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Harvest stages and their influences on *Lantana camara* L. essential oil

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ABSTRACT

Essential oil (EO) of *Lantana camara* L. (*L. camara*) had different biological activities. Harvest stage is one way of scientific research that has the potential to modify the EO composition because it plays an important role in the physiological processes of *L. camara* EO. Thus, the aim of this trial was to evaluate the EO isolated from areal parts of two types (yellow-orange and pink-violet) of *L. camara* during various harvest stages (vegetative, flowering and fruiting). The EO of areal parts which collected during the various growth stages was isolated by hydro distillation method (HD), then, analyzed by GC and GC/MS equipments. Data were statistically analyzed using ANOVA-1. The EO percentages and constituents were significantly affected due to various harvest stages. The major component of yellow-orange flower color type EO was β-caryophyllene while it was davanone of pink-violet flower color type EO. The areal parts collected at flowering stage resulted in the greatest amounts of EO (%) and major constituents. Harvest stages caused different variations in all chemical classes {monoterpene hydrocarbons (MCH), oxygenated monoterpenes (MCHO), sesquiterpene hydrocarbons (SCH) and oxygenated sesquiterpenes (SCHO)}of EO isolated from both types of *L. camara*.

1. Introduction

Various plant parts are considered to be a natural source of active substances such as essential oil (EO), flavonoids, alkaloids, vitamins and pigments (Mir et al., 2015). The phytochemical components of medicinal and aromatic plants produce different physiological activities on human body which attracted the researcher's attention (Mushtaq and Wani, 2013). The EO is secondary product formed in aromatic plants; it is volatile used in food and pharmaceutical industries (Bakkali et al., 2008).

Lantana camara L. (*L. camara*) is a noxious evergreen perennial shrub, belongs to family Verbenaceae which comprise of about 650 species spread over 60 countries (Sharma et al., 1988). It is also known as an ornamental plant for pink, orange, yellow, violet and white lilac flowers depending on the variety (Sonibare and Effiong, 2008). The areal parts (leaves, stems, flowers and fruits) of *L. camara* have been used in traditional medicines to treat fever, influenza, asthma, skin itches, ulcers, tumors, malaria, bronquitis and rheumatism (Attri and Singh, 1978; Chharba et al., 1993). The EO of *L. camara* is reported to be insecticidal, nematicidal, acting as bees, mosquitoes and flies repellent (Ghisalberti, 2000). Beside that the EO constituents have highly significant antibacterial, antifungal, carminative, antiseptic, antitumoral and antihypertensive properties (Chavan and Nikam, 1982; Deena and Thoppil, 2000; Pattnaik and Pattnaik, 2010; Seth et al., 2012).

The quantity and quality of EO bearing plants are affected by different factors such as species, varieties, plant organ, soil type, location, irrigation and plant nutrition (Jing et al., 2014). For example, areal parts of thyme that collected during the flowering stage resulted in higher yield of EO, thymol and carvacrol than those collected at vegetative stage (Jordan et al., 2006; Nejad-Ebrahimi et al., 2008; Omidbaigi et al., 2010). The EO content and composition of pickling herb (*Echinophora tenuifolia* subsp. *sibthorpiana* Tutin) were collected during rosette, vegetative, full flowering and fruit ripening stages (Sanli et al., 2016); EO content showed significant variation during the various growth stages, methyl eugenol content decreased during vegetation period while α-phellandrene level increased.

Scientific research had different techniques to improve the EO composition as demand for food and pharmaceutical row materials. The selection of plant harvest stage is one way of research that has the potential to increase the productivity of EO. Therefore, the changes in EO composition during different growth stages of two types of *L. camara* were evaluated.

2. Materials and methods

2.1. Plant material

Aerial parts of *L. camara* were collected during vegetative, flowering

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and fruiting stages from the yellow-orange and pink-violet flower color types growing in the botanical garden of National Research Centre (NRC), Egypt.

2.2. EO isolation

The fresh aerial parts of *L. camara* (Fig. 1) were collected during the various growth stages and then 250 g from each replicate (four replicates) of all stages were subjected to hydro-distillation (HD) for 3 h using a Clevenger-type apparatus (Clevenger, 1928).

2.3. GC and GC–MS conditions

GC analyses were performed using a Shimadzu GC-9 gas chromatograph equipped with a DB-5 (dimethylsiloxane, 5% phenyl) fused silica column (J & W Scientific Corporation) (60 m × 0.25 mm i. d., film thickness 0.25 μm). Oven temperature was held at 50 °C for 5 min and then programmed to rise to 240 °C at a rate of 3 °C/min. The flame ionization detector (FID) temperature was 265 °C and injector temperature was 250 °C. Helium was used as carrier gas with a linear velocity of 32 cm/s. The percentages of compounds were calculated by the area normalization method, without considering response factors.

GC–MS analyses were carried out in a Varian 3400 GC-MS system equipped with a DB-5 fused silica column (60 m × 0.25 mm i. d., film thickness 0.25 ml); oven temperature was 50–240 °C at a rate of 4 °C/min, transfer line temperature 260 °C, carrier gas, helium, with a linear velocity of 31.5 cm/s, split ratio 1:60, ionization energy 70 eV, scan time 1s, and mass range 40–300 amu.

2.4. Identification of volatile components

The components of EO were identified by comparison of their mass spectra with those of a computer library or with authentic compounds and confirmed by comparison of their retention indices, either with those of authentic compounds or with data published in the literature (Adams, 1995). Mass spectra from the literature were also compared (Adams, 1995). Further identification was made by comparison of their mass spectra on both columns with those stored in NIST-98 and Wiley-5 Libraries. The retention indices were calculated for all volatile constituents using a homologous series of n-alkanes.

2.5. Statistical analysis

In this experiment, one factor was considered: Harvest stages (vegetative, flowering and fruiting). For each stage there were 4 replicates; the experimental design followed a complete random block design. The averages data were statistically analyzed using one-way analysis of variance (ANOVA-1) (De-Smith, 2015). Significant values determined according to P values ($P < 0.05$ = significant, $P < 0.01$ = moderate significant and $P < 0.001$ = highly significant). The applications of that technique were according to the STAT-ITCF program version 10 (Statsoft, 2007).

3. Results

3.1. Changes in EO of yellow-orange flower color type during various growth stages

Data in Table 1 showed that various growth stages (vegetative, flowering and fruiting) had significant variations ($P < 0.05$) in the EO (%) of yellow-orange flower color type. The EO samples collected during flowering stage resulted in higher value in EO content (0.4%) than those collected at vegetative or fruiting stages (0.2%). Forty one compounds have been characterized and identified by GC/MS (Table 1). Among the EO samples belonging to the yellow-orange flower color type the main component was β-caryophyllene (36.9–42.7%), followed by β-bisabolene (19.8–22.4%), sabinene (11.9–14.2%) and γ-cadinene (9.3–12.7%). The greatest amounts of β-caryophyllene, β-bisabolene, sabinene and γ-cadinene were produced from the samples collected during the flowering stage. All constituents belonged to 4 chemical classes. The major classes were sesquiterpene hydrocarbons, SCH (72.8–80.4%) and monoterpene hydrocarbons, MCH (16.4–20.9%) while the oxygenated sesquiterpenes, SCHO (2.2–5.4%) and oxygenated monoterpenes, MCHO (0.7–2.1) were the minor classes. The samples collected at fruiting stage resulted in the highest values of MCH and MCHO while the greatest amounts of SCH and SCHO were recoded with the samples collected during the flowering and vegetative stages respectively. Growth stages caused different changes in EO components and various chemical groups (Table 1).

3.2. Changes in EO of pink-violet flower color type during various growth stages

Significant variations ($P < 0.05$) were found in the EO (%) of pink-violet flower color type through various growth stages (Table 2). The highest EO content (0.3%) was obtained from the flowering samples. The same forty one components were detected in the EO isolated from pink-violet flower color type. The major constituent was davanone (41.2–44.8%), followed by β-caryophyllene (17.9–21.8%) and linalool (7.9–8.7%). The SCHO (44.4–47.1%), SCH (24.2–25.0%) and MCH (19.3–21.3%) were the major chemical classes while the minor class was MCHO (8.9–9.3%). The greatest values of MCH and SCH were recorded in the samples harvested at vegetative stage, while the samples collected at flowering stage produced the highest amounts of major constituent, MCHO and SCHO classes. Different changes were found in all detected components and various chemical classes (Table 2).

4. Discussion

In this investigation, obtained results indicated that some changes in EO composition of both types of *L. camara;* the highest values of EO (%) and major constituent were recorded from the samples collected at the

Fig. 1. *Lantana camara* L.

Table 1
The EO constituents of *L. camara* (yellow-orange flower color type).

No.	Components	RT	RI^C	RI^L	Stages			F value
					Vegetative	Flowering	Fruiting	
1	α-Pinene	8.6	939	939	0.7 ± 0.1	0.1 ± 0.0	0.4 ± 0.1	40.5***
2	Camphene	9.1	955	953	0.5 ± 0.1	0.1 ± 0.0	0.5 ± 0.1	24.0***
3	Sabinene	9.8	976	976	11.9 ± 1.0	14.2 ± 0.2	13.6 ± 0.2	11.9**
4	β-Pinene	10.7	981	980	0.5 ± 0.1	0.3 ± 0.1	0.6 ± 0.1	7.0*
5	Myrcene	11.1	991	991	0.6 ± 0.1	0.2 ± 0.1	0.6 ± 0.1	16.0**
6	α-Phellandrene	13.4	1008	1005	0.6 ± 0.1	0.2 ± 0.1	1.2 ± 0.2	38.0***
7	Δ-3-Carene	13.9	1012	1011	0.8 ± 0.2	0.4 ± 0.1	0.6 ± 0.1	6.0*
8	p-Cymene	14.8	1026	1026	0.9 ± 0.1	0.2 ± 0.1	0.7 ± 0.1	19.8**
9	Limonene	15.9	1031	1031	1.3 ± 0.3	0.1 ± 0.0	0.6 ± 0.1	32.7***
10	β-Phellandrene	16.8	1032	1032	0.8 ± 0.2	0.3 ± 0.1	1.1 ± 0.1	24.5***
11	cis-β-Ocimene	16.9	1040	1040	0.6 ± 0.1	0.1 ± 0.0	0.5 ± 0.1	31.5***
12	γ-Terpinene	17.5	1062	1062	0.8 ± 0.2	0.2 ± 0.1	0.5 ± 0.1	13.5**
13	Linalool	17.8	1099	1098	0.8 ± 0.2	0.2 ± 0.1	0.3 ± 0.1	15.5**
14	Camphor	18.7	1145	1143	0.5 ± 0.1	0.2 ± 0.1	1.3 ± 0.3	26.5***
15	α-Terpineol	19.6	1189	1189	0.1 ± 0.0	0.2 ± 0.1	0.2 ± 0.1	1.5ns
16	2-Hydroxy-1,8-Cineole	20.9	1219	1219	0.3 ± 0.1	0.1 ± 0.0	0.3 ± 0.1	6.0*
17	δ-Elemene	21.5	1339	1339	0.7 ± 0.2	0.1 ± 0.0	0.6 ± 0.1	18.6**
18	α-Cubebene	22.9	1355	1351	0.1 ± 0.0	0.3 ± 0.1	0.3 ± 0.1	6.0*
19	β-Elemene	23.7	1378	1375	0.8 ± 0.2	0.3 ± 0.1	0.2 ± 0.1	15.5**
20	α-Copaene	24.9	1377	1376	0.5 ± 0.1	0.2 ± 0.1	0.2 ± 0.1	9.0*
21	β-Caryophyllene	26.2	1418	1418	36.9 ± 1.8	42.7 ± 0.3	38.1 ± 0.1	19.5**
22	β-Humulene	27.7	1441	1440	0.9 ± 0.1	0.2 ± 0.1	0.3 ± 0.1	43.0***
23	(E)-β-Farnesene	29.8	1458	1458	0.6 ± 0.1	0.3 ± 0.1	0.5 ± 0.1	7.0*
24	Alloaromadendrene	30.7	1461	1461	0.2 ± 0.1	0.2 ± 0.1	0.1 ± 0.0	1.5ns
25	γ-Muurolene	32.7	1477	1477	0.4 ± 0.1	0.3 ± 0.1	0.3 ± 0.1	0.1ns
26	Germacrene D	33.8	1480	1480	0.7 ± 0.2	0.1 ± 0.0	0.2 ± 0.0	23.3***
27	α-Curcumene	34.7	1485	1483	0.8 ± 0.2	0.1 ± 0.0	0.3 ± 0.1	23.4***
28	α-Selinene	35.9	1495	1494	0.7 ± 0.1	0.4 ± 0.1	0.2 ± 0.0	11.4**
29	β-Bisabolene	37.9	1509	1509	19.8 ± 0.3	22.4 ± 0.4	20.6 ± 0.4	16.5**
30	γ-Cadinene	38.5	1515	1513	9.3 ± 0.2	12.7 ± 0.7	11.2 ± 0.2	42.2***
31	δ-Cadinene	40.2	1525	1524	0.4 ± 0.1	0.1 ± 0.0	0.3 ± 0.1	4.2*
32	trans-Nerolidol	41.7	1564	1564	0.5 ± 0.1	0.3 ± 0.1	0.4 ± 0.1	3.0ns
33	Spathulenol	43.9	1576	1576	0.2 ± 0.1	0.1 ± 0.0	0.3 ± 0.1	4.5*
34	Caryophyllene oxide	44.8	1583	1581	0.8 ± 0.2	0.1 ± 0.0	0.7 ± 0.2	16.1**
35	Davanone	45.8	1587	1586	0.7 ± 0.2	0.1 ± 0.0	0.2 ± 0.1	1.8**
36	Viridiflorol	47.2	1590	1590	0.4 ± 0.1	0.2 ± 0.1	0.3 ± 0.1	3.0ns
37	1-epi-Cubenol	49.6	1617	1616	0.6 ± 0.1	0.3 ± 0.1	0.4 ± 0.1	7.0*
38	T-Muurolol	51.8	1633	1632	0.8 ± 0.2	0.2 ± 0.1	0.3 ± 0.1	15.5**
39	T-Cadinol	52.7	1640	1640	0.3 ± 0.1	0.2 ± 0.1	0.3 ± 0.1	1.0ns
40	Cubenol	54.7	1642	1642	0.4 ± 0.1	0.3 ± 0.1	0.3 ± 0.1	1.0ns
41	α-Cadinol	55.9	1655	1653	0.7 ± 0.2	0.4 ± 0.1	0.2 ± 0.1	1.1**
MCH (1-12)					20.0 ± 2.0	16.4 ± 0.4	20.9 ± 0.1	12.2**
MCHO (13–16)					1.7 ± 0.2	0.7 ± 0.2	2.1 ± 0.1	52.0***
SCH (17–31)					72.8 ± 0.8	80.4 ± 0.4	73.4 ± 0.4	167.4***
SCHO (32–41)					5.4 ± 0.4	2.2 ± 0.2	3.4 ± 0.2	65.3***
EO (%)					0.2 ± 0.1	0.4 ± 0.1	0.2 ± 0.1	9.1*
Total detected compounds					99.9	99.7	99.8	

Note: EO, essential oil; RT., retention time; RI^L, retention index from literature; RI^C, retention index calculated; MCH, monoterpene hydrocarbons; MCHO, oxygenated monoterpenes; SCH, sesquiterpene hydrocarbons; SCHO, oxygenated sesquiterpenes;; ns, non significant; *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$; values are given as Mean ± SD.

flowering stage. The effect of growth stages on EO and its constituents may be due to its effect on enzyme activity and metabolism of EO production (Burbott and Loomis, 1969). The results in this study are in accordance with those obtained by previous literature; Muller-Riebau et al. (1997) indicated that the greatest values of some EO bearing plants resulted at the full blooming period. Tonçer and Kýzýl (2005) showed that the highest EO contents of thyme was at the full flowering stage while the lowest was before flowering and these results may be due to the higher yields of fresh and dry mass during the flowering stage than other stages. The geranium EO usually increases from the onset of flowering to be the highest at full bloom and decreased very rapidly thereafter (Sangwan et al., 2001). The greatest amounts of EO yield and major constituents (apiol, myristicin, α-pinene and β-pinene) in parsley {*Petroselinum crispum* (Mill)} were recorded at flowering stage compared with vegetative and fruiting stages (Ahmed et al., 2018a). The EO composition of celery (*Apium graveolens* L.) was investigated through various growth stages (vegetative, flowering and fruiting); results showed that the highest value of EO yield was observed in the samples collected during the flowering stage (Ahmed et al., 2018b). On the other hand, different variations were found in *Artemisia herba-alba* Asso EO during growth stages (vegetative and flowering); the chemical classes such as MCH, MCHO, SCH and SCHO were increased at vegetative stage; however diterpene hydrocarbons (DCH) class was increased during the flowering stage (Behtari et al., 2012). Similar constituents were found by Randrianalijaona et al. (2006) in the EO of both types of *L. camara* from Madagascar; they indicated that the main components of the yellow orange type were β-caryophyllene, β-bisabolene, sabinene, γ-cadinene and α-humulene; while the pink-violet flower type contained mainly davanone, β-caryophyllene, sabinene, linalool and α-humulene. The changes in EO composition of *L. camara* during different growth stages also may be de to some environmental factors such as location, plant nutrition, salinity and metrological factors. In this concern, different variations were found in *Plectranthus amboinicus* (Lour.), *Solenstemma arghel* (Dellile) Hayne and onion EOs under metrological factors (temperature, humidity and soil temperature), soil fertility and geographical locations (Yassen and Khalid, 2009; Khalid and El-Gohary, 2014;

Table 2
The EO constituents of *L. camara* (pink-violet flower color type).

No.	Components	RT	RI^C	RI^L	Stages			F value
					Vegetative	Flowering	Fruiting	
1	α-Pinene	8.6	939	939	0.9 ± 0.1	0.2 ± 0.1	0.5 ± 0.1	37.0***
2	Camphene	9.1	955	953	0.5 ± 0.1	0.2 ± 0.1	0.4 ± 0.1	7.0*
3	Sabinene	9.8	976	976	14.7 ± 0.3	16.9 ± 0.2	15.3 ± 0.3	61.3***
4	β-Pinene	10.7	981	980	0.5 ± 0.1	0.3 ± 0.1	0.3 ± 0.1	4.0*
5	Myrcene	11.1	991	991	0.4 ± 0.1	0.3 ± 0.1	0.5 ± 0.1	3.0ns
6	α-Phellandrene	13.4	1008	1005	0.4 ± 0.1	0.3 ± 0.1	0.1 ± 0.0	10.5*
7	Δ-3-Carene	13.9	1012	1011	0.6 ± 0.2	0.2 ± 0.1	0.7 ± 0.2	7.0*
8	p-Cymene	14.8	1026	1026	0.6 ± 0.2	0.3 ± 0.1	0.3 ± 0.1	4.5*
9	Limonene	15.9	1031	1031	1.3 ± 0.3	0.2 ± 0.1	1.2 ± 0.2	23.8***
10	β-Phellandrene	16.8	1032	1032	0.6 ± 0.2	0.2 ± 0.1	0.5 ± 0.1	6.5*
11	cis-β-Ocimene	16.9	1040	1040	0.2 ± 0.1	0.1 ± 0.0	0.6 ± 0.2	12.6**
12	γ-Terpinene	17.5	1062	1062	0.6 ± 0.2	0.1 ± 0.0	0.5 ± 0.1	12.6**
13	Linalool	17.8	1099	1098	7.9 ± 0.1	8.7 ± 0.3	8.2 ± 0.2	10.5*
14	Camphor	18.7	1145	1143	0.1 ± 0.0	0.2 ± 0.1	0.3 ± 0.1	4.5*
15	α-Terpineol	19.6	1189	1189	0.4 ± 0.1	0.2 ± 0.1	0.1 ± 0.0	10.5*
16	2-Hydroxy-1,8-Cineole	20.9	1219	1219	0.6 ± 0.2	0.2 ± 0.1	0.3 ± 0.2	5.6*
17	δ-Elemene	21.5	1339	1339	0.2 ± 0.1	0.2 ± 0.1	0.2 ± 0.1	0.0ns
18	α-Cubebene	22.9	1355	1351	0.7 ± 0.2	0.2 ± 0.1	0.6 ± 0.1	7.0*
19	β-Elemene	23.7	1378	1375	0.6 ± 0.1	0.1 ± 0.0	0.4 ± 0.1	28.5***
20	α-Copaene	24.9	1377	1376	0.5 ± 0.1	0.2 ± 0.1	0.3 ± 0.1	7.0*
21	β-Caryophyllene	26.2	1418	1418	17.9 ± 0.3	21.8 ± 0.2	19.5 ± 0.5	115.3***
22	β-Humulene	27.7	1441	1440	0.6 ± 0.1	0.2 ± 0.1	0.4 ± 0.1	12.0**
23	(E)-β-Farnesene	29.8	1458	1458	0.4 ± 0.1	0.2 ± 0.1	0.5 ± 0.1	7.0*
24	Alloaromadendrene	30.7	1461	1461	0.4 ± 0.1	0.1 ± 0.0	0.2 ± 0.1	10.5*
25	γ-Muurolene	32.7	1477	1477	0.8 ± 0.2	0.1 ± 0.0	0.4 ± 0.1	22.2**
26	Germacrene D	33.8	1480	1480	0.7 ± 0.1	0.1 ± 0.0	0.2 ± 0.1	18.6**
27	α-Curcumene	34.7	1485	1483	0.9 ± 0.1	0.2 ± 0.1	0.3 ± 0.1	43.0***
28	α-Selinene	35.9	1495	1494	0.2 ± 0.1	0.2 ± 0.1	0.5 ± 0.1	9.0*
29	β-Bisabolene	37.9	1509	1509	0.3 ± 0.1	0.3 ± 0.1	0.2 ± 0.1	1.0ns
30	γ-Cadinene	38.5	1515	1513	0.6 ± 0.1	0.2 ± 0.1	0.2 ± 0.1	16.0**
31	δ-Cadinene	40.2	1525	1524	0.2 ± 0.1	0.1 ± 0.0	0.4 ± 0.1	10.5*
32	trans-Nerolidol	41.7	1564	1564	0.3 ± 0.1	0.3 ± 0.1	0.1 ± 0.0	6.0*
33	Spathulenol	43.9	1576	1576	0.2 ± 0.1	0.3 ± 0.1	0.2 ± 0.0	4.5*
34	Caryophyllene oxide	44.8	1583	1581	0.5 ± 0.1	0.3 ± 0.1	0.1 ± 0.0	18.0**
35	Davanone	45.8	1587	1586	41.2 ± 0.2	44.8 ± 0.3	42.9 ± 0.4	324.3***
36	Viridiflorol	47.2	1590	1590	0.5 ± 0.1	0.3 ± 0.1	0.3 ± 0.1	4.0ns
37	1-epi-Cubenol	49.6	1617	1616	0.2 ± 0.1	0.2 ± 0.1	0.2 ± 0.1	0.0ns
38	T-Muurolol	51.8	1633	1632	0.3 ± 0.1	0.1 ± 0.0	0.4 ± 0.1	10.5**
39	T-Cadinol	52.7	1640	1640	0.2 ± 0.1	0.2 ± 0.1	0.3 ± 0.1	1.0ns
40	Cubenol	54.7	1642	1642	0.4 ± 0.1	0.4 ± 0.1	0.5 ± 0.1	1.0ns
41	α-Cadinol	55.9	1655	1653	0.6 ± 0.1	0.2 ± 0.1	0.5 ± 0.1	13.0**
MCH (1-12)					21.3 ± 0.3	19.3 ± 0.3	20.9 ± 0.1	53.1***
MCHO (13–16)					9.0 ± 0.1	9.3 ± 0.3	8.9 ± 0.1	0.4ns
SCH (17–31)					25.0 ± 0.1	24.2 ± 0.2	24.3 ± 0.3	1.5ns
SCHO (32–41)					44.4 ± 0.4	47.1 ± 0.3	45.5 ± 0.5	39.5***
EO (%)					0.1 ± 0.0	0.3 ± 0.1	0.2 ± 0.1	4.5*
Total detected compounds					99.7	99.9	99.6	

Note: EO, essential oil; RT., retention time; RI^L, retention index from literature; RI^C, retention index calculated; MCH, monoterpene hydrocarbons; MCHO, oxygenated monoterpenes; SCH, sesquiterpene hydrocarbons; SCHO, oxygenated sesquiterpenes; ns, non significant; *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$; values are given as Mean ± SD.

Ibrahim et al., 2014). Significant increases were produced in *Nigella sativa* L. EO and its constituents (p-cymene, α-thujene and γ-terpinene) with saline soil conditions (Khalid and Ahmed, 2017). Plant nutrition caused significant increases in EO yield and main components (α-cadinol, Δ-and γ -cadinene) of marigold (Khalid, 2013). Previously, there were no research papers on the evaluation of *L. camara* EO under various growth stages in Egypt. This variability highlights the importance of the growth stages which could affect the EO composition and therefore the biological activities.

5. Conclusion

It may be concluded that harvest stages produce significant variation in EOs isolated from two flower color types of *L. camara* (yellow-orange and pink-violet). The plants harvested during the flowering stage resulted in the highest amounts of EO and its major constituents. The effect of growth stages on the *L. camara* EO has not been investigated before. This study discovered that production of *L. camara* EO at flowering stage is required because the plants collected during the flowering stage produced significant variation in the EO composition of *L. camara* types and this study helps the farmers and pharmaceutical companies to increase the yield and major constituents of the EO extracted from *L. camara* as a natural source for drug industries.

Availability of data and materials

The datasets supporting the results are included within the article.

Declaration of competing interest

No potential conflict of interest was reported by the authors.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.bcab.2019.101403.

References

Adams, R.P., 1995. Identification of Essential Oil Components by Gas Chromatography/Mass Spectrometry. Allured Publ. Corp., Carol Stream, IL.

Ahmed, A.M.A., El-Kady, F.A., Khalid, A.K., 2018. Morphological and chemical characters of *Petroselinum crispum* (Mill) subjected to some biostimulants. Asian J. Plant Sci. 17, 96–106.

Ahmed, A.M.A., El-Kady, F.A., Khalid, A.K., 2018. Comparison between salicylic acid and selenium effect on growth and biochemical composition of celery. Asian J. Plant Sci. 17, 150–159.

Attri, B.S., Singh, R.P., 1978. A note on biological activity of the oil of *Lantana Camara* L. Indian Entomol. J. 39, 384–385.

Bakkali, F., Averbeck, S., Averbeck, D., Idaomar, M., 2008. Biological effects of essential oils - a review. Food Chem. Toxicol. 46, 446–475.

Behtari, B., Gholami, F., Khalid, A.K., Tilaki, G.D., Bahari, R., 2012. Effect of growth stages and altitude on *Artemisia herba-alba* Asso essential oil growing in Iran. J. Essent. Oil Bearing Plants 15, 307–313.

Burbott, A.J., Loomis, D., 1969. Evidence for metabolic turnover monoterpene in peppermint. Plant Physiol. 44, 173–179.

Chavan, S.R., Nikam, S.T., 1982. Investigation of *Lantana camara* Linn (Verbenaceae) leaves for larvicidal activity. Bull. Haffkine Inst. 10, 21–22.

Chharba, S.C., Mahunnah, R.L.A., Mshiu, E.N., 1993. Plants used in traditional medicine in eastern Tanzania. J. Ethnopharmacol. 39, 83–103.

Clevenger, J.F., 1928. Apparatus for determination of essential oil. J. Am. Pharm. Assoc. 17, 346–349.

Deena, M.J., Thoppil, J.E., 2000. Antimicrobial activity of the essential oil of *Lantana camara*. Fitoterapia 71, 453–455.

De-Smith, M.J., 2015. STATSREF: Statistical Analysis Handbook - a Web-Based Statistics Resource. The Winchelsea Press, Winchelsea.

Ghisalberti, E.L., 2000. *Lantana camara* Linn (Rev.). Fitoterapia 71, 467–485.

Ibrahim, M.E., Ahmed, S.S., El-Sawi, S.A., Khalid, K.A., 2014. Investigation of essential oil extracted from *Solenstemma arghel* (Dellile) Hayne. J. Essent. Oil Bearing Plants 17, 629–632.

Jing, L., Lei, Z., Li, L., Xie, R., Xi, W., Guan, Y., Zhou, Z., 2014. Antifungal activity of citrus essential oils. J. Agric. Food Chem. 62, 3011–3033.

Jordan, M.J., Martınez, R.M., Cases, M.A., Sotomayor, J.A., 2006. Seasonal variation of *thymus hyemalis* Lange and Spanish *thymus vulgaris* L. essential oils composition. Ind. Crops Prod. 24, 253–263.

Khalid, A.K., Ahmed, M.A., 2017. Growth and certain biochemical components of black cumin cultivated under salinity stress factor. J. Mater. Environ. Sci. 8, 7–13.

Khalid, A.K., El-Gohary, A.E., 2014. Effect of seasonal variations on essential oil production and composition of *Plectranthus amboinicus* (Lour.) grow in Egypt. Int. Food Res. J. 21, 1859–1862.

Khalid, A.K., 2013. Effect of potassium uptake on the composition of *Calendula Officinalis* L. flower's content of essential oil. Emir. J. Food Agric. 25, 189–195.

Mir, S.A., Masoodi, F.A., Gani, A., Ganaie, S.A., Reyaz, U., Wani, S.M., 2015. Evaluation of antioxidant properties of methanolic extracts from different fractions of quince (*Cydonia oblonga* Miller). Adv. Biomed. Pharm. 2, 1–6.

Muller-Riebau, J.F., Berger, B.M., Yegen, O., Cakir, C., 1997. Seasonal variations in the chemical compositions of essential oils of selected aromatic plants growing wild in Turkey. J. Agric. Food Chem. 45, 4821–4825.

Mushtaq, M., Wani, S.M., 2013. Polyphenols and human health - a review. Int. J. Pharma Bio Sci. 4, 338–360.

Nejad-Ebrahimi, S., Hadian, J., Mirjalili, M.H., Sonboli, A., 2008. Essential oil composition and antibacterial activity of *Thymus caramanicusat* different phenological stages. Food Chem. 110, 927–931.

Omidbaigi, R., Fattahi, F., Karimzadeh, G.H., 2010. Harvest time effect on the herb yield and essential oil content of lemon thyme (*Thymus* × *citriodorus* (Pers.) Schreb). Iran. J. Med. Aromatic Plants 26, 318–325.

Pattnaik, S., Pattnaik, B., 2010. A study of *Lantana camara* Linn. aromatic oil as an antimicrobial agent. Int. Res. J. Pharm. Sci. 1, 32–35.

Randrianalijaona, J., Ramanoelina, P.A.R., Rasoarahona, J.R.E., Gaydou, E.M., 2006. Chemical compositions of aerial part essential oils of *Lantana camara* L. Chemotypes from Madagascar. J. Essent. Oil Res. 18, 405–407.

Sangwan, N.S., Farooqi, A.H.A., Shabih, F., Sangwan, R.S., 2001. Regulation of essential oil production in plants. Plant Growth Regul. 34, 21.

Sanli, A., Karadogani, T., Tosuni, B., Tonguc, M., Erbasi, S., 2016. Growth stage and drying methods affect essential oil content and composition of pickling herb (*Echinophora tenuifolia* subsp. *sibthorpiana* Tutin). J. Nat. Appl. Sci. 20, 43–49.

Seth, R., Mohan, M., Singh, P., Haider, S.Z., Gupta, S., Bajpai, I., Singh, D., Dobhal, R., 2012. Chemical composition and antibacterial properties of the essential oil and extracts of *Lantana camara* Linn. from Uttarakhand (India). Asian Pacific J. Trop. Biomed. S1407–S1411.

Sharma, O.P., Makkar, H.P.S., Dawara, R.K., 1988. A review of the noxious plant of *Lantana camara*. Toxicon 28, 975–987.

Sonibare, O.O., Effiong, I., 2008. Antibacterial activity and cytotoxicity of essential boil of *Lantana camara* L. leaves from Nigeria. Afr. J. Biotechnol. 7, 2618–2620.

Statsoft, 2007. Statistica Version 7. 1. Statsoft Inc., Tulsa, OK.

Tonçer, O., Kýzýl, S., 2005. Determination of yield and yield components in wild thyme (*Thymbra spicata* L. var. spicata) as influenced by development stages. Hortic. Sci. (HORTSCI) 32, 100–103.

Yassen, A.A., Khalid, K.A., 2009. Influence of organic fertilizers on the yield, essential oil and mineral content of onion. Int. Agrophys. 23, 183–188.