary metabolites compounds, which closely linked with photosynthetic cycle [80,199]. The antioxidant activity of MP mainly depends on the content of phenolic compounds and flavonoids, which can be improved by amending soils with organic manures [46,74,192]. Phenolic compounds and flavonoids show strong antioxidant activities and can scavenge and neutralize free radicals and perform well this task.Organic manures induce the production of more shikimic acid, leading to more production of phenolic compounds and flavonoids [46,107].

Overall, although organic manures are only used to increase the yield of crops and many studies showed that the use of these manures raised their yield, the main aim of organic cultivation of MP is to achieve a better and higher quality of the product, and in the second instance, a higher productivity of these plants. For MP, the consumption of CF should be minimized and emphasis should be placed on their organic cultivation. Results obtained by various researchers (Tables 1–4) indicated that the utilization of different organic manures led to various responses of biomass and quality of MP to these manures, and in many studies, MP treated with organic manures had higher yield and quality compared to control plants or CF or both. Details of the properties of the organic manures studied in this review are indicated in Table 5. Initially, we examined all the characteristics of a type of organic manure as reported in the different studies, and then we presented them in the form of a span. In several studies, some parameters were not taken into account, and in many others, no parameters were reported at all. EC, pH, N, P, K, Zn, Fe, Cu, Mn, OC, and C/N ratio were different in various organic manures (Table 5). The highest pH (9.17) belonged to study of SM. COMs had the greatest EC (19.74 dS m^{-1}), OC (850 g kg^{-1}) and C/N (43.63%) and these amounts were reported in three independent studies. The largest N (49.2 g kg^{-1}), P (25 g kg^{-1}), and K (39 g kg^{-1}) values were obtained from VCs in different studies. The highest Fe value (13300 mg kg^{-1}) was detected in CAM. VCs had the highest Cu (3000 mg kg^{-1}), Zn (7000 mg kg^{-1}), and Mn (8000 mg kg^{-1}) values, and these amounts were presented in the same study. Concerning organic manures, both the type and amount of nutrients, and also the balance between nutrients are important. In general, depending on nutrients content (both macro and micro), C/N ratio and mineralization potential, the appropriate type and amount of organic manures should be added to the soil. Choosing the best organic manure to use can improve the soil's physical, chemical, and biological properties, ensure higher productivity and quality, and mitigate CF-induced risks [40,43,47,48,69,82,90,92,95,101,102,110,113,117–120,144,148].

5. Limitation

This review has limitations that should be noted. The scope of this review was confined to Journal publications exclusively. The reason to include only Journal publications is to ensure the findings are of high quality and standard despite that there could be relevant studies published in conference, book and chapters books [200]. The selection of manuscripts was restricted to papers published in English and the non-inclusion of papers in other languages is also a limitation. Furthermore, our search was limited to papers indexed in databases such as Science Direct, Google Scholar, PubMed, and Scopus. It is important to note that other databases may have indexed a diverse range of papers and yielded different results. Additionally, there may be existed papers that were not included selected keyword (s) but capture the main content of this review.

6. Conclusion

The present review indicates that research in the field of organic production of MP and the effect of organic manures on the quantity and quality of MP is progressing fast, as evidenced by the growing number of studies (especially over the past two decades). Although additional research is required, numerous previous studies have demonstrated that diverse MP exhibited a favorable reaction when exposed to various types of organic manures. These positive responses were observed in terms of biomass, essential oil content and chemical compositions, as well as antioxidant activity. These positive effects are most probably due to the higher and longer availability of vital nutrients for plant growth and to the improvement of physical, chemical and biological properties of soil eventually creation a suitable environment for higher productivity and quality of MP. Among the organic manures, BL and, C can be recommended as the best choices for increasing MP biomass, while SM, VC, and C seem the recommendable options to enhance the essential oil content of MP. Our findings show that organic manures affected the aroma profile of essential oils and raised the main chemical

Table 5
Chemical properties of the various types of organic manures as reported by the literature sources used in this study.

Parameter	Type of organic manure								
	BL	PM	CM	SM	CAM	COM	FM	VC	C
EC* (dS m^{-1})	4.73–18.56	7.73	9.71	2.53–4.6	2.35–16.4	1–19.74	–	0.89–7.96	0.72–12
pH	7.56–8.24	4.91	7.4	7.1–9.17	7.3–8.84	7.5–8.95	–	4.65–8.5	7.0–8.1
OC (g kg^{-1})	278.1–472.6	163–303.3	303.1	282–284.7	197–390	39–850	126.9–127	71.3–377	23.5–344
N (g kg^{-1})	14.5–29.1	17.2–38	23.5–32.6	15.5–28.6	5.4–21	10.34–25.6	8.2–15.7	10–49.2	1.1–18
P (g kg^{-1})	1.72–6.9	0.06–22	7.4–16.8	0.0005–6.2	0.19–8	0.001–12.98	0.03–21.4	0.0004–25	0.004–16
K (g kg^{-1})	8.55–16.3	0.19–23.7	14.3–22	0.003–23.6	0.8–17.6	1.29–20.4	0.11–9.5	0.0002–39	0.48–23
Fe (mg kg^{-1})	389–998.2	24.01–2400	2184	280–2895	15.16–13300	652.47–1856	–	36.5–5100	320–1800
Cu (mg kg^{-1})	16.5–92.1	36–97	35	10–30	18–87.6	4.5–55	–	8.2–3000	75–240
Zn (mg kg^{-1})	101.2–401.3	16.6–314.8	200	25–136	12.9–270	188.2–235	–	14.7–7000	150–380
Mn (mg kg^{-1})	124–411.5	39.42–342	320	120–290	65.3–461	164.3–238	–	4.48–8000	25–350
C/N (%)	9.55–27.16	7.40–10.97	12.9	10.09–13.42	12.84–18.57	3.59–43.63	14.25–15.48	7.66–30.43	4.45–30.43

EC: Electrical conductivity, OC: organic carbon, N: nitrogen, P: phosphorus, K: potassium, Fe: iron, Cu: copper, Zn: zinc, Mn: manganese.
BL: broiler litter, PM: poultry manure, CM: chicken manure, SM: sheep manure, CAM: cattle manure, COM: cow manure, FM: farmyard manure, VC: vermicompost and C: compost.

compounds in many studies. The utilization of VC boosted the content of linalool of the examined MP. Most of the organic manures, especially BL, PM, FM, and VC enhanced the antioxidant capacity of these plants. In general, substituting organic manure for CF can be a valuable tool to improve the biomass and quality of MP, while eliminating the harmful effects of CF on human health and the environment.

7. Future trends and recommendations

The use of MP as the primary material is on the rise in various industries globally, including food, agriculture, sanitation, cosmetics, and pharmaceuticals. MP with higher levels of secondary metabolites is particularly valuable. In recent years, the importance of using organic manures to improve the quality of MP has gained recognition. This has led to a surge in research investigating the impact of organic manures on the quality of MP. While the effects of different types of organic manures on the quantity and quality of many MP have been extensively studied, there is still limited information available regarding their effects on some MP and further investigation is needed. In conclusion, this review emphasizes that organic manures can be an effective approach to achieving higher yield and quality in MP without negative effects on the environment and human health. However, caution is advised in generalizing the findings of this review, as further research is necessary to confirm the positive effects of organic manures on the productivity, content, and chemical compounds of essential oil and antioxidant activity of MP. Additionally, given that most studies on the impact of organic manures on the quantity and quality of MP have been conducted in semi-arid conditions, such as Iran, Egypt, and India, it is crucial to explore the influence of organic manures on biomass and quality of MP in other countries. Furthermore, given the apparent climate change in agricultural environments, it is recommended to examine the combined influence of organic manures and factors such as rising carbon dioxide levels, temperature variations, and precipitation on the production of secondary metabolites.

Data availability statement

No data was used for the research described in this paper.

CRediT authorship contribution statement

Maryam Rostaei: Writing – review & editing, Writing – original draft. **Sina Fallah:** Writing – review & editing. **Alessandra Carrubba:** Writing – review & editing. **Zahra Lorigooini:** Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e36693.

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