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Ngari Ann G
(a) University of Eldoret, Department of Chemistry and Biochemistry, P.O. Box 1125-30100, Eldoret, Kenya
(b) Karatina University, Department of Physical Sciences, P.O. Box 1957-10100, Karatina, Kenya

Omolo Maurice V
Masinde Muliro University of Science and Technology, Department of Pure and Applied Chemistry, P.O. Box 190-50100, Kakamega, Kenya

Tarus Paul K
University of Eldoret, Department of Chemistry and Biochemistry, P.O. Box 1125-30100, Eldoret, Kenya

Ng'ang'a Margaret M
Kenyatta University, Department of Chemistry, P.O. Box 43844 - 00100, Nairobi, Kenya

Hassanali Ahmed
Kenyatta University, Department of Chemistry, P.O. Box 43844 - 00100, Nairobi, Kenya

Corresponding Author:
Omolo Maurice V
Masinde Muliro University of Science and Technology, Department of Pure and Applied Chemistry, P.O. Box 190-50100, Kakamega, Kenya

Chemical compositions of essential oils of some Kenyan *Ocimum* species

Ngari Ann G, Omolo Maurice V, Tarus Paul K, Ng'ang'a Margaret M and Hassanali Ahmed

Abstract
The natural aroma of *Ocimum* species varies, implying that variations in chemical compositions of their essential oils are likely to be observed. Steam distilled essential oils from leaves and flowers of *Ocimum kenyense*, *Ocimum kilimandscharicum* and *Ocimum lamiifolium* growing in various parts of Kenya were analyzed by gas chromatography-mass spectrometry (GC-MS). There were notable variations in individual composition of foliar and floral essential oils although some chemical constituents were common in investigated species. In *O. kenyense*, eucalyptol (20.01-24.81%) and estragole (22.01-35.06%) were identified as major compounds of its foliar and floral essential oils. Camphor (16.9-30.6%) and α-phellandrene (12.36-14.69%) were identified as major compounds of *O. kilimandscharicum* and *O. lamiifolium*, respectively. This study reports the existence of α-phellandrene chemo type of Kenyan *O. lamiifolium* species for the first time. Chemical compositions and percent mean yields of investigated *Ocimum* essential oils varied with species, plant organ used and agro ecological zones.

Keywords: *Ocimum*, leaf, floral, essential oil

1. Introduction
Ocimum species are annual and perennial herbs and shrubs of Lamiaceae family. It is estimated that all the genus *Ocimum* consists of about 200 species with a large number of varieties [1]. Plants of genus *Ocimum* are found in Africa, Asia, central and southern America [2]. Traditionally, *Ocimum* extracts are used as a remedy for colds, nose bleeds and diarrhea [3, 4]. They are also used as repellents against stored grains, particularly the weevil and biting insects such as mosquitoes [3]. *Ocimum* species have also been reported to have biological activities such as analgesic [5], antiplasmodial [6, 7], antimicrobial [8, 9, 10], pesticidal [11, 12, 13], mosquito repellent [14, 15] and antioxidant [16].
The essential oils of *Ocimum* have attracted a lot of attention from researchers worldwide due to their great potential as commercial sources of natural flavours, perfumes and medicine [17]. A new pharmaceutical product Naturub™ was formulated using *Ocimum kilimandscharicum* essential oil extracts and has been registered by the Pharmacy and Poisons Board of Kenya. Naturub™ balm is used to alleviate muscle pain, insect bites, colds and chest congestion while ointment is used to manage lumbago, arthritis, sciatica and muscular strains [18, 19].
The viability of commercial exploitation of *Ocimum* oils depends on their quality and quantity. Factors such as methods of extraction, climate, soil type and organ of plant used can influence the quality and quantity of essential oils [20, 21, 22]. In previous studies, hydro distillation, steam distillation, maceration, solvent and supercritical fluid extraction methods have been used to extract essential oils from plant materials [23, 24]. Steam distillation extraction method gives more chemical constituents as compared to oven hydro distillation [25]. The present study was carried out to quantity and quality of steam distilled foliar and floral essential oils of *Ocimum kilimandscharicum*, *Ocimum lamiifolium* and *Ocimum kenyense* growing in different agro ecological zones in Kenya.

2. Materials and methods
2.1 Plant collection
Fresh leaf and floral materials of each the selected *Ocimum* species were collected from two Counties in different agro ecological zones. *Ocimum kenyense* was collected from Nanyuki-Laikipia County (0.016ºN, 37.07ºE) and Kiganjo-Nyeri County (0.23ºS, 37.01ºE). *Ocimum kilimandscharicum* was collected from Sagana-Kirinyaga County (0.47ºS, 37.15ºE) and

Kabaru-Nyeri (0.23ºS, 37.01ºE) while *O. lamiifolium* was collected from Ol jororok-Nyandarua County (0.03ºN, 36.36ºE) and Bahati-Nakuru County (0.28ºN, 36.06ºE). Specimens of mature plants were collected from their respective natural populations in May 2014, immediately after the long rain season. Botanical identification of the plant materials was carried out at the Herbarium of Department of Botany, University of Nairobi, Kenya where voucher specimen, (AN2014/001/ AN2014/002, AN2014/003) for *O. kenyense*, *O. kilimandscharicum* and *O. lamiifolium*, respectively, were deposited.

2.2 Extraction of essential oils
Fresh flowers and leaves of each species weighing 150 g were separately steam distilled in Steam distillation apparatus (Science Company NC-13223) for 2 hours. The distillates were dried over anhydrous sodium sulphate, packed in sealed glass vials and refrigerated until GC-MS analyses.

2.3 Gas chromatography Mass Spectrometry (GC-MS) analyses of essential oils
GC-MS analyses were performed on HP GC 1800 II equipped with DB-5 MS column (30 m x 0.25 mm, 0.25 mm film thickness). Mass spectra were acquired on E1 mode (70 eV) in m/z range of 0-400 a.m.u with a scan time of 1.5 seconds. Carrier gas used was helium at flow rate of 1ml/min and split ratio 1:30. The injector temperature was 250 ºC; detector temperature was set at 270 ºC, while column temperature was linearly programmed at 40-240 ºC (at the rate of 5 ºC/min). The essential oil chemical components were identified on the basis of their retention indices (RI) and comparison of mass spectra fragmentation patterns stored in MS library (NIST and Wiley database) as well as reference to literature [26]. Quantification of components was done by correlation of peak area percent obtained when a known amount of 1-heptene was added to each oil sample as internal standard during analyses.

3. Results and discussion
3.1 Essential oil yield
Means of essential oil yield of each species, plant part used and location of origin were analyzed to determine their significant differences [27] and presented in table 1.

Table 1: Percent means of foliar and floral essential oil yields of three *Ocimum* species growing in various agro ecological zones in Kenya

Species	Yield per species	Agro ecological zone	Plant organ	
			Foliar yield	Floral yield
O. kilimandscharicum	0.494 ± 0.005^{a}	Nyeri	0.648 ± 0.01^{a}	0.554 ± 0.01^{b}
		Kirinyaga	0.426 ± 0.01^{d}	0.346 ± 0.01^{e}
O. kenyense	0.397 ± 0.005^{b}	Nyeri	0.482 ± 0.01^{c}	0.360 ± 0.01^{e}
		Laikipia	0.440 ± 0.01^{d}	0.306 ± 0.01^{fg}
O. lamiifolium	0.325 ± 0.005^{c}	Nyandarua	0.334 ± 0.01^{ef}	0.230 ± 0.01^{h}
		Nakuru	0.440 ± 0.01^{d}	0.294 ± 0.01^{g}

Yields of *Ocimum* essential oils varied with species, plant organ used and agro ecological area of origin. Significant differences were observed in essential oil yields of O. *kilimandscharicum* (0.49 ± 0.05%), *O. kenyense* (0.39 ± 0.01%) and *O. lamiifolium* (0.33 ± 0.06%). Generally, foliar essential oil yield was significantly higher than floral yield for each species regardless of agro ecological area of origin. *O. kenyense* (Nyeri County), *O. kilimandscharicum* (Nyeri County) and *O. lamiifolium* (Nakuru County) had higher foliar and floral essential oil yields as compared to their counterparts from Laikipia, Kirinyaga and Nyandarua Counties. The highest and lowest essential oil yields were observed in *O. kilimandscharicum* (Nyeri County) and *O. lamiifolium* (Nyandarua County) at (0.55-0.65%) and (0.23-0.33%) respectively. In this study, foliar and floral essential oils' yields of *O. kenyense, O. kilimandscharicum and O. lamiifolium* were found to be within the yield range of *Ocimum* species (Table 1). The essential oil yield of *Ocimum* species generally ranges from 0.2 to 1.0% (v/w) but can be as high as 1.7% (v/w) depending on source and developmental stage of plants [25].

3.2. Chemical composition of selected *Ocimum* species' foliar essential oils
The foliar essential oil composition of the three *Ocimum* species is shown in the GC-MS total ion chromatograms (Figures 1-6) and the chemical components are summarized in Table 2. A total of 59 chemical constituents were identified in foliar essential oils of investigated *Ocimum* species.

3.2.1 Chemical composition of *Ocimum kenyense* foliar essential oil
GC-MS analyses led to identification total of twenty-six chemical constituents in foliar essential oil of *Ocimum kenyense* from Laikipia County (Table 2). The major constituents of the foliar essential oil were estragole (22.01%), eucalyptol (20.01%), chavicol (11.21%), β-bisabolene (7.52%), α-pinene (4.76%), (*Z*)-piperitol (4.61%) and α-humulene (4.57%). The minor compounds present in the foliar essential oil were identified as bisabolol (3.65%), ethyl isovalerate (3.06%), (*E*)-β-caryophyllene (1.52%) and β-pinene (1.08%) (Figure 1).

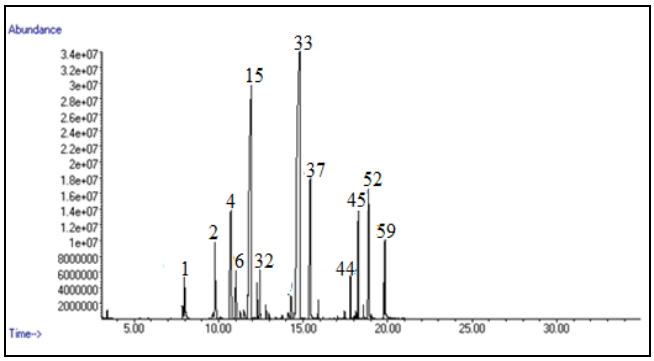

Fig 1: Total ion chromatogram of foliar essential oil of *O. kenyense* (Laikipia County)

Sixteen chemical constituents were identified in foliar essential oil *Ocimum kenyense* from Nyeri County (Table 2).Estragole (33.45%), eucalyptol (24.81%), chavicol (8.06%) and β-bisabolene (7.27%), α-humulene (4.90%) and (*E*)-β-caryophyllene (3.05%) were the major components of the foliar essential oil. Minor constituents of foliar essential oils were α-pinene (1.53%), ethyl isovalerate (1.99%) and β-pinene (1.02%) among others (Figure 2).

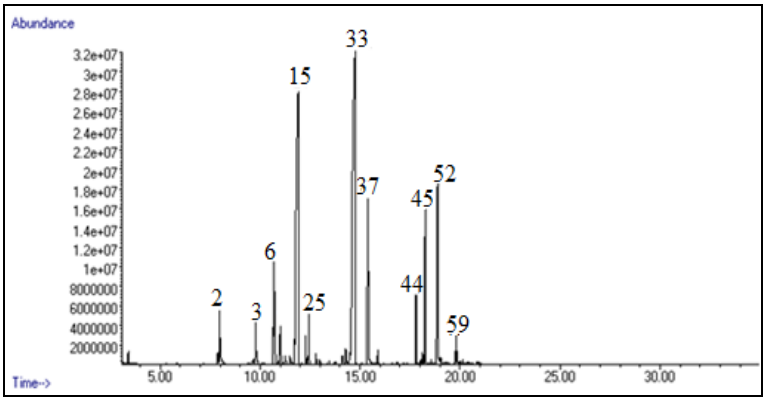

Fig 2: Total ion chromatogram of foliar essential oil of *O. kenyense* (Nyeri County)

3.2.2 Chemical composition of *Ocimum kilimandscharicum* foliar essential oils

Foliar essential oil of *O. kilimandscharicum* from Kirinyaga County had a total of twenty-five chemical constituents (Table 2). Camphor (16.9%), geraniol (11.10%), eucalyptol (8.65%) and camphene (3.24%) were the major chemical constituents of the foliar essential oil while its minor constituents were limonene (2.44%), (*E*)-β-caryophyllene (2.14%), (*E*)-β-ocimene (2.54%), fenchone (2.43%), nerol (1.48%) and α-pinene (1.76%) among others (Figure 3).

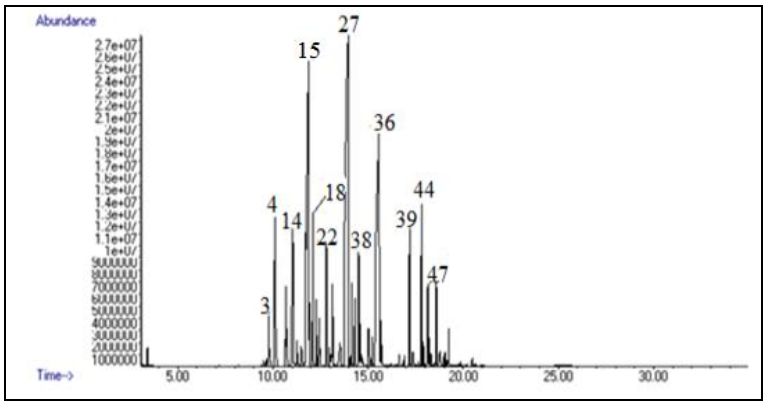

Fig 3: Total ion chromatogram of foliar essential oil of *O. kilimandscharicum* (Kirinyaga County)

Foliar essential oil of *O. kilimandscharicum* from Nyeri County had a total of eighteen chemical constituents (Table 2). Camphor (30.6%), eucalyptol (19.02%) and camphene (6.33%) were the major chemical constituents of the foliar essential oil while (*E*)-β-caryophyllene (1.37%), fenchone (3.44%), limonene (4.66%) and β-myrcene (2.08%) among others were the minor constituents of the foliar essential oil (Figure 4).

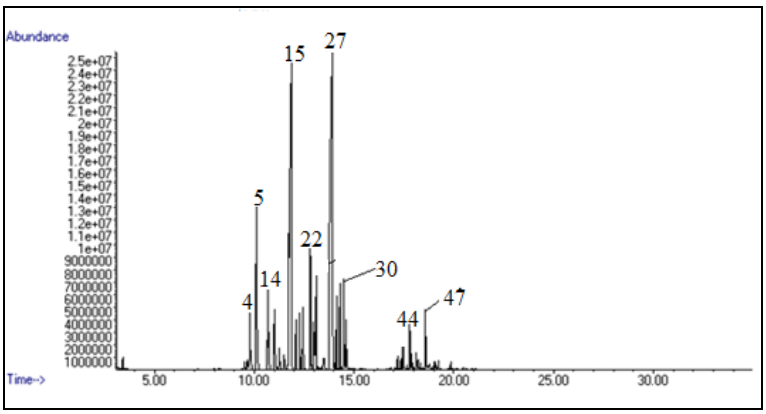

Fig 4: Total ion chromatogram of foliar essential oil of *O. kilimandscharicum* (Nyeri County)

3.2.2 Chemical composition of *Ocimum lamiifolium* foliar essential oils

A total of twenty-seven compounds chemical compounds were identified in foliar essential oil of *O. lamiifolium* from Nyandarua County (Table 2). Major compounds of the foliar essential oil were α-phellandrene (14.69%), germacrene-A (6.05%), (*E*)-2-octen-1-yl acetate (6.22%), (*E*)-2-octen-1-ol (5.69%) and eucalyptol (5.48%). On the other hand, (*E*)-β-caryophyllene (3.05%), (*E*)-β-farnesene (3.58%) and δ-cadinene (4.17%) among others were minor compounds of *O. lamiifolium* essential oils (Figure 5).

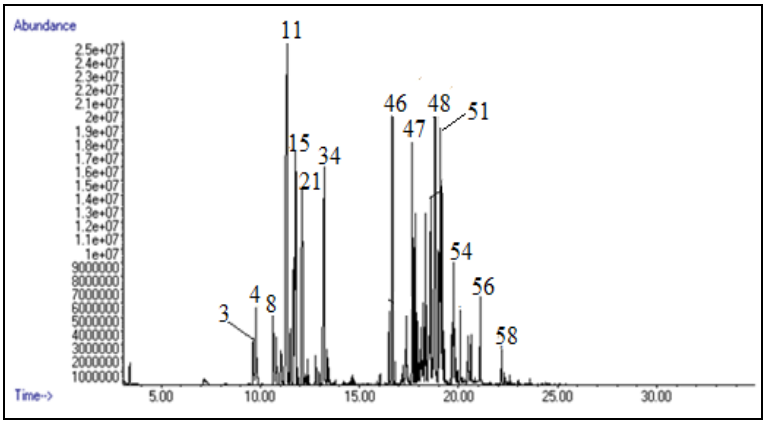

Fig 5: Total ion chromatogram of foliar essential oil of *O. lamiifolium* (Nyandarua County)

A total of twenty-six chemical compounds were identified in foliar essential oil of *O. lamiifolium* from Nakuru County (table 2). Major compounds of the foliar essential oil were α-phellandrene (14.58%), eucalyptol (5.41%), epi-cubebol (8.74%), (*E*)-β-farnesene (5.05%), (*E*)-2-octen-1-yl acetate (7.71%) and (*E*)-2-octen-1-ol (6.71%). Minor compounds of the foliar essential oil were germacrene-A (4.17%) and α-gurjenene (3.09%), α-humulene (1.52%) and (*E*)-β-caryophyllene (1.38%) (Figure 6).

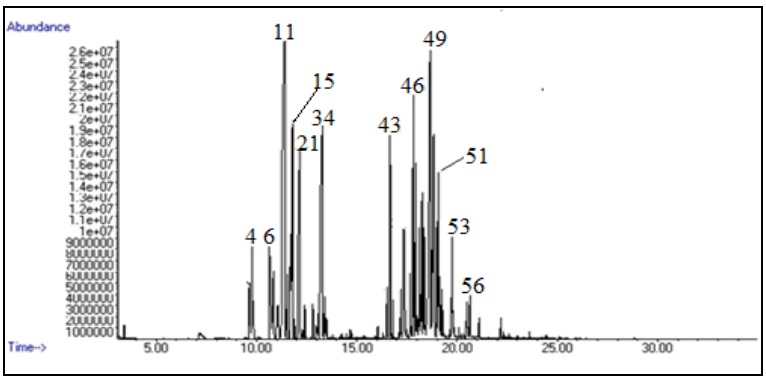

Fig 6: Total ion chromatogram of foliar essential oil of *O. lamiifolium* (Nakuru County)

Table 2: Chemical constituents of foliar essential oils of selected *Ocimum* species growing in various agro ecological zones in Kenya

GC peak	R1	Identity of the compound	O.KE		O.K		OL	
			LKP	NYR	KRN	NYR	NYD	NKU
1	846	Ethyl-α-methyl butyrate	0.61	-	-	-	-	-
2	856	Ethyl isovalerate	3.06	1.99	-	-	-	-
3	924	α-Thujene	-	-	-	-	0.85	1.03
4	932	α-Pinene	4.76	1.53	1.22	1.93	1.46	1.78
5	948	Camphene	-	-	3.24	6.33	-	-
6	953	Thuja-2,4-diene	0.76	0.82	-	0.65	1.59	2.43
7	974	β-Pinene	1.08	1.02	1.76	-	-	-
8	980	1-Octen-3-ol	2.89	1.31	-	-	0.94	1.85
9	988	β-Myrcene	0.68	-	-	2.08	1.03	1.26
10	990	2-Octanal	-	-	1.72	-	-	-
11	1005	α-Phellandrene	-	-	-	0.76	14.69	14.58
12	1008	δ-3-Carene	0.81	-	-	-	0.89	0.89
13	1022	*o*-Cymene	-	-	-	-	2.35	2.09
14	1024	Limonene	-	-	2.44	4.66	-	-
15	1026	Eucalyptol	20.01	24.81	15.65	19.02	5.48	5.41
16	1030	2-Ethylhexan-1-ol	1.14	-	-	-	-	-
17	1032	(*Z*)-β-Ocimene	-	-	1.25	1.07	-	-
18	1044	(*E*)-β-Ocimene	-	-	2.54	-	-	-
19	1054	ɤ-Terpinene	-	0.63	1.55	-	-	-
20	1060	(*E*)-2-Octenal	1.85	1.19	1.01	1.25	-	-
21	1066	(*E*)-2-Octen-1-ol	-	-	-	-	5.69	6.71
22	1083	Fenchone	-	-	2.43	3.44	-	-
23	1086	Terpinolene	-	-	1.01	-	-	-
24	1095	Linalool	-	-	1.18	2.67	-	-
25	1129	β-Terpineol	1.95	1.85	-	-	-	-
26	1140	(*Z*)-Neo-allo ocimene	-	-	1.95	-	-	-
27	1141	Camphor	-	-	16.9	30.6	-	-

28	1165	Borneol	-	-	1.45	1.58	-	-
29	1174	Terpinen-4-ol	1.68	0.63	1.05	1.77	-	-
30	1186	α-Terpineol	-	-	1.76	1.97	-	-
31	1191	Octyl acetate	-	-	1.13	0.45	-	-
32	1194	(*Z*)-Piperitol	4.61	-	-	-	-	-
33	1195	Estragole	22.01	33.45	-	-	-	-
34	1208	(*E*)-2-Octen-1-yl acetate	-	-	-	-	6.22	7.71
35	1227	Nerol	-	-	1.48	-	-	-
36	1249	Geraniol	-	-	11.10	-	-	-
37	1253	Chavicol	11.21	8.06	-	-	-	-
38	1299	Terpinen-4-yl acetate	-	-	1.32	-	-	-
39	1302	Methyl geranate	-	-	1.85	-	-	-
40	1315	(*E*)-3-Hexenyl tiglate	-	-	-	-	4.74	0.61
41	1387	β-Bourbonene	-	-	-	-	0.45	-
42	1391	β-Elemene	-	-	-	-	1.11	-
43	1409	α-Gurjunene	-	-	-	-	-	3.09
44	1417	(*E*)-β-Caryophyllene	1.52	3.05	2.14	1.37	3.05	1.38
45	1452	α-Humulene	4.57	4.90	-	-	1.01	1.52
46	1454	(*E*)-β-Farnesene	-	-	-	-	3.58	5.05
47	1484	Germacrene-D	-	-	0.98	1.55	0.95	2.20
48	1492	(*Z*)-β-Guaiene	-	-	-	-	1.77	2.01
49	1493	Epi-cubebol	-	-	-	-	-	8.74
50	1500	α-Muurolene	-	-	-	-	1.01	1.05
51	1503	Germacrene-A	-	-	-	-	6.05	4.17
52	1505	β-Bisabolene	7.52	7.27	-	-	-	-
53	1513	γ-cadinene	-	-	-	-	1.01	2.70
54	1522	δ-Cadinene	-	-	-	-	4.17	0.66
55	1523	Eugenyl acetate	-	-	-	-	1.66	-
56	1537	α-Cadinene	-	-	-	-	2.71	1.23
57	1606	Geranyl isovalerate	-	-	-	-	0.66	0.67
58	1652	δ-Cadinol	-	-	-	-	1.11	0.64
59	1672	β-Bisabolol	3.65	0.83	-	-	-	-
Monoterpene hydrocarbons			8.09	4.00	15.95	17.48	20.51	21.97
Sesquiterpene hydrocarbons			13.61	15.22	3.12	2.92	26.87	25.06
Oxygenated monoterpenes			23.64	27.29	57.13	61.05	6.14	6.08
Oxygenated sesquiterpenes			3.65	0.83	-	-	1.11	9.38
Benzenoids			33.22	41.51	-	-	4.01	2.09
Non-terpenoids			14.16	4.49	3.66	1.7	17.59	16.88
Total			96.37	93.34	80.06	83.15	75.12	81.46

Key: OKE-*Ocimum kenyense*, OK-*Ocimum kilimandscharicum*, OL-*Ocimum lamiifolium*, LKP-Laikipia, NYR-Nyeri, KRN-kirinyaga, NYD-Nyandarua, NKU-Nakuru

From the table, it was determined that the most dominant classes of compounds from foliar essential oils of *O. kenyense*, *O. kilimandscharicum* and *O. lamiifolium* species were benzenoids (33.22-41.51%), oxygenated monoterpenes (57.13-61.05%) and sesquiterpene hydrocarbons (25.06-26.87%), respectively. The other classes of chemical constituents present in foliar essential oils of investigated *Ocimum* species included monoterpene hydrocarbons (4.00-21.97%), oxygenated sesquiterpenes (0.83-9.38%) and oxygenated non-terpenes (1.77-17.59%). Benzenoid and oxygenated sesquiterpenoid classes of chemical constituents were absent from *O. kilimandscharicum* species foliar essential oils though present in all investigated oils in varying concentrations.

3.3 Chemical composition of selected *Ocimum* species' floral essential oils

The floral essential oil composition of the three *Ocimum* species is shown in the GC-MS total ion chromatograms (Figures 7-12) and the chemical components are summarized in Table 3. A total of 63 chemical constituents were identified in floral essential oils of investigated *Ocimum* species.

3.3.2 Chemical composition of *Ocimum kenyense* floral essential oils

GC-MS analyses led to identification total of sixteen chemical constituents in floral essential oil of *Ocimum kenyense* from Laikipia County (Table 3). The major constituents of the floral essential oil were identified as estragole (35.06%), eucalyptol (24.6%), chavicol (6.78%), β-bisabolene (7.52%) and β-myrcene (6.60%) and bisabolol (4.23%). Ethyl isovalerate (1.50%), α-pinene (3.06%), α-humulene (2.77%) and (*E*)-β-caryophyllene (0.86%) were present as minor compounds of the floral essential oil. β-Pinene was conspicuously absent in the floral essential oil though present as a major component of floral essential oil of *Ocimum kenyense* from Laikipia County (Figure 7).

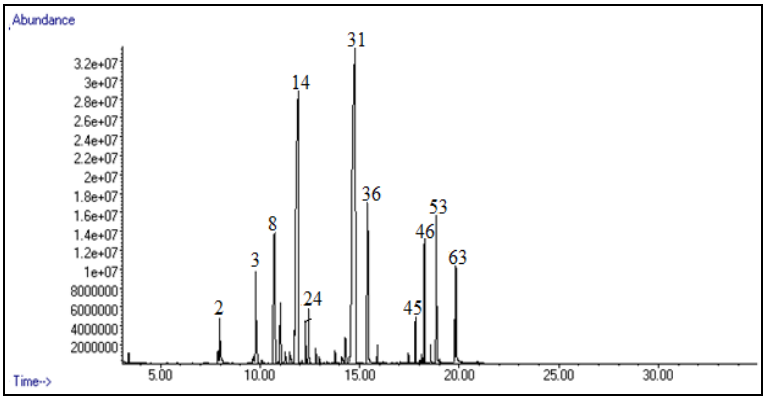

Fig 7: Total ion chromatogram of floral essential oil of *O. kenyense* (Laikipia County)

A total of fifteen chemical constituents were identified in floral essential oil of *Ocimum kenyense* from Nyeri County (Table 3). Estragole (22.19%), eucalyptol (20.24%), α-humulene (10.37%), chavicol (6.74%), β-bisabolene (14.18%), α-humulene (4.90%), ethyl isovalerate (4.49%) β-pinene (3.22%) and (*E*)-β-caryophyllene (3.38%) were the major components of the floral essential oil. Minor components of the floral essential oil were identified as α-pinene (1.16%) and geranyl isovalerate (1.19%) among others (Figure 8).

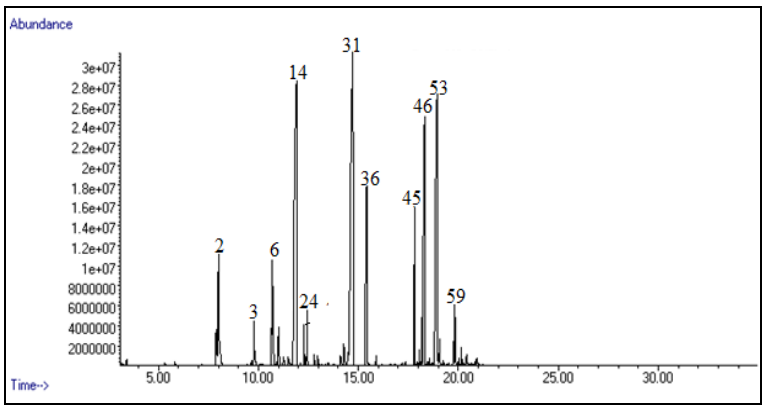

Fig 8: Total ion chromatogram of floral essential oil of *O. kenyense* (Nyeri County)

3.3.3 Chemical composition of *Ocimum kilimandscharicum* floral essential oils

A total of twenty-three chemical constituents were reported in floral essential oil of *O. kilimandscharicum* from Kirinyaga County (table 3). Camphor (21.15%), geraniol (14.5%), limonene (5.55%), (*E*)-β-caryophyllene (5.44%), β-myrcene (5.14%), (*E*)-β-ocimene (4.43%) eucalyptol (3.79%) and camphene (3.35%) were the major chemical constituents of the foliar essential oil. On the other hand, linalool (1.32%) and nerol (1.76%) were its minor constituents of the floral essential oil (Figure 9).

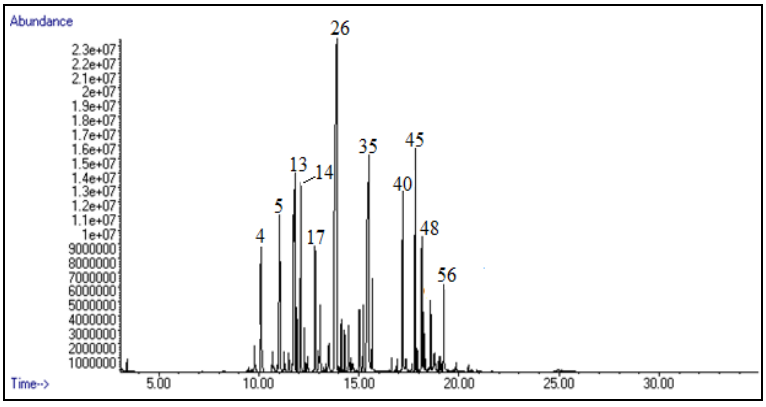

Fig 9: A Total ion chromatogram of floral essential oil of *O. kilimandscharicum* (Kirinyaga County)

Floral essential oil of *O. kilimandscharicum* from Nyeri County contained a total of twenty-two chemical constituents (Table 3). Camphor (27.36%), eucalyptol (12.29%), camphene (5.44%) linalool (4.17%) and limonene (4.25%) were the major chemical constituents of the floral essential oil. (*E*)-β-caryophyllene (2.99%), β-pinene (1.99%) and β-myrcene (1.84%) among others were the minor constituents of *O. kilimandscharicum* of Nyeri County origin (Figure10).

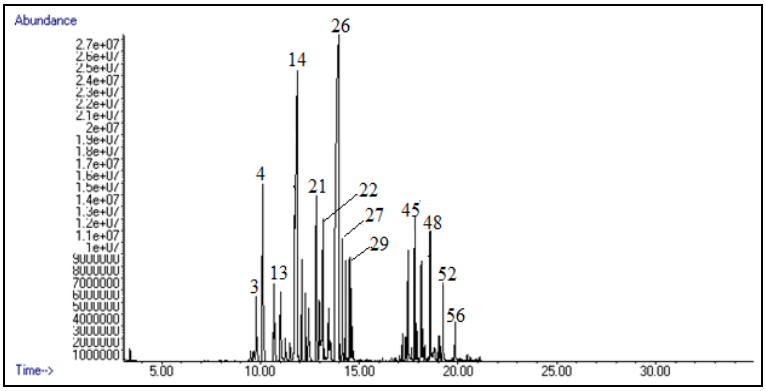

Fig 10: Total ion chromatogram of floral essential oil of *O. kilimandscharicum* (Nyeri County)

3.3.4 Chemical composition of *lamiifolium* floral essential oils

A total of twenty-eight chemical constituents were identified in floral essential oil of *O. lamiifolium* from Nyandarua County (Table 3). Major compounds of the floral essential oil were α-phellandrene (13.01%), germacrene-A (7.16%), (*E*)-2-octen-1-yl acetate (6.42%), α-cadinene (5.23%), carvacrol acetate (4.82%) and δ-cadinene (4.17%), epicubebol (3.17%) and α-gurjenene (3.71%). Minor chemical compounds of the floral essential oil were (*E*)-β-caryophyllene (1.68%) and eucalyptol (0.43%) among others (Figure11).

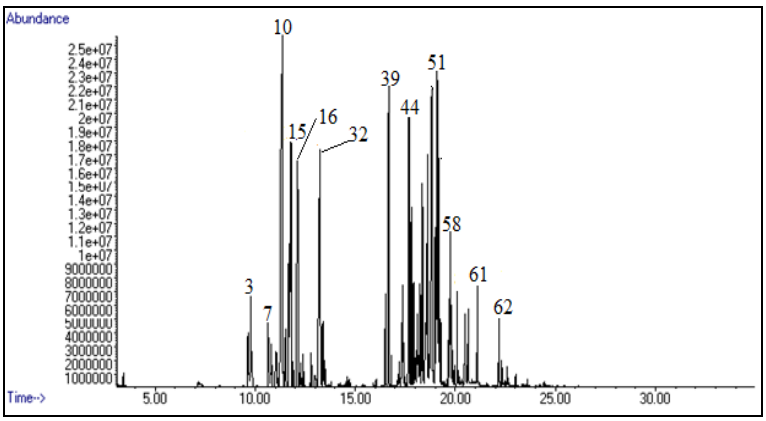

Fig 11: Total ion chromatogram of floral essential oil of *O. lamiifolium* (Nyandarua County)

A total of twenty-six chemical constituents were identified in floral essential of *O. lamiifolium* from Nakuru County. The major compounds of the foliar essential oil were α-phellandrene (12.36%), germacrene-A (6.01%), (E)-β-caryophyllene (5.29%) epi-cubebol (7.88%), (E)-β-farnesene (2.29%), (E)-2-octen-1-yl acetate (7.53%), (E)-2-octen-1-ol (5. 10%), (Z)-β-ocimene (4.70%) and carvacrol acetate (3.96%). The minor compounds of the floral essential oil were α-humulene (2.04%), α-cadinene (1.55%) and eucalyptol (0.41%) among others (Figure12).

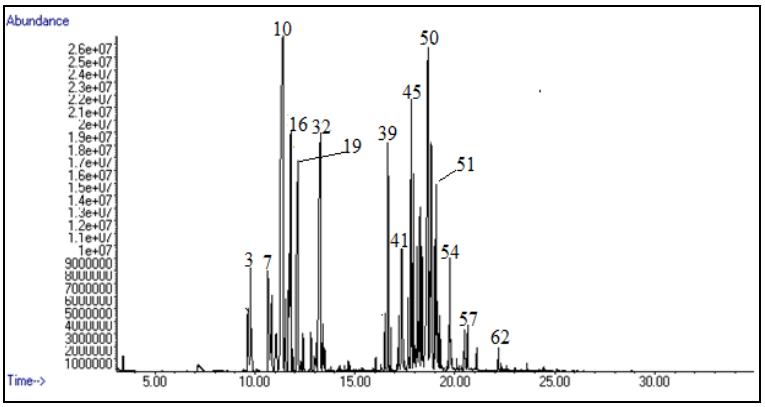

Fig 12: Total ion chromatogram of floral essential oil of *O. lamiifolium* (Nakuru County)

Table 3: Chemical constituents of floral essential oils of selected *Ocimum* species growing in various agro ecological zones

GC peak	R1	Identity of the compound	O.KE		O.K		OL	
			LKP	NYR	KRN	NYR	NYD	NKU
1	846	Ethyl-α-methyl butyrate	-	0.91	-	-	-	-
2	856	Ethyl isovalerate	1.50	4.49	-	-	-	-
3	932	α-Pinene	3.06	1.16	0.67	1.66	1.49	1.23
4	948	Camphene	-	-	3.35	5.44	-	-
5	953	Thuja-2,4-diene	-	-	-	-	1.30	0.98
6	974	β-Pinene	-	3.22	-	1.99	-	-
7	980	1-Octen-3-ol	-	-	-	-	0.78	1.06
8	988	β-Myrcene	6.60	1.02	5.14	1.84	0.98	0.85
9	990	2-Octanal	0.45	-	-	-	-	-
10	1005	α-Phellandrene	-	-	0.56	0.61	13.01	12.36
11	1008	δ-3-Carene	-	-	-	-	0.78	0.67
12	1022	*o*-Cymene	2.12	-	-	-	2.42	2.10
13	1024	Limonene	0.64	-	5.55	4.25	-	-
14	1026	Eucalyptol	24.6	20.24	3.79	12.29	0.43	0.41
15	1030	2-Ethylhexan-1-ol	-	-	-	-	4.98	-
16	1032	(*Z*)-β-Ocimene	-	-	1.24	1.67	5.13	4.70
17	1044	(*E*)-β-Ocimene	-	-	4.43	-	-	-
18	1054	ɤ-Terpinene	0.71	0.61	0.72	1.06	-	-
19	1060	(*E*)-2-Octen-1-ol	-	-	-	-	-	5.10
20	1083	Fenchone	-	-	-	1.47	-	-
21	1086	Terpinolene	-	-	2.97	4.56	-	-
22	1095	Linalool	-	-	1.32	4.17	-	-
23	1118	Exo-fenchol	-	-	-	1.18	-	-
24	1129	β-Terpineol	1.13	0.94	-	-	-	-
25	1140	Neo-allo-ocimene	-	-	1.21	-	-	-
26	1141	Camphor	-	-	21.15	27.36	-	-
27	1165	Borneol	-	-	0.87	2.22	-	-
28	1174	Terpinen-4-ol	-	-	-	1.55	-	-
29	1186	α-Terpineol	-	-	0.82	1.76	-	-
30	1194	(*Z*)-Piperitol	0.99	0.61	-	-	-	-
31	1195	Estragole	35.06	22.19	-	-	-	-
32	1208	(*E*)-2-Octen-1-yl acetate	-	-	-	1.67	6.42	7.53
33	1227	Nerol	-	-	1.76	-	-	-
34	1235	Neral	-	-	1.12	-	-	-
35	1249	Geraniol	-	-	14.5		-	-
36	1253	Chavicol	6.78	6.74	-	-	-	-
37	1254	Geranial	-	-	1.81	-	-	-
38	1315	(*E*)-3-Hexenyl tiglate	-	-	-	-	0.95	0.73
39	1370	Carvacrol acetate	-	-	-	-	4.82	3.96
40	1379	Geranyl acetate	-	-	4.24	-	-	-
41	1387	β-Bourbonene	-	-	-	-	0.67	1.61
42	1387	β-Cubebene	-	-	-	-	1.24	-
43	1391	β-Elemene	-	-	-	-	-	1.31
44	1409	α-Gurjunene	-	-	-	-	3.71	-
45	1417	(*E*)-β-Caryophyllene	0.86	3.38	5.48	2.99	1.68	5.29
46	1452	α-Humulene	2.77	10.37	-	-	1.05	2.04
47	1454	(*E*)-β-Farnesene	-	-	-	-	-	2.29
48	1484	Germacrene-D	-	-	1.36	2.62	1.01	1.61
49	1492	(*Z*)-β-Guaiene	-	-	-	-	2.70	2.13
50	1493	Epi-cubebol	-	-	-	-	3.17	7.88
51	1503	Germacrene-A	-	-	-	-	7.16	6.01
52	1504	(*E*,*E*)-α-Farnesene	-	-	-	1.96	-	-
53	1505	β-Bisabolene	4.23	14.18	-	-	-	-
54	1513	γ-Cadinene	-	-	-	-	-	2.02
55	1522	δ-Cadinene	-	-	-	-	1.85	1.03
56	1523	Eugenyl acetate	-	-	1.58	1.25	-	-
57	1537	α-Cadinene	-	-	-	-	5.23	1.55
58	1574	Germacrene-D-4-ol	-	-	-	-	1.88	-
59	1587	Geranyl isovalerate	-	1.19	-	-	-	-
60	1602	Ledol	-	-	-	-	1.01	-
61	1626	Epi-α-cadinol	-	-	-	-	2.81	-
62	1652	δ-Cadinol	-	-	-	-	1.04	1.11
63	1672	β-Bisabolol	2.48	-	-	-	-	-
Monoterpene hydrocarbons			11.01	6.01	25.84	23.08	22.69	20.79
Sesquiterpene hydrocarbons			7.86	27.93	6.84	7.57	26.30	26.89

Oxygenated monoterpenes	25.73	22.37	51.38	53.25	0.43	0.41
Oxygenated sesquiterpenes	2.48	-	-	-	9.91	8.99
Benzenoids	43.96	28.93	-	-	7.24	6.06
Oxygenated non-terpenoids	2.94	6.01	-	1.67	12.35	14.83
Total	93.98	91.25	84.06	85.57	78.92	77.97

Key: OKE-*Ocimum kenyense,* OK-*Ocimum kilimandscharicum,* OL-*Ocimum lamiifolium,* LKP-Laikipia, NYR-Nyeri, KRN-kirinyaga, NYD-Nyandarua, NKU-Nakuru

From the table, it was determined that the most dominant classes of compounds from floral essential oils of *O. kenyense, O. kilimandscharicum* and *O. lamiifolium* species were benzenoids (28.93-43.96%), oxygenated monoterpenes (51.38-53.25%) and sesquiterpene hydrocarbons (26.30-26.89%), respectively. The other classes of chemical constituents present in foliar essential oils of investigated *Ocimum* species included monoterpene hydrocarbons (6.01-23.08%), oxygenated sesquiterpenes (2.48-9.91%) and oxygenated non-terpenes (1.68-14.83%). Benzenoid and oxygenated sesquiterpenoid classes of chemical constituents were absent from *O. kilimandscharicum* species foliar essential oils.

Three compounds namely α-pinene (0.67-4.76%), eucalyptol (0.41-24.81%) and (*E*)-β-caryophyllene (0.86-5.48%) were present in all foliar and floral essential oils of *O. kenyense, O. lamiifolium* and *O. kilimandscharicum* (peaks 4, 15 and 44 in Table 2; peaks 3, 14 and 45 in Table 3). Some major constituents were unique markers of essential oils of specific species. Chavicol (6.74-11.21%) and β-bisabolene (4.23-14.18%), germacrene-A (4.17-7.16%) and camphene (3.24-6.33%) were unique markers of *O. kenyense, O. kilimandscharicum* and *O. lamiifolium* foliar and floral essential oils, respectively. Geraniol (11.10-14.50%) only occurred in foliar and floral essential oils of *O. kilimandscharicum* from Kirinyaga County while neral (1.12%), geranial (1.81%) and geranyl acetate (4.24%) were only reported in its floral essential oil. Ledol (1.01%), germacrene-D-4-ol (1.88%) and epi-α-cadinol (2.81%) were only reported in *O. lamiifolium* floral essential oils from Nakuru County (Table 3).

In the present study, chemical analyses of steam distilled foliar and floral oils from *Ocimum kilimandscharicum, Ocimum kenyense* and *O. lamiifolium* led to identification of camphor, eucalyptol-estragole and α-phellandrene chemo types respectively. The selected *Ocimum* species populations growing in various parts of the world have also been studied by other researchers. Eucalyptol-estragole chemo type of *O. kenyense* was previously described in Kenya [6, 13]. Camphor, eucalyptol and methyl eugenol chemo types of *O. kilimandscharium* were described in Kenya [12], Rwanda [28] and Nigeria [9] respectively. Phellandrene chemo type of Kenyan *Ocimum lamiifolium* is being described for the first time in this study. Bornyl acetate and sabinene chemo types of *O. lamiifolium* were previously described in other studies in Ethiopia [29] and Tanzania [30] respectively.

In general, the observed variations in chemical composition of various essential oils as compared to those described in previous studies could be attributed to various factors such as differences in climate, soil type, organ used and plant's stage of development among others. Soil and climatic features of various sampling sites in Laikipia, Nyeri, Kirinyaga, Nakuru and Nyandarua Counties have been described by Jaeztold and co-workers [31].

Comparative analysis of essential of various *Ocimum* species is vital in exploration of plants' potential use in pharmaceutical, pest control, food and cosmetic industries. *Ocimum* essential oils rich in ocimene, eucalyptol, germacrene-D and estragole can be used as insect repellents [13, 23]. Essential oils with high concentrations of camphor, limonene and camphene could be exploited in medicine [28, 30, 32]. On the other hand, food and cosmetic industries could exploit *Ocimum* essential oils with high concentrations of geraniol, linalool and nerol [17].

4. Conclusion

The foliar and floral essential oils of *O. kenyense, O. kilimandscharicum* and *O. lamiifolium* species were qualitatively and quantitatively analyzed. Camphor and α-phellandrene were the most dominant chemical constituents of *O. kilimandscharicum* and *O. lamiifolium* essential oils respectively while estragole and eucalyptol dominated *O. kenyense* essential oils. Major chemical constituents of *Ocimum* species contribute to the unique aroma of respective essential oils.

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