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Ngari Ann G
(1) University of Eldoret, Department of Chemistry and Biochemistry, Eldoret, Kenya
(2) Karatina University, Department of Physical Sciences, Karatina, Kenya

Omolo Maurice O
Masinde Muliro University of Science and Technology, Department of Pure and Applied Chemistry, Kakamega, Kenya

Tarus Paul K
University of Eldoret, Department of Chemistry and Biochemistry, Eldoret, Kenya

Ng'ang'a Margaret M
Masinde Muliro University of Science and Technology, Department of Pure and Applied Chemistry, Kakamega, Kenya

Hassanali Ahmed
Kenyatta University, Department of Chemistry, Nairobi, Kenya

Corresponding Author:
Omolo Maurice O
Masinde Muliro University of Science and Technology, Department of Pure and Applied Chemistry, Kakamega, Kenya

Chemical compositions of smoke volatiles of some Kenyan *Ocimum* species

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

Abstract
The natural aroma of *Ocimum* species vary, implying that variations in chemical compositions of their smoke aroma are likely to be observed. Air entrained smoke volatiles from leaves and flowers of *Ocimum kenyense*, *Ocimum kilimandscharicum* and *Ocimum lamiifolium* species growing in various parts of Kenya were analyzed by gas chromatography-mass spectrometry (GC-MS). Chemical compositions of investigated *Ocimum* smoke volatiles varied with species and agro ecological zones. Five classes of chemical constituents namely; monoterpenoids (14.11-64.40%), benzenoids (3.04-38.2%), sesquiterpenoids (14.12-37.69%), triterpenoids (0.48-2.07%) and non-terpenoids (0.83-17.85%) were identified in this study. There were notable variations in individual chemical compositions of smoke volatiles although α-phellandrene (0.81-12.76%) was identified in all investigated *Ocimum* species. In *O. kenyense*, eucalyptol (10.71-27.93%) and estragole (18.32-30.93%) were identified as major compounds of its smoke volatiles. Camphor (12.62-17.32%) and α-phellandrene (8.41-12.76%) were identified as major compounds of smoke volatiles derived from *O. kilimandscharicum* and *O. lamiifolium* species, respectively. This study reports the smokes derived volatile chemical composition of *O. kenyense, O. kilimandscharicum* and *O. lamiifolium* species for the first time. The volatile chemical profiles of smokes of investigated *Ocimum* species provide a scientific basis for their traditional use as incenses and insect repellents.

Keywords: *Ocimum*, smoke, volatiles, aroma

1. Introduction

Smoke derived from plants is traditionally used in various parts of the world as medicine, incense, food preservative and insect repellents among other purposes [1]. It is estimated that 1500 plant species are traditionally burnt to produce smoke for various purposes although limited research has been conducted on chemistry of their fragrant fumes [2]. Plants emit a wide range of biogenic volatile organic compounds (BVOC) comprising of monoterpenes, sesquiterpenes and isoprenes [3].

BVOCs are important in protecting plants against biotic stresses such as predation by herbivores [4]. Production and storage of BVOCs depends on species, plant growth stage, season and environmental conditions [5]. Plants produce copious amount of BVOCs in response to wounding [6, 7] as well as on exposure to high temperature [8]. Fragrant and therapeutic chemical agents that are released from plant tissues at high temperature are of great economic and social importance [1]. Chemical compositions of BVOCs emitted naturally, during distillation as well as during flaming and smoldering combustions are remarkably different [9].

Since time immemorial smokes of genus *Ocimum* plants which comprises of approximately 200 species, have been commonly used as ritual and medicinal incense [1], as well as mosquito and house fly repellents [10, 11]. A study comparing mosquito repellent activity of fresh, dried and smoke volatiles of five plants traditionally used in Ethiopia as protection against mosquito bites, among them *Ocimum suave* and *Ocimum lamiifolium* demonstrated repellent activity of smoke volatiles against *Aedes aegypti* and *Anopheles arabiensis*. However, chromatograms of smoked leaf extracts were highly complex and hence they were difficult to interpret [12].

In a field study conducted in Tanzania, *O. suave* and *O. kilimandscharicum* species' smoke induced mosquito deterrence of 73.1-81.95% against *Anopheles arabiensis* and *Culex. quinquefaciatus* when dry plant materials were burnt in experimental houses [13]. Similarly, in a semi field study conducted in Western Kenya, burning of *O. basilicum* and *O. americanum* species' plant materials resulted in significantly high mosquito repellency of 30.4% and 64.1% against *An. gambiae*. On the other hand, thermally expelled volatiles of *O. kilimandscharicum* and *O. suave* species plant materials exhibited mosquito repellency of 52.0% and 53.1%, respectively in the same study [10].

An ethnobotanical survey conducted in Jinja District in Uganda by Baana and co-workers identified *Ocimum kilimandscharicum* as one of the plants whose smoke is traditionally used to repel house flies (*Musca domestica)* [11]. In Nigeria, toxicity of *O. suave* (wild basil) against houseflies had also been previously reported [14]. According to indigenous knowledge systems of Mount Kenya region, smokes derived from three *Ocimum* species namely *O. kenyense*, *O. kilimandscharicum* and *O. lamiifolium* species are traditionally used as deterrents of annoying insects such as mosquitoes and houseflies, among others. However, very little is known about the volatile chemical constituents of the various *Ocimum* species' derived smokes. In this work, chemical composition of smoke volatiles of *O. kenyense*, *O. kilimandscharicum* and *O. lamiifolium* species growing in various agro ecological zones in Kenya, is presented for the first time.

2. Materials and methods

2.1 Plant collection

Fresh leaf and floral materials of each of the selected *Ocimum* species were collected from two Counties in different agro ecological zones in Kenya. *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 in the Department of Botany, University of Nairobi, Kenya where voucher specimen, (AN2014/001, AN2014/002, AN2014/003) for *O. kenyense, O. kilimandscharicum* and *O. lamiifolium* species, respectively, were deposited.

2.2 Air entrainment of the *Ocimum* species' smoke volatiles

Samples of fresh aerial parts of each selected *Ocimum* species weighing 10g were air dried under shade for three days at the Centre for African Medicinal and Nutritional Flora and Fauna (CAMNFF) in Masinde Muliro University of Science and Technology in Kakamega County, Kenya; prior to volatiles' collection. The air dried plant materials were separately placed into stain-less steel containers (diameter=10 cm) containing glowing charcoal, enclosed in a large stain-less container (volume of 1 litre) and sealed with Teflon tape. Collection of smoke volatiles was conducted using air entrainment kit for 20 minutes [15, 16] on different Soxhlet cleaned Porapak Q adsorbent glass tube filters fitted into the large stain-less container containing smoldering plant materials.

The glass filters contained 40 mg of Porapak Q polymer on which volatile constituents of *Ocimum* species smoke aerial parts' aroma volatiles adsorbed. Clean air was pulled for 20 minutes through an empty stain-less container (1 liter) with a glowing charcoal and fitted with a glass tube filter to provide a control sample. After collection of volatiles, the volatile collection traps (VCTs) were heat sealed in borosilicate glass tubes and refrigerated at -20 ºC until needed for analysis. The volatiles were eluted from the Porapak Q filters with GC grade dichloromethane solvent where 100 µl samples were collected and used for chemical analysis.

2.3 Gas chromatography Mass Spectrometry (GC-MS) analyses of smoke volatiles

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 smoke volatiles' 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 [17]. Quantification of components was done by correlation of peak area percent obtained when a known amount of n-decane was added to each sample as internal standard during analyses.

3. Results and discussion

3.1 Chemical composition of smoke volatiles of the *Ocimum* species

GC-MS analyses of smoke volatiles of the three *Ocimum* species led to identification of a total of twenty-two, forty-three and fifty chemical constituents in *O. kenyense, O. kilimandscharicum* and *O. lamiifolium* species' smoke volatiles, respectively. Chemical composition of smoke volatiles of *O. kenyense O. kilimandscharicum* and *O. lamiifolium* species are presented in tables 1, 2 and 3.

3.1.1 Chemical composition of *O. kenyense* species' smoke volatiles

A total of twenty-two chemical constituents were identified in smoke volatiles of *O. kenyense* species from both Laikipia and Nyeri Counties (Table 1).

Table 1: Chemical constituents of *O. kenyense* species' smoke volatiles

GC Peak	RI	Identity of the compound	Amount in %	
			Laikipia	Nyeri
1	932	α-Pinene	-	0.93
2	974	β-Pinene	0.46	3.27
3	988	β-Myrcene	0.48	1.26
4	1002	α-Phellandrene	1.23	1.04
5	1026	Eucalyptol	10.71	27.93
6	1141	Camphor	-	2.19
7	1144	(2)-Bornanone	1.23	-
8	1074	Sabinene hydrate	1.46	1.79
9	1315	*p*-Vinyl-guaicol	0.88	-
10	1417	(*E*)-β-Caryophyllene	4.32	1.54

11	1452	α-Humuulene	4.88	4.44
12	1505	β-Bisabolene	7.47	6.70
13	1608	Humulene epoxide II	0.86	-
14	1028	*o*-Cymene	6.61	-
15	1195	Estragole	18.32	30.93
16	1242	Anethole	7.65	-
17	1247	Chavicol	3.31	6.27
18	1346	2,6-dimethoxy phenol	1.19	-
19	1403	Methyl eugenol	1.12	-
20	2132	Linoleic acid	1.25	-
21	2257	8-isopropyl-1,3-dimethylphenathrene	0.98	-
22	2808	Squalene	0.48	-
		Monoterpenoids	14.11	39.62
		Sesquiterpenoids	17.36	14.47
		Benzenoids	38.20	34.20
		Triterpenoids	0.48	-
		Non-terpenoids	2.47	0.83

Twenty and twelve compounds were identified in smoke volatiles of *O. kenyense* species from Laikipia County (OKE-LKP) and Nyeri County (OKE-NYR), respectively (Figure 1 and 2). The chemical composition of the various constituents of smoke volatiles of *O. kenyense* species from Laikipia (OKE-LKP) and Nyeri (OKE-NYR) included monoterpenoids (14.1-39.6%), sesquiterpenoids (14.5-17.5%), benzenoids (34.2-38.2%), triterpenoids (0.5%) and non-terpenoids (0.8-2.5%). Eucalyptol (peak 5) (10.7-27.9%) β-bisabolene (peak 12) (6.7-7.5%) and estragole (peak 15) (18.3-30.9%) occurred as major compounds of smoke volatiles of *O. kenyense* species from Laikipia (OKE-LKP) and Nyeri (OKE-NYR).

In addition to three compounds, *o*-cymene (peak 14) (6.6%) and anethole (peak 16) (7.7%) occurred as major compounds in smoke volatiles of OKE-LKP. Chavicol (peak 17) (6.3%) also occurred as a major compound of OKE-NYR smoke volatiles. Minor components such as (2)-bornanone (peak 7) (2.19%) and 2,6-dimethoxyphenol (peak 18) (1.19%) were identified as unique markers of OKE-LKP smoke volatiles.

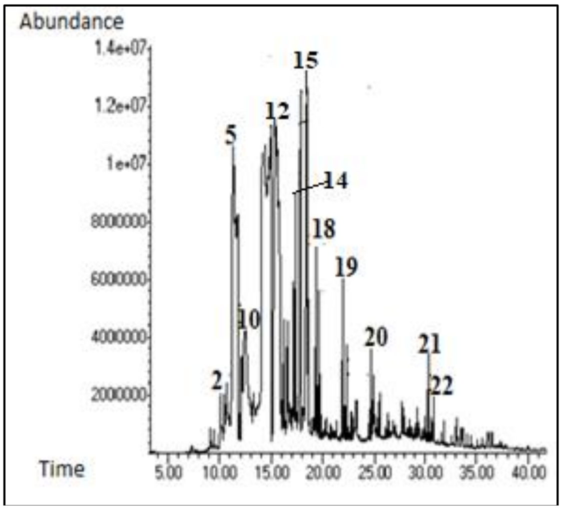

Fig 1: Total ion chromatogram of smoke volatiles of *O. kenyense* species (Laikipia County)

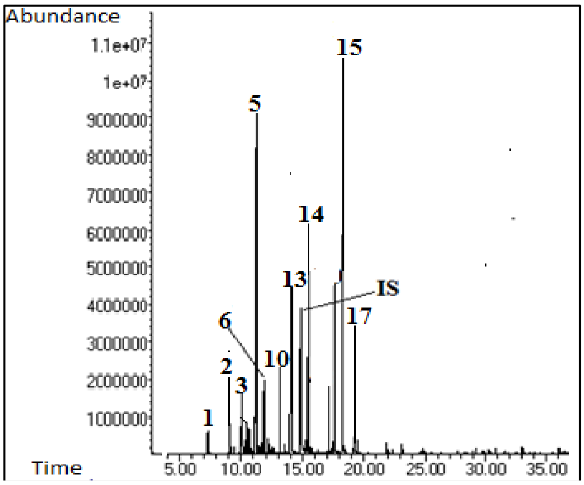

Fig 2: Total ion chromatogram of smoke volatiles of *O. kenyense* species (Nyeri County)

3.1.2 Chemical composition of *O. kilimandscharicum* species smoke volatiles

A total of forty-three chemical constituents were identified in smoke volatiles of *O. kilimandscharicum* species from both Kirinyaga and Nyeri Counties (Table 2).

Table 2: Chemical constituents of *O. kilimandscharicum* species' smoke volatiles

GC Peak	RI	Identity of the compound	Amount in %	
			Kirinyaga	Nyeri
1	932	α-Pinene	1.56	-
2	946	Camphene	4.80	-
3	974	β-Pinene	1.68	0.92
4	988	β-Myrcene	1.98	0.77
5	1002	α-Phellandrene	2.31	0.81
6	1008	3-carene	-	2.36
7	1018	α-Terpinene	0.71	-
8	1024	Limonene	13.36	3.62
9	1026	Eucalyptol	-	10.66
10	1027	Sylvestrene	-	1.38
11	1044	(*E*)-β-Ocimene	1.14	6.05
12	1050	Phenol	0.67	-
13	1083	Fenchone	2.36	4.45
14	1122	2-Carene	-	2.51
15	1141	Camphor	17.32	12.62
16	1162	Borneol	-	0.84
17	1174	Terpinen-4-ol	-	1.40
18	1195	Estragole	9.81	3.45
19	1224	Nerol	2.15	-
20	1247	Chavicol	-	0.72
21	1249	Geraniol	10.67	6.74
22	1315	*p*-Vinyl-guaicol	-	0.61
23	1350	Eugenol	0.51	-
24	1351	α-Cubebene	-	0.74
25	1359	Neryl acetate	2.39	-
26	1374	β-Bourbonene	-	0.85
27	1389	β-Cubebene	-	1.52
28	1391	α-Copaene	1.18	1.80
29	1409	α-Gurjunene	-	0.71
30	1416	β-Copaene	-	4.41
31	1417	(*E*)-β-Caryophyllene	5.38	8.00
32	1452	α-Humulene	-	2.07
33	1454	(*E*)-β-Farnesene	4.38	3.94
34	1484	Germacrene-D	1.78	-
35	1485	α-Amorphene	-	1.20
36	1491	α-Bisabolene	0.76	-
37	1505	β-Bisabolene	1.82	3.32
38	1963	Hexadecanoic acid	-	0.83
39	1993	1,3-dimethylphenathrene	-	0.51
40	2132	Linoleic acid	-	0.87
41	1886	Farnesyl acetate	-	0.59
42	2808	Squalene	-	0.56
43	2987	α-Tocopherol	-	0.57
		Monoterpenoids	64.40	54.00
		Sesquiterpenoids	14.12	23.55
		Benzenoids	10.99	4.17
		Triterpenoids	-	0.56
		Non-terpenoids	2.39	2.76

Twenty-two and thirty four compounds were identified in smoke volatiles of *O. kilimandscharicum* species from Kirinyaga County (OKI-KRN) and Nyeri County (OKI-NYR), respectively (Figure 3 and 4). Smoke volatiles of *O. kilimandscharicum* from both Kirinyaga (OKI-KRN) and Nyeri (OKI-NYR) Counties were dominated by monoterpenoids (61.2-61.3%), sesquiterpenoids (14.1-23.5%), benzenoids (4.2-10.9%), triterpenoids (0.6%) and non-terpenoids (2.4-2.8%). Camphor (12.6-17.3%) (peak 15), geraniol (6.7-10.6%) (peak 21) and (*E*)-β-caryophyllene (peak 31) (5.4-8.0%) were major compounds of OKI-KRN and OKI-NYR smoke volatiles.

In addition to the three compounds, limonene (peak 8) (13.4%) and estragole (peak 18) (9.8%) also occurred as major compounds of OKI-KRN while (*E*)-β-ocimene (peak 11) (6.1%) occurred as a major compound of OKI-NYR smoke volatiles. β-Pinene (peak 3) (0.9-1.75%), α-phellandrene (peak 5) (0.8-2.3%), (*E*)-β-farnesene (peak 33) (3.9-4.4%) and α-copaene (peak 28) (1.2-1.8%) among others, occurred as minor constituents of both OKI-KRN and OKI-NYR smoke volatiles. Neryl acetate (peak 25) (2.4%) was identified as a unique marker of OKI-KRN smoke volatiles.

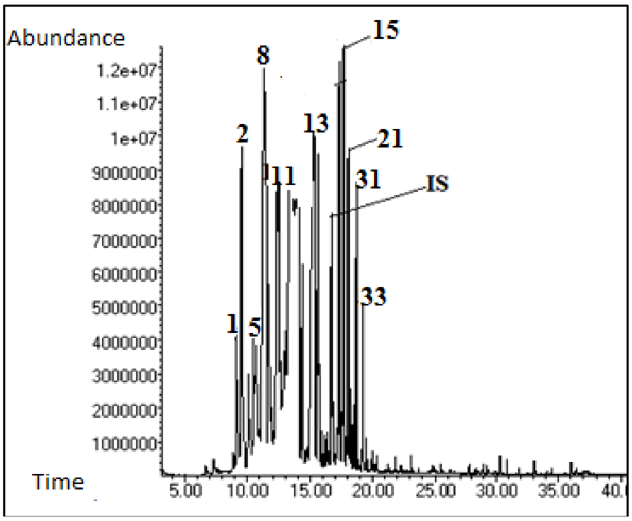

Fig 3: Total ion chromatogram of smoke volatiles of O. *kilimandscharicum* (Kirinyaga County)

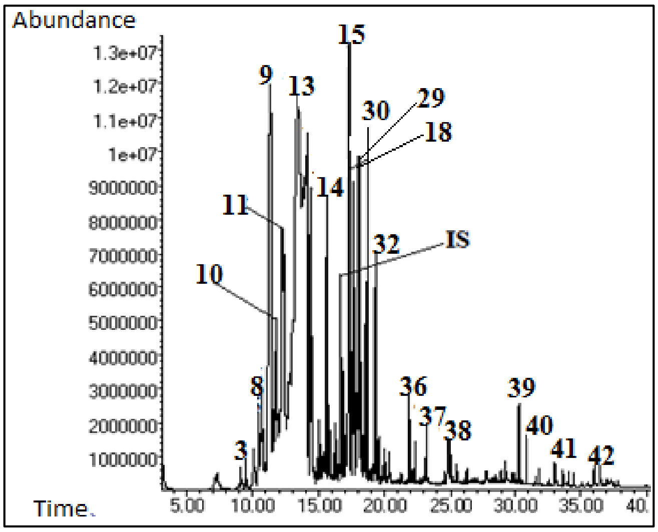

Fig 4: Total ion chromatogram of smoke volatiles of *O. kilimandscharicum* (Nyeri County)

3.1.3 Chemical composition of *O. lamiifolium* species' smoke volatiles

A total of fifty chemical constituents were identified in smoke volatiles of *O. lamiifolium* species from both Nyandarua and Nakuru Counties (Table 3).

Table 3: Chemical constituents of *O. lamiifolium* species' smoke volatiles

GC Peak	RI	Identity of the compound	Amount in %	
			Nyandarua	Nakuru
1	932	α-Pinene	-	0.52
2	974	β-Pinene	-	0.51
3	1002	α-Phellandrene	8.41	12.76
4	1028	*o*-Cymene	-	7.96
5	1032	β-Phellandrene	-	1.09
6	1044	(*E*)-β-Ocimene	5.14	-
7	1068	4-ethyl-o-xylene	5.41	-
8	1076	*p*-Cymenene	1.13	1.40
9	1113	3,4-dimethylbenzyl alcohol	-	2.94
10	1135	(E)-Sabinol	-	1.30
11	1141	Camphor	3.03	0.76
12	1157	Propenyl-2-phenol	0.78	-
13	1195	Estragole	1.13	-
14	1249	Geraniol	0.98	-
15	1315	*p*-Vinyl-guaicol	3.59	0.53
16	1351	α-Cubebene	-	0.67
17	1374	β-Bourbonene	2.85	4.63
18	1391	α-Copaene	-	1.12
19	1409	α-Gurjunene	4.89	2.03
20	1416	β-Copaene	1.64	2.11

21	1417	(*E*)-β-Caryophyllene	3.90	-
22	1451	Spirolepechinene	-	2.09
23	1461	Allo-aromanderene	2.09	-
24	1465	Dauca-5,8-diene	-	1.42
25	1472	γ-Muurolene	-	1.92
26	1484	Germacrene-D	2.94	6.35
27	1494	Bicyclogermacrene	4.01	2.69
28	1508	6-Epi-shybunol	2.78	0.81
29	1524	Δ-Cadinene	4.48	-
30	1548	Palustrol	0.61	-
31	1576	Spathulenol	2.66	-
32	1586	Germacra-1,6-diene-5-ol	1.27	4.04
33	1590	Viridiflorol	-	2.14
34	1602	Ledol	0.75	0.72
35	1652	α-Cadinol	-	0.67
36	1675	Cadalene	0.51	-
37	1685	Oplopanone	-	0.64
38	1688	Shybunol	1.36	-
39	1886	Farnesyl acetone	-	0.57
40	1967	Sclarene	-	0.75
41	1993	1,3-dimethylphenathrene	1.00	0.96
42	2080	Heptadecanoic acid	0.71	-
43	2158	Octadecanoic acid	0.72	-
44	2176	Retene	0.75	0.88
45	2198	Benzo (a) phenazine	0.57	-
46	2257	8-isopropyl-1,3-dimethylphenathrene	-	0.96
47	2274	Dehydroabietan	-	1.06
48	2808	Squalene	0.60	0.59
49	2987	α-Tocopherol	0.59	0.81
50	3376	α-Amyrin	0.47	0.67
		Monoterpenoids	19.20	18.87
		Sesquiterpenoids	37.69	33.42
		Benzenoids	3.04	12.30
		Triterpenoids	1.66	2.07
		Non-terpenoids	17.85	13.17

Thirty-two and Thirty-five chemical compounds were identified in smoke volatiles of *O. lamiifolium* species from Nyandarua County (OLA-NYD) and Nakuru County (OLA-NKU), respectively (Figure 5 and 6). The chemical composition of smoke volatiles of *O. lamiifolium* species from Nyandarua (OLA-NYD) and Nakuru (OLA-NKU) comprised of monoterpenoids (18.9-19.2%), sesquiterpenoids (33.4-37.7%), benzenoids (3.0-12.3%), triterpenoids (1.7-2.1%) and non-terpenoids (13.2-17.6%). α-Phellandrene (peak) (8.4-12.8%) was identified as a major chemical constituent of OLA-NYD and OLA-NKU. In addition to α-phellandrene (peak 3), (*E*)-β-ocimene (peak 6) (5.1%) and 4-ethyl-*o*-xylene (peak 7) (5.4%) also occurred as major constituents of OLA-NYD smoke volatiles. On the other hand, *o*-cymene (peak 4) (7.9%) and germacrene-D (peak 26) (6.4%) also occurred as major constituents of OLA-NKU smoke volatiles.

Minor chemical constituents such as β-bourbonene (peak 17) (2.9-4.6%) α-gurjunene (peak 19) (2.0-4.9%) and bicylogermacrene (peak 27) (2.7-4.0%), among others are reported in smoke volatiles of OLA-NYD and OLA-NKU. Unique markers of OLA-NYD smoke volatiles were identified as allo-aromandrene (peak 23) (2.09%), Δ-cadinene (peak 29) (4.48%) and spathulenol (peak 31) (2.66%). Similarly, *O. lamiifolium*-Nakuru (OLA-NKU) smoke volatiles were marked by 3,4-dimethylbenzyl alcohol (peak 9) (2.94%), spirolepichinene (peak 22) (2.09%) and viridiflorol (peak 33) (2.14%).

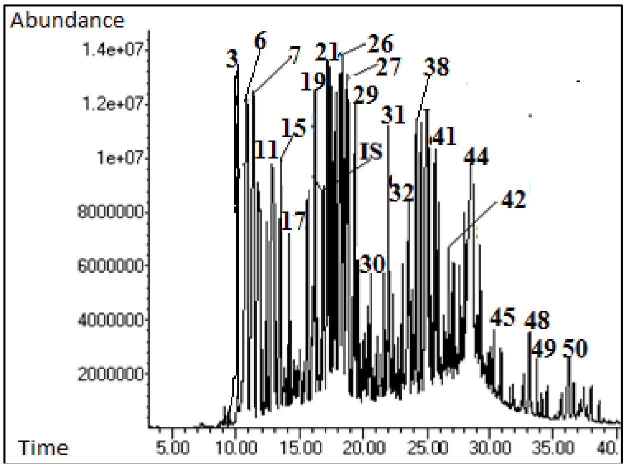

Fig 5: Total ion chromatogram of smoke volatiles of *O. lamiifolium* (Nyandarua County)

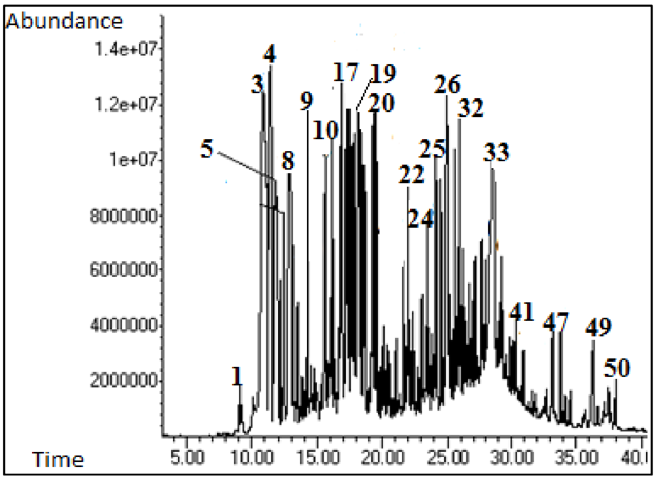

Fig 6: Total ion chromatogram of smoke volatiles of *O. lamiifolium* (Nakuru County)

Five classes of chemical constituents namely; monoterpenoids (14.11-64.40%), benzenoids (3.04-38.2%), sesquiterpenoids (14.12-37.69%), triterpenoids (0.48-2.07%) and non-terpenoids (0.83-17.85%) were identified in this study. There were notable variations in individual chemical compositions of smoke volatiles although α-phellandrene (0.81-12.76%) was identified in all investigated *Ocimum* species. In *O. kenyense*, eucalyptol (10.71-27.93%) and estragole (18.32-30.93%) were identified as major compounds of its smoke volatiles. Camphor (12.62-17.32%) and α-phellandrene (8.41-12.76%) were identified as major compounds of smoke volatiles derived from *O. kilimandscharicum* and *O. lamiifolium* species, respectively.

Findings of this study have demonstrated remarkable variations in chemical constituents of smoke volatiles of the same *Ocimum* species based on agro ecological areas of origin. The observed chemical variations could largely be attributed to differences in edaphic and climatic factors [18] of various agro ecological zones. Qualitative and quantitative variations in emission of smoke volatiles in *O. kenyense, O. kilimandscharicum* and *O. lamiifolium* species are strongly influenced by factors such as soil type [19-21] temperature [22], rainfall [23] and solar irradiation [24] 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 [25].

Chemical profiles of the three *Ocimum* species' smoke volatiles explain their possible use in incense. Several chemical constituents such as limonene, α-copaene, β-bourbonene, cadinol, α-humulene, β-cubebene, bicyclogermacrene, germacrene-D, geraniol, linalool and δ-cadinene identified in smoke of volatiles of investigated *Ocimum* species have also been reported in myrrh (*Commiphora* spp.) incense hydrodistillates [26, 27]. Despite the extensive use of myrrh incense in rituals, medicine and perfumes dating back to biblical times, its chemical composition was first determined in 1906 [26].

Traditional use of the three *Ocimum* species smokes as house fly (*Musca domestica*) repellents is strongly supported by findings of a recent study which identified limonene, linalool, estragole, eugenol and terpinene as repellents of house flies at different concentrations [28]. Other studies identified eucalyptol [29], α-pinene and β-pinene [30] and myrcene [31] as house fly repellent chemical constituents. In this work, previously reported house fly repellent chemicals such as α-pinene (0.52-1.56%), β-pinene (0.46-3.27%), eucalyptol (10.66-27.93%), limonene (3.62-13.36%), estragole (1.13-30.93%), eugenol (0.51%) and terpinene (0.71%) were identified as chemical constituents of smokes derived from investigated *Ocimum* species.

Presence of chemical compounds such as anethole (7.65%), estragole (1.13-30.93%), β-caryophellene (1.52-8.00%), geraniol (6.74-10.67%) and camphor (0.76-17.32%) in the three *Ocimum* species supports their traditional use as mosquito repellents. Anethole, estragole and caryophyllene were previously reported as mosquito repellent chemical constituents of essential oil of Brazilian *O. selloi* [32]. Camphor was also identified as a mosquito repellent constituent of *Cymbopogan camphora* essential oil with repellent activity of 97.6% and 80.7% in landing assays against *Anopheles culicifacies* and *Culex quinquefasciatus* females, respectively [33].

Efficacy of botanical repellents based on geraniol and other compounds against mosquitoes was reported in both indoor and outdoor assays. Geraniol diffusers repelled 50% and 75% of mosquitoes during indoor and outdoor studies, respectively [34]. Chemical profiles of smoke volatiles of *O. kenyense, O. kilimandscharicum* and *O. lamiifolium* species from two different agro ecological zones point to their potential commercial use in medicinal and ritual incense as well as insect repellents (Table 4).

Table 4: Insect repellent and ritual incense chemical constituents' content in smoke volatiles of selected *Ocimum* species

Potential use	*O. kenyense*		*O. kilimandscharicum*		*O. lamiifolium*	
	Laikipia	Nyeri	Kirinyaga	Nyeri	Nyandarua	Nakuru
House fly repellent	27.97%	63.39%	29.61%	19.42%	3.29%	-
Mosquito repellent	30.29%	34.66%	43.18%	30.81%	9.04%	0.76%
Incense	4.88%	4.44%	26.99%	21.01%	15.92%	18.25%

Smoke derived from *O. kenyense* species could be used as an insect repellent due to its high house fly and mosquito repellent compounds' contents of 27.97-63.39% and 30.29-34.66%, respectively. House fly repellent, mosquito repellent and incense chemical constituents' contents of 19.42-29.61%, 30.81-43.18% and 21.01-26.99%, respectively, were present in *O. kilimandscharicum* species' derived smokes. This observation indicates a great economic potential of *O. kilimandscharicum* species as a source of incense and insect repellents. On the other hand, smoke from *O. lamiifolium* species could only be used in medicinal and ritual incense since it has high content of incense compounds (15.92-18.25%) and low content of insect repellent compounds (0.76-9.04%). Variation in chemical profiles of smoke derived from plants of the same species from two different agro ecological zones points to possibility of their individual biological activities being different. Although, identification of several incense and insect repellent constituents in selected *Ocimum* species' smokes provides a scientific basis for their traditional use, there is need to conduct confirmatory behavioral studies.

4. Conclusion

This study reports chemical compositions of smoke volatiles' aromas of Kenyan *O. kenyense, O. kilimandscharicum* and *O.*

lamiifolium species for the first time. Remarkable variations in chemical profiles of smoke volatiles' aromas of the three investigated *Ocimum* species were observed in this study. Since the smoke aroma of *Ocimum* species is largely influenced by its most dominant constituent(s), plants growing in certain agro ecological zones in Kenya could be potential sources of incense and insect repellents.

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