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Article

Impact of Drying Methods on the Chemical Profile of *Zingiber officinale* Rosc. Rhizome Essential Oil

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Abstract: *Zingiber officinale* Rosc. belonging to the family Zingiberaceae, is mentioned as Maha-aushadhi in Ayurveda and is also used in many processed dried ginger-based products. The present work was designed to determine the effect of drying on the essential oil content and composition of *Zingiber officinale* Rosc. rhizomes collected when matured, from Khatima, Uttarakhand region. The GC and GC/MS analysis of the oils resulted in the identification of total 56 (fresh), 45 (sun dried), 47 (blower dried), 37 (shade dried), 46 (oven dried at 30ºC) and 44 (oven dried at 50ºC) compounds representing 97.93 %, 98.48%, 98.26%, 99.25%, 99.10% and 98.65% of the total oil respectively. The predominant compounds in the oil were geranial (17.53-35.24%), neral (12.47-24.59%), β-phellandrene (9.84-14.12%), geraniol (5.43-10.19%), geranyl acetate (1.33-12.23%), camphene (4.45-7.87%) and zingiberene (0.92-5.24%). The content of camphene, β-phellandrene and geranyl acetate decreased while the percentage of geranial, neral, geraniol and zingiberene increased on drying the ginger rhizomes. The essential oil of all the samples had high percentage of oxygenated monoterpenes. This study was one of its kind and showed a significantly different deduction from other studies.

Key words: *Zingiber officinale*, drying, essential oil, ginger, neral, geranial.

Introduction

The family Zingiberaceae had 56 genera and more than 1300 species of which 85 species are found in Asia, America and Africa. The major genera of this family include *Zingiber* (100), *Alpinia* (200), *Etlingera* (110), *Curcuma* (100) and *Globba* (100). *Curcuma longa*, *Zingiber officinale, Alpinia galanga* and *Etlingera cardamomum* are some of the commonly known plants. The members of *Zingiber* genus are similar in morphology but differ in their therapeutic and pharmacological properties [1].

Ginger is mentioned in Ayurveda as *Maha-aushadhi* which means a great Ayurvedic medicine used in curing diseases like asthma, cancer, menstrual pain etc [2]. The ethnobotanical studies of ginger benefits are defined by many researchers. It is used in many dried and processed ginger-based products like spices, candies, bread, soft drinks, beer, tea and cosmetics [3,4]. Furthermore, it is known for its herbal properties thereby useful in different healing systems. It is used in flavouring foods and also in preparation of nutraceutical formulations [2]. Ginger is also used in the prevention of arthritis, muscular aches, rheumatism, indigestion, nausea and vomiting

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and also known for its antipyretic, antioxidant, hypotensive and hepatoprotective activities [5]. The odour of the fresh and dried ginger is due to the presence of various bioactive components such as shogaols, gingerols and terpenes like zingiberene and β-phellandrene in the essential oil [6].

Preserving better quality of fruits, vegetables and herbal based products, after processing them, has been very challenging [5]. Drying, generally inhibits microbial growth and prevents deteriorative biochemical reactions. Various drying methods like air drying, sun drying, shade drying, vacuum drying, freeze drying, oven drying and microwave drying have been observed to change the aroma profile of herbal based food and other processed products due to loss or transformation of volatile components [7]. Changes in the content of volatile components also affect the quality and flavour of dried ginger, which is valued in the form of ginger powder, ginger oil and soft drinks in international food and flavouring industry and in medicinal industry as well [8, 9]. The previous literature reveals that there are some studies on the investigation of chemical composition of *Z. officinale* from China [5], Nigeria [10], Cuba [11], Egypt [12], India (Mizoram, Chennai, Sikkim, Himanchal Pradesh and Kerala) [13-15], ran [16] and Nepal [17]. On the other hand, the effect of drying on the essential oil content and chemical composition of flavour constituents of *Z. officinale* have been investigated in limited localities such as China [5, 18-20], Mysore [21], Tamil Nadu [22], USA [23] and Korea [24]. Therefore, in the present study, different drying methods were applied to the ginger rhizomes for evaluating their impact on the chemical profile of its essential oil using GC and GC/MS analysis. It is the first report from North India, which studies and highlights the variation in the essential oil content and composition by methods of natural drying (sun drying and shade drying) and mechanical drying (blower drying and oven drying at two temperatures) methods.

Materials and methods

Plant collection and identification

Zingiber officinale rhizomes were collected at maturation stage from Nandhaur Range, Khatima region of Uttarakhand (29˚ 02′ 44″ N, 79˚ 56′ 41″ E) at an altitude of 242 m in the month of December, 2021. The specimen plant was identified properly and then deposited at Botanical Survey of India, Dehradun (Voucher number 5921).

Isolation of essential oil

The rhizomes were firstly soaked in water for an hour so that the soil would loosen the rhizomes. Then these soaked rhizomes were washed under running water. After washing, these were sliced into pieces of 0.5*0.5*2cm dimension and divided into six batches of 1000 gm each, so that different types of drying conditions (fresh, sun drying, blower drying, shade drying, oven drying at 30ºC and 50ºC) be applied on them The essential oil of the fresh and dried rhizomes was extracted by using the Clevenger apparatus for 6 hours. The oil yield under each condition is shown in Figure 1. The hydrodistillation method was replicated three times to obtain the essential oil and the extracted oil was dried over anhydrous sodium sulphate (drying agent) and then stored in vials at 4ºC in the BOD incubator until further testing.

Identification of individual compounds

Retention index and library matching

The components of the essential oils were identified by comparing the retention index (RI) which was calculated relative to C_7-C_{30} n-alkane homologous series and mass spectral data reported in the literature [25], NIST (Version 2.1) and Wiley (7th edition) libraries. The calculation of retention index was done by using the following equation:

$$RI = 100 * \{N + (R_{derived} - R_{before})\} / R_{after} - R_{before}$$

N= Carbon number of RI of the carbon which is lower than the derived RI, $R_{derived}$ = RI of the compound for which RI is being calculated, R_{before} = RI of the carbon number, which is lower than the derived RI, R_{after} = RI of the carbon number, which is higher than the derived RI.

Gas chromatography (GC)

The six essential oil samples of *Z. officinale* were run on a Shimadzu 2010 GC. Table 1 shows the operating conditions of GC.

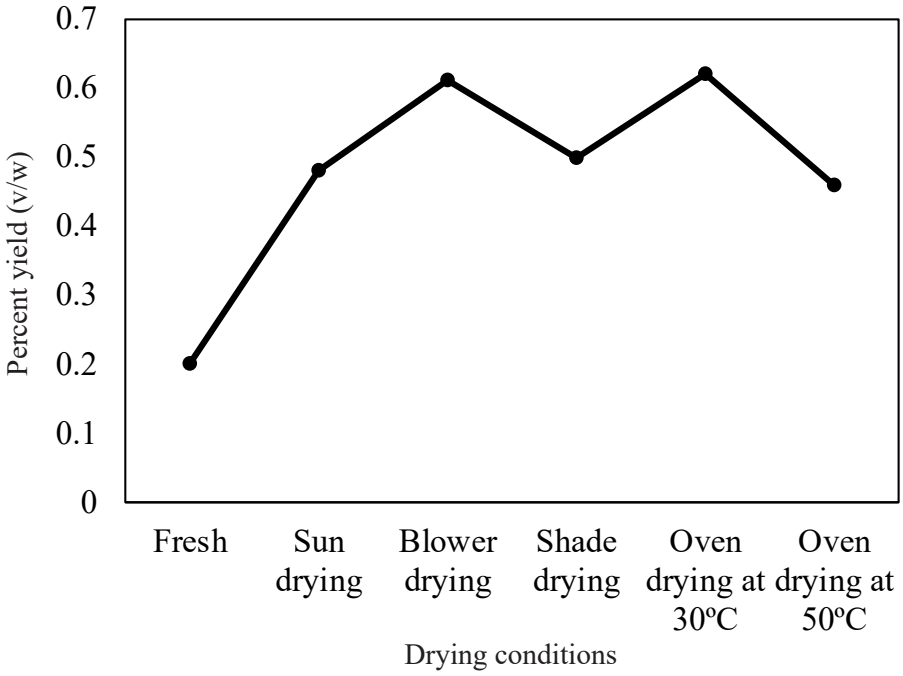

Figure 1. Variation in the essential oil yield by different drying conditions

Table 1. GC operating conditions

Make/ Model	Shimadzu 2010 GC
Column	Rtx-5 column (30m x 0.25mm x 0.25µm film coating)
Detector	Flame ionization detector
Temperature programming	50°C for 2min, 210°C at 3/min, 280°C at 13min
Carrier gas (flow rate)	Nitrogen (30 mL/min)
Column oven temperature	50 ºC
Injector port temperature	210 ºC
Detector temperature	280 ºC
Injection volume	0.2 µL
Column flow	1.21 mL/min
Split ratio	1:10
Inlet pressure	69.00 kPa

Gas chromatography/ mass spectrometry (GC/ MS)

The GC/MS analysis of all six oil samples was done using Shimadzu 2010 GC/MS. Table 2 shows the operating conditions of GC/MS.

Quantification of the compounds

The percentage of the representative compounds was calculated by using an external reference method under identical GC conditions. The response factor of each standard was used to calculate the percentage of that particular compound [26].

Statistical analysis

The data of the percentage variation in the

Table 2. GC/MS operating conditions

Make/ Model	Shimadzu 2010 GC/MS-QP2010 Ultra
Temperature programming	50ºC for 2min, 210ºC at 3/min, 280ºC at 13min
Column	Rtx-5 column (30m x 0.25mm x 0.25µm film coating)
Ion source temperature	220 ºC
Interface temperature	270 ºC
Solvent Cut time	2.50 min
Start time	3.00 min
End time	81.98 min
Start m/z	40.00
End m/z	650.00
Carrier gas	Helium
Column flow	1.21 mL/min
Split ratio	1:10

essential oil components was statistically analyzed by applying cluster analysis and one-way ANOVA using SPSS 16.0. The results were expressed as mean value ± standard deviation (SD) which was calculated by using MS-Excel 2019.

Essential oil content and composition of fresh Z. officinale

The essential oil obtained from fresh ginger rhizomes showed the presence of 73 compounds out of which 56 compounds were identified representing 97.93% of the oil (Figure 2). The oil yield was 0.20% (v/w) (Figure 1). The fresh rhizomes had 74% moisture content. The essential oil obtained by fresh *Z. officinale* showed the presence of geranial (17.53%), β- phellandrene (14.12%), neral (12.47%), geranyl acetate (12.23%), camphene (7.87%) and geraniol (5.43%) as the predominant components. Additionally, zingiberene (3.42%), α-pinene (3.71%), (E, E)-α-farnesene (3.09%), β-myrcene (2.61%), β-sesquiphellandrene (2.37%) and ar-curcumene (2.24%) were identified as the minor components. The oil had the highest amount of β- phellandrene and geranyl acetate (Table 3).

Essential oil content and composition of sun-dried Z. officinale

Forty-five compounds were identified in sun dried ginger rhizomes which represented 98.48 % of the total oil (Figure 3). The oil yield was observed to be 0.48% (v/w) (Figure 1). The rhizomes obtained by sun drying had 7.65% of moisture content. It took 36 hours to obtain the constant weight. During sun drying, the temperature was 21-27ºC. The predominant components in the essential oil obtained from sun dried *Z. officinale* rhizomes were geranial (24.60%), neral (17.30%), geranyl acetate (11.87%), geraniol (10.19%) and β-phellandrene (9.84%) while camphene (4.58%) and zingiberene (2.70%) were the minor constituents of the oil. It had the highest geraniol content (Table 3).

Essential oil content and composition of blower dried Z. officinale

The essential oil obtained from blower dried ginger rhizomes showed the presence of 56 compounds out of which 47 compounds were identified representing 98.26 % of the oil (Figure 4). The oil yield was found to be 0.61% (v/w) (Figure 1). Blower dried rhizomes had

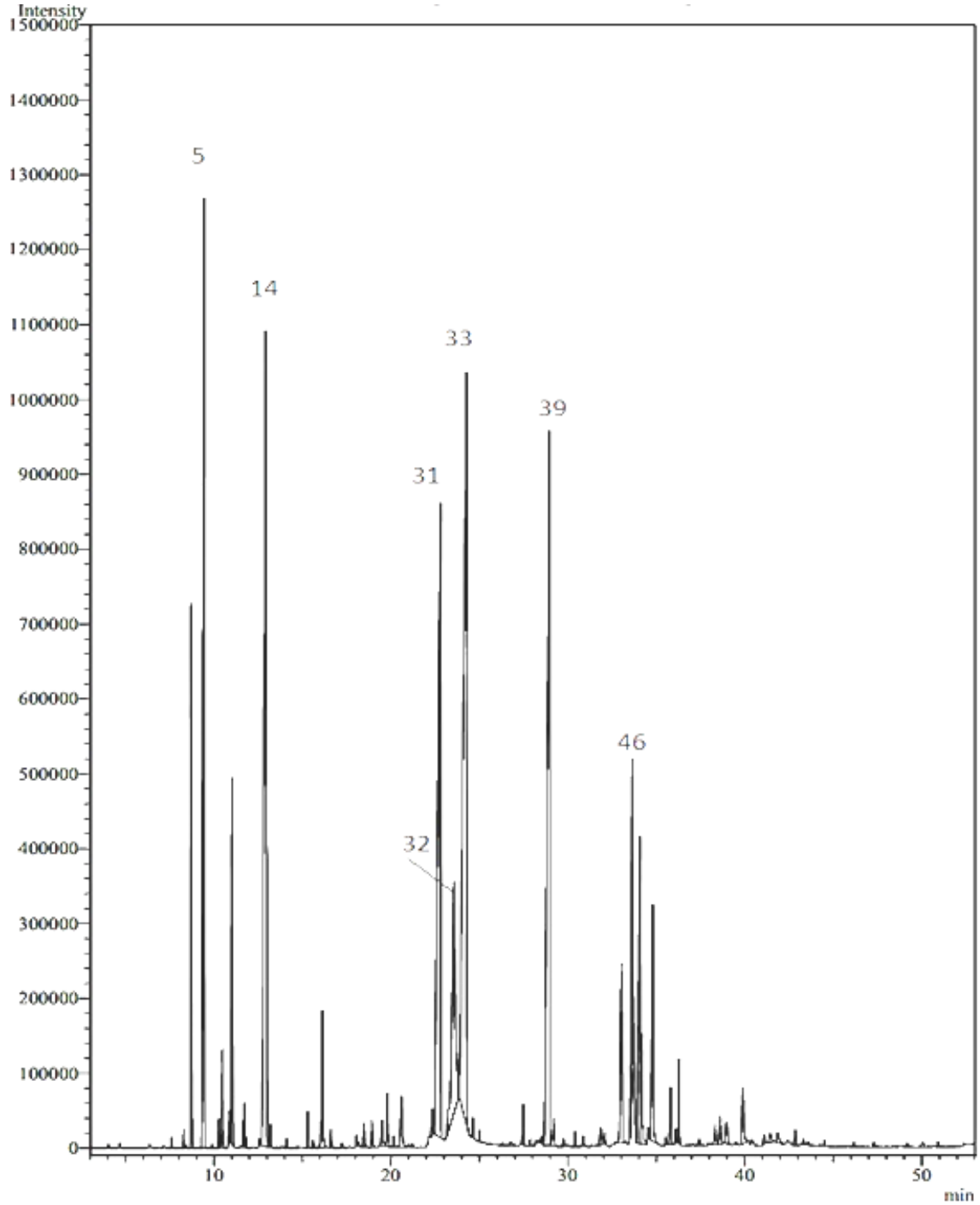

Figure 2. Gas chromatogram of fresh rhizome essential oil of *Z. officinale*

8.57% of moisture content. The constant weight was obtained after 47 hours. The Orpat blow dryer was used at high temperature settings. Its power consumption was 2kW. The major compounds in the essential oil were geranial (22.63%), neral (17.56%), geranyl acetate (11.45%), β-phellandrene (10.37%) and geraniol (8.53%). However, camphene (4.79%), zingiberene (3.39%), β-sesquiphellandrene (2.09%), ar-curcumene (2.03%) and α-pinene (2.03%) were noted as the minor components (Table 3).

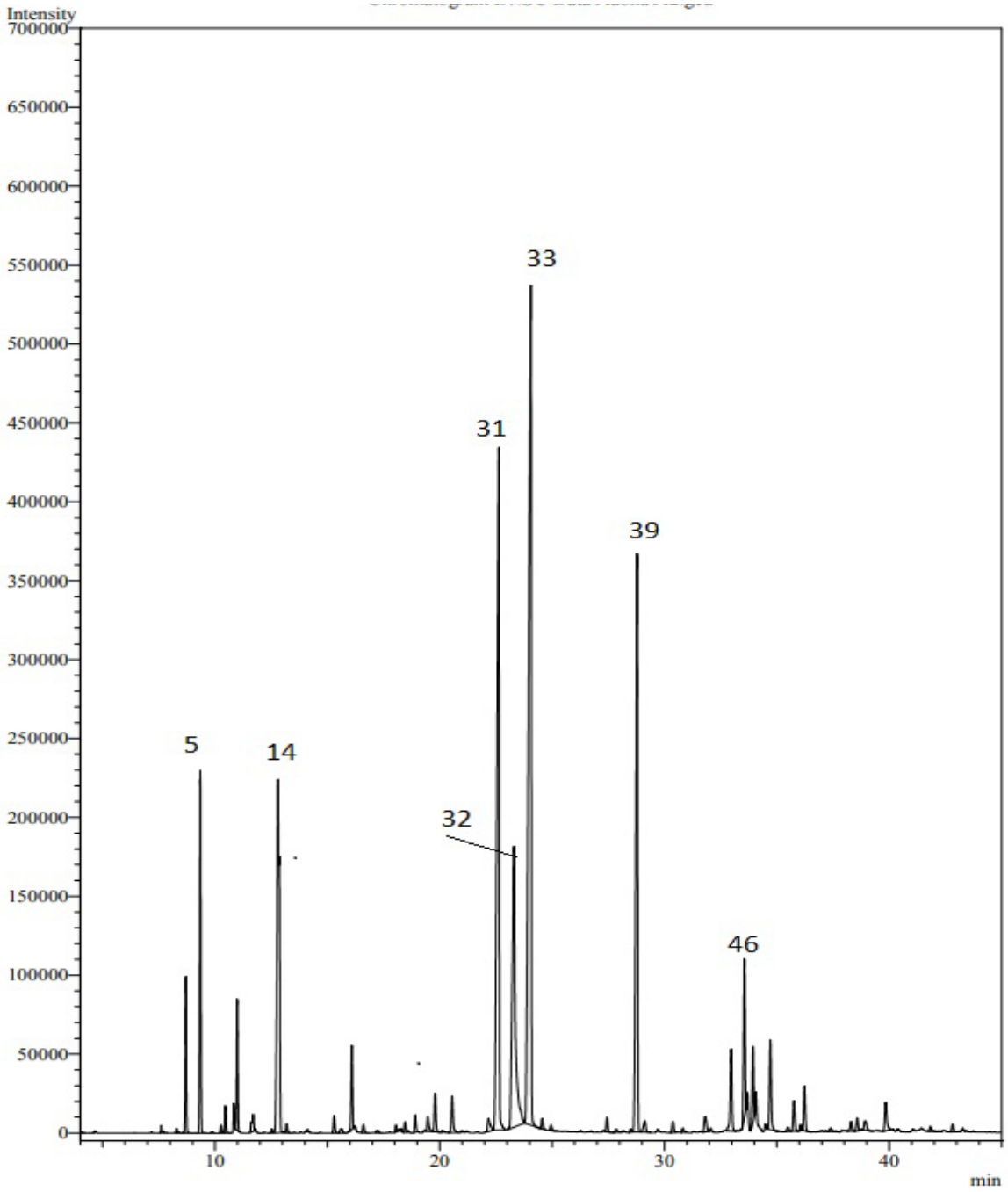

Figure 3. Gas chromatogram of sun dried rhizome essential oil of *Z. officinale*

Essential oil content and composition of shade dried Z. officinale

Total 45 compounds were analyzed and out of these only 37 compounds were identified which represented 99.25% of the total oil of shade dried *Z. officinal* (Figure 5). The oil content was 0.50% (v/w) (Figure 1). Shade drying resulted in 8.36% of moisture content and the constant weight was obtained after 28 days when the temperature was 7-10ºC. The essential oil obtained from shade dried *Z. officinale* showed the presence of geranial (35.24%), neral (24.59%), β-phellandrene (13.21%) and geraniol (5.56%) as the predominant

Table 3. Compounds present in *Z. officinale* in different drying conditions

No.	Compounds	RI [a]	RI [b]	RT (min)	Fresh (%)	Sun dry (%)	Blower drying	Shade drying	Oven drying at 30°C (%)	Oven drying at 50°C (%)
1	2-Heptanol	904	894	7.62	0.08	0.11	0.14	0.20	0.13	0.22
2	Tricyclene	921	921	8.29	0.11	0.05	0.06	0.05	0.07	0.05
3	α-Thujene	924	924	8.43	0.02	ND	ND	ND	ND	ND
4	α-Pinene	932	932	8.73	3.71c±0.27	1.89a±0.04	2.03a±0.10	1.84a±0.13	2.64b±0.32	1.65a±0.16
5	**Camphene**	**949**	**946**	**9.41**	**7.87c±0.33**	**4.58a±0.08**	**4.79a±0.22**	**4.45a±0.06**	**5.93b±0.89**	**4.23a±0.11**
6	Verbenene	961	961	9.88	0.02	0.02	0.01	ND	ND	ND
7	Sabinene	971	969	10.28	0.19	0.11	0.10	0.11	0.13	0.09
8	β-Pinene	976	974	10.48	0.65	0.37	0.38	0.30	0.45	0.37
9	β-Myrcene	990	988	11.03	2.61e ±0.09	1.71c±0.17	1.78c±0.08	1.29a±0.02	2.24d±0.18	1.51b±0.17
10	Mentha-1(7),8-diene-para	1004	1003	11.63	0.18	ND	ND	ND	0.19	ND
11	α-phellandrene	1006	1002	11.71	0.33	0.36	0.12	0.46	0.38	0.27
12	δ-3-Carene	1008	1008	11.82	0.08	ND	ND	ND	0.07	ND
13	p-Cymene	1020	1022	12.54	ND	ND	0.06	0.06	0.07	ND
14	**β-Phellandrene**	**1033**	**1025**	**12.93**	**14.12f±0.17**	**9.84a±0.33**	**10.37b±0.07**	**13.21e±0.11**	**12.10d±0.19**	**11.01c±0.09**
15	Heptyl-2-acetate	1039	1038	13.20	0.16	0.13	0.11	0.04	0.14	0.13
16	β-(*E*)-Ocimene	1046	1044	13.54	0.01	ND	ND	ND	ND	ND
17	γ-Terpinene	1059	1059	14.11	0.11	0.03	0.10	0.13	0.12	0.09
18	2(*E*)-Octen-1-ol	1071	1060	14.68	0.01	ND	ND	ND	ND	0.02
19	Terpinolene	1085	1086	15.31	0.28	0.28	0.27	0.20	0.34	0.23
20	2-Nonanone	1091	1087	15.60	0.09	0.12	0.15	0.18	0.12	0.33
21	Linalool	1103	1095	16.13	1.32a±0.10	1.30a±0.04	1.37a,b±0.09	1.63c±0.05	1.48b±0.04	2.12d±0.05
22	*trans*-Pinene hydrated-	1127	1119	17.24	0.06	0.06	0.07	0.10	0.07	0.09
23	*exo*-Isocitral	1144	1140	18.06	0.09	0.11	0.10	0.24	0.12	0.08
24	Citronellal	1153	1153	18.47	0.18	0.16	0.16	0.23	0.18	0.13
25	(*Z*)-Isocitral	1163	1164	18.92	0.23	0.29	0.34	0.62	0.57	0.33
26	Borneol	1175	1165	19.49	0.28	0.29	0.31	0.53	0.28	0.37
27	(*E*)-Isocitral	1181	1177	19.81	0.47a±0.01	0.67b±0.04	0.72b,c±0.03	1.21e±0.06	1.00d±0.06	0.79c±0.03
28	Terpineol	1198	1186	20.59	0.66	0.72	0.71	0.91	0.73	0.96

table 3. (continued).

No.	Compounds	RI [a]	RI [b]	RT (min)	Fresh (%)	Sun dry (%)	Blower drying	Shade drying	Oven drying at 30ºC (%)	Oven drying at 50ºC (%)
29	Octanol acetate	1211	1211	21.20	0.04	ND	ND	ND	ND	ND
30	Citronellol	1232	1223	-	ND	ND	ND	0.44	ND	ND
31	**Neral**	**1246**	**1235**	**22.76**	**12.47a±0.37**	**17.30b±0.02**	**17.56b,c±0.14**	**24.59d±0.49**	**18.00b ±0.11**	**17.18b±0.14**
32	**Geraniol**	**1263**	**1249**	**23.57**	**5.43a±0.08**	**10.19d±0.02**	**8.53c±0.05**	**5.56a±0.15**	**7.54b±0.21**	**10.04d±0.11**
33	**Geranial**	**1278**	**1264**	**24.26**	**17.53a±0.49**	**24.60e±0.47**	**22.63d±0.23**	**35.24f±0.56**	**21.94c±0.21**	**18.74b±0.11**
34	Undecan-2-one	1295	1293	25.00	0.10	0.10	0.09	0.10	ND	0.20
35	Myrtenyl acetate	1323	1324	26.30	0.03	ND	ND	ND	0.03a	0.10b
36	δ-Elemene	1333	1335	26.76	0.05	ND	ND	ND	ND	ND
37	Citronellyl acetate	1349	1350	27.47	0.35	0.24	0.22	ND	0.22	0.31
38	α-Copaene	1364	1374	28.19	0.05	0.06	0.06	ND	0.05	0.10
39	Geranyl acetate	1381	1379	28.94	12.23f±0.16	11.87e±0.32	11.45d±0.04	1.33a±0.07	10.93c±0.07	10.16b±0.14
40	β-Cubebene	1386	1387	29.18	0.29	0.29	0.34	ND	0.27	0.23
41	7-*epi*-Sesquithujene	1403	1390	29.74	0.10	ND	0.08	ND	0.08	ND
42	Caryophyllene	1419	1417	30.41	0.15	0.20	0.15	ND	0.18	0.23
43	γ-Elemene	1429	1434	30.85	0.09	0.07	0.11	ND	0.09	0.21
44	9-*epi*-(*E*)-Caryophyllene	1453	1464	31.85	0.24	0.41	0.42	0.31	0.38	0.20
45	*ar*-Curcumene	1482	1479	33.02	2.24e±0.02	1.68c±0.04	2.03d±0.15	0.57a±0.07	1.53b±0.07	2.22e±0.04
46	**Zingiberene**	**1497**	**1493**	**33.65**	**3.19c± 0.05**	**2.70b±0.24**	**3.39c±0.13**	**0.92a±0.05**	**2.88b±0.17**	**5.24d±0.17**
47	(*E,E*)-α-Farnesene-	1507	1505	34.04	3.09f±0.03	1.19b±0.03	1.57e±0.04	0.34c±0.04	1.32d ±0.04	ND
48	δ-Amorphene	1509	1511	34.14	1.16c±0.02	0.14b±0.04	0.14b±0.01	ND	ND	3.21d±0.07
49	β-Sesquiphellandren	1525	1521	34.79	2.37d±0.15	1.71b±0.04	2.09c±0.06	0.60a±0.04	1.65b±0.09	2.28d±0.06
50	α-Elemol	1551	1548	35.80	0.53	0.58	0.73	0.30	0.55	0.69
51	*cis*-Sesquisabinene hydrated	1559	1542	36.10	0.11	0.10	0.11	ND	ND	ND
52	*trans*-Nerolidol	1563	1561	36.27	0.76c±0.10	0.81c±0.13	1.04d±0.03	0.42b±0.04	0.87c±0.02	1.10d±0.06
53	*trans*-Sesquisabinene hydrate	1592	1577	37.42	0.08b±0.01	0.08	0.07	ND	ND	ND
54	β-Eudesmol	1657	1649	39.89	0.67b±0.10	0.70	0.87	0.43	0.67	0.82
55	Shyobunol	1689	1688	41.09	0.09c±0.02	ND	ND	ND	0.06	0.10

table 3. (continued).

No.	Compounds	RI [a]	RI [b]	RT (min)	Fresh (%)	Sun dry (%)	Blower drying	Shade drying	Oven drying at 30°C (%)	Oven drying at 50°C (%)
56	(2*E*,6*Z*)-Farnesal	1710	1713	41.86	0.16c±0.02	0.13	0.16	ND	0.13	0.07
57	(*E*,*E*)-Farnesal	1738	1740	42.84	0.15b±0.02	0.15	0.18	0.09	0.16	0.14
58	Geranyl linalool	1975	1987	50.93	0.05b±0.01	ND	ND	ND	ND	ND

The bold values indicated the major constituents of the essential oils.
Mean values of components followed by different alphabets (a-f) are significantly different at $p<0.05$ for each row
SD =Standard deviation
ND = Not detected
Class of compounds
MH = Monoterpene hydrocarbons (2,3,4,5,6,7,8,9,10,11,12,13,14,16,17,19)
OM = Oxygenated monoterpenes (21,22,23,24,25,26,27,28,30,31,32,33,35,39)
SH = Sesquiterpene hydrocarbons (36,38,40,41,42, 43, 44, 45, 46, 47, 48,49)
OS = Oxygenated sesquiterpenes (50,51,52,53,54,55,56,57)
Others (1,15,18,20,29,34,37,58)
RIa = Retention indices according to the literature /Adams RI
RIb = Retention indices experimental (calculated)
RT = Retention time

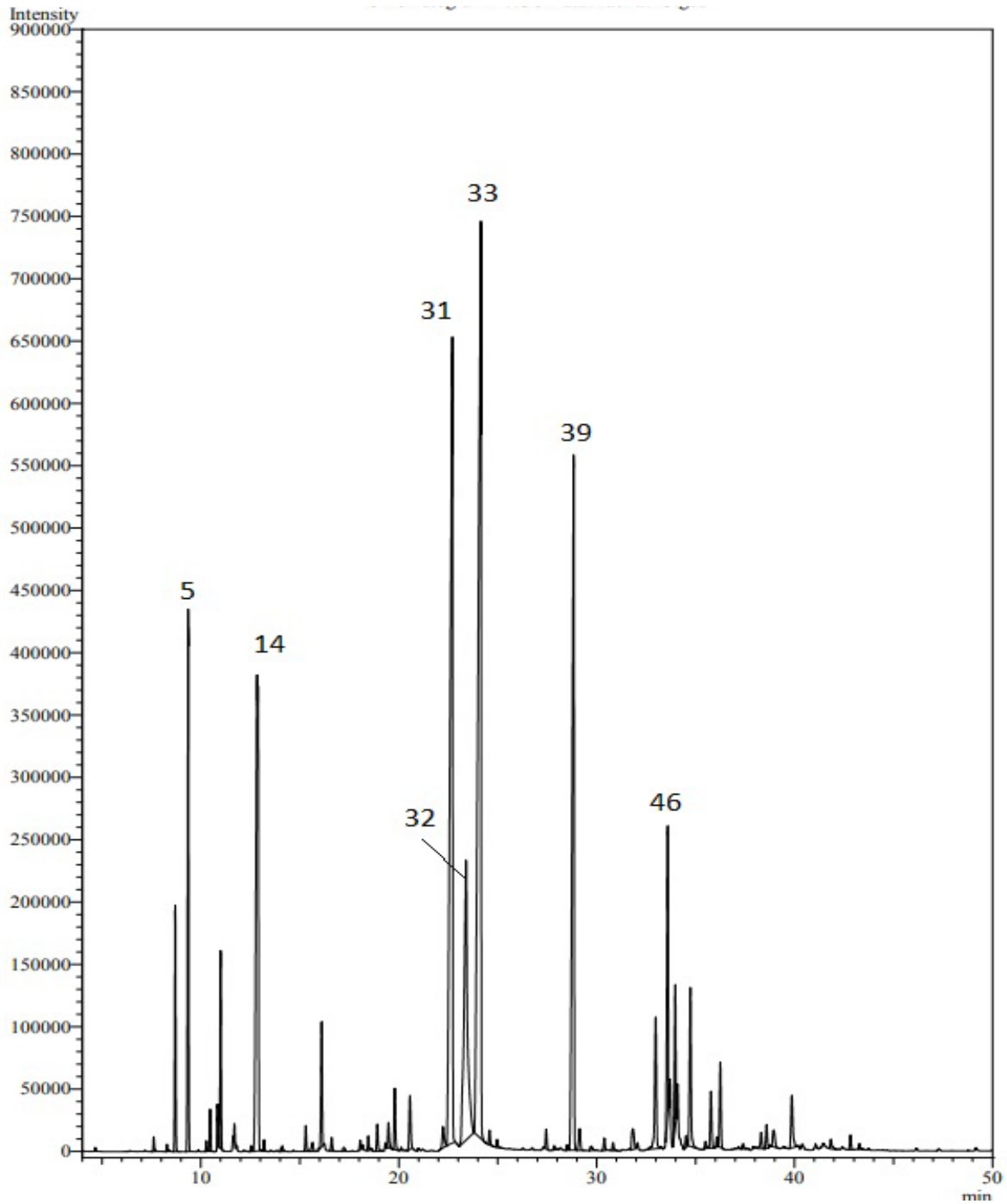

Figure 4. Gas chromatogram of blower dried rhizome essential oil of *Z. officinale*

components. However, camphene (4.45%), geranyl acetate (1.33%) and zingiberene (0.92%) were the minor components of the essential oil obtained. It was concluded that the shade dried sample retained the neral and geranial content (Table 3).

Essential oil content and composition of oven dried (30ºC) Z. officinale

The essential oil extracted from oven dried ginger rhizomes at 30ºC showed the presence of 52 compounds out of which 46 compounds were identified representing 99.10 % of the total

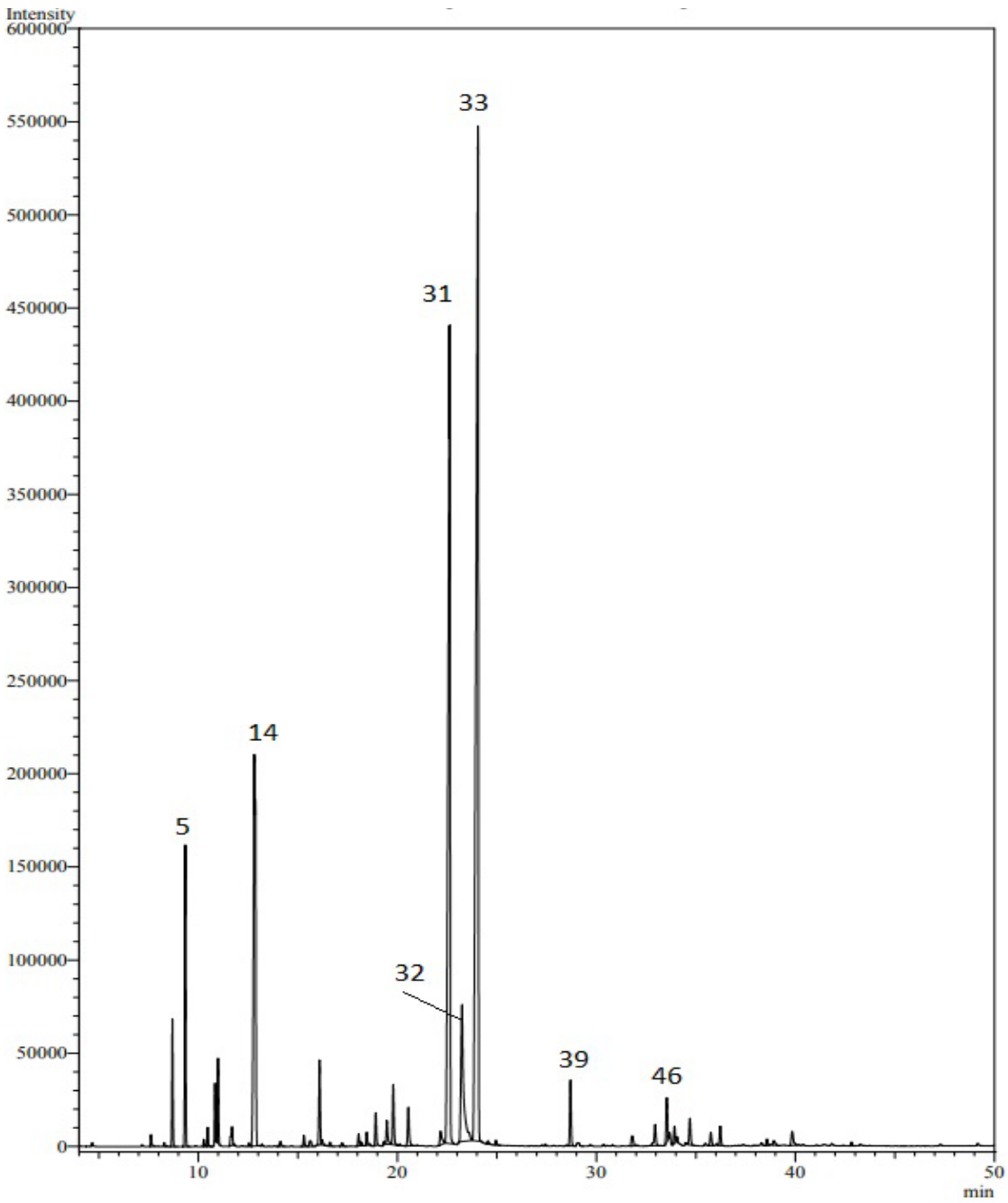

Figure 5. Gas chromatogram of shade dried rhizome essential oil of *Z. officinale*

oil (Figure 6). The oil yield was 0.62% (v/w) (Figure 1). It had 10.01% moisture content and the constant weight was observed after 72 hours. The essential oil obtained by oven drying of *Z. officinale* at 30ºC was rich in geranial (21.94%), neral (18.00%), β-phellandrene (12.10%), geranyl acetate (10.93%), geraniol (7.54%) and camphene (5.93%). Zingiberene (2.88%), α-pinene (2.64%) and β- myrcene (2.24%) were the minor components (Table 3).

Essential oil content and composition of oven dried (50ºC) Z. officinale

A total of 52 compounds were present in the oil out of which 44 compounds were identified representing 98.65% of the oil (Figure 7). The

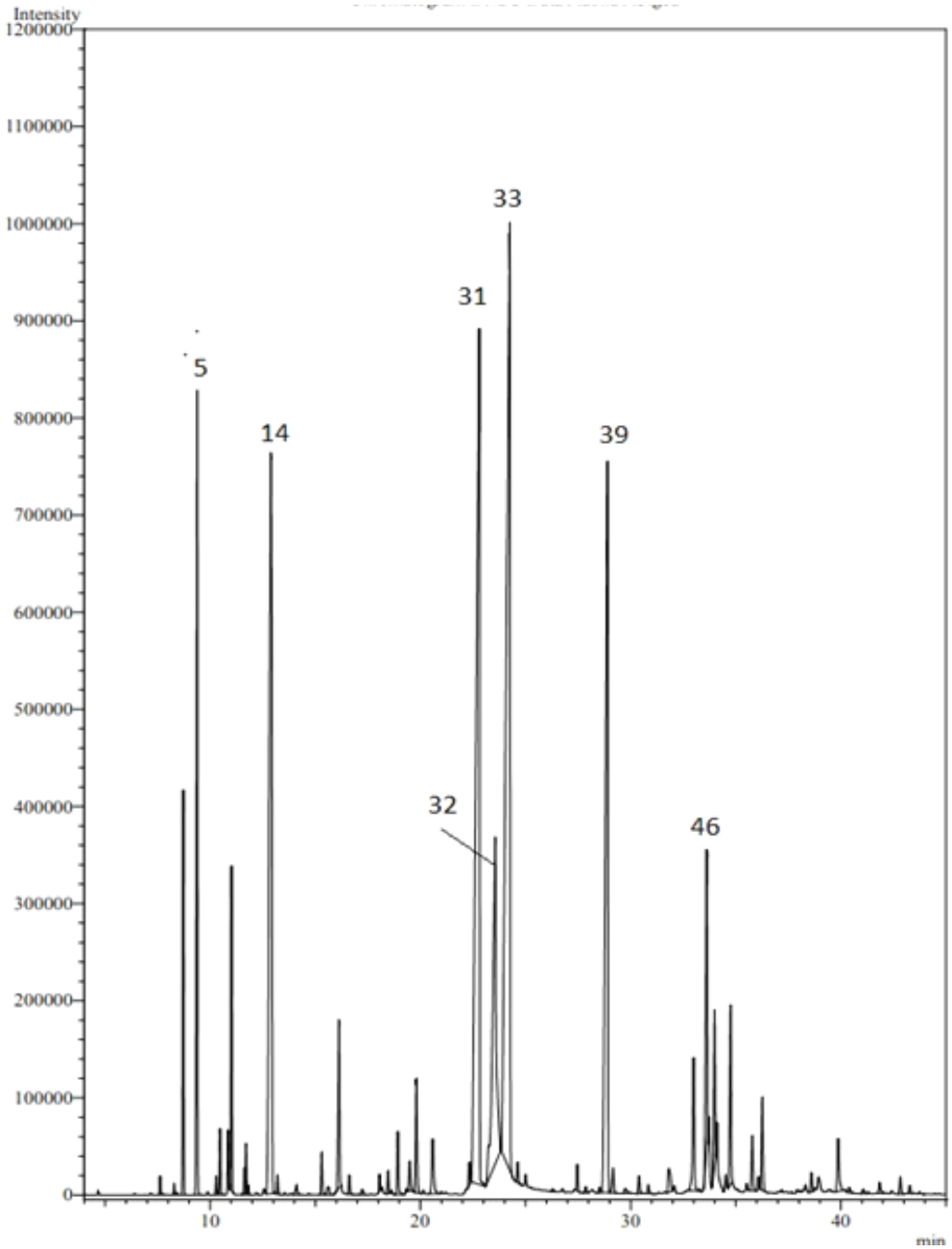

Figure 6. Gas chromatogram of oven dried at 30°C rhizome essential oil of *Z. officinale*

oil yield was 0.46% (v/w) (Figure 1). Oven drying at 50ºC rhizomes had 10.35% of moisture content. The constant weight, was obtained after 42 hours. The major compounds in the essential oil were geranial (18.74%), neral (17.18%), β-phellandrene (11.01%), geranyl acetate (10.16%), geraniol (10.04%) and zingiberene (5.24%). δ- Amorphene (3.21%), β-sesquiphellandrene (2.28%), ar-curcumene (2.22%) and linalool (2.12%) were reported as the minor constituents. It had the highest amount of zingiberene content (Table 3).

The study showed that as the temperature increased, the amount of zingiberene content increased. The dehydration rate was reported to increase with increase in mass of ginger samples

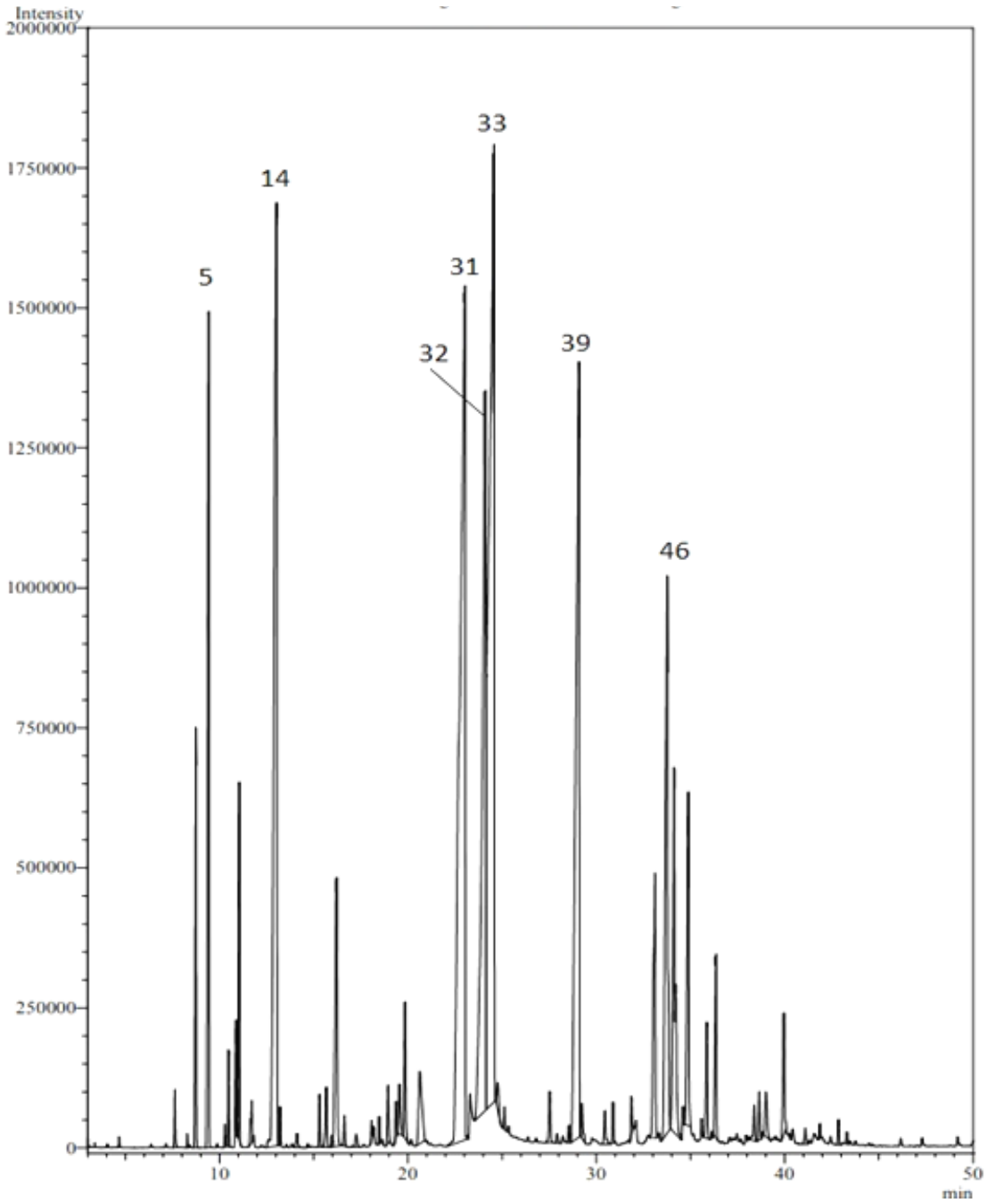

Figure 7. Gas chromatogram of oven dried at 50°C rhizome essential oil of *Z. officinale*

and decreased with the progression of drying days.

Class of compounds

The percentage of oxygenated monoterpenes was highest in the essential oil followed by monoterpene hydrocarbons and sesquiterpenes. Shade dried sample had the maximum amount of oxygenated monoterpenes as compared to other samples. Sesquiterpene hydrocarbon percentage was found to be lowest for shade dried sample. (Table 4).

Cluster analysis

The hierarchical cluster analysis classified the essential oils, under different drying conditions, into three clusters (Figure 8). Cluster I comprised

Table 4. Variation in the percentage of class of compound in *Z. officinale* under different drying conditions

Class of compounds	ZOD_1	ZOD_2	ZOD_3	ZOD_4	ZOD_5	ZOD_6
Monoterpene hydrocarbons	30.31	19.22	20.08	22.12	24.72	19.50
Oxygenated monoterpenes	50.96	67.56	63.95	72.63	62.87	61.10
Sesquiterpene hydrocarbons	13.25	8.45	10.37	2.74	8.44	13.92
Oxygenated sesquiterpenes	2.53	2.55	3.16	1.24	2.45	2.92
Others	0.88	0.71	0.71	0.52	0.61	1.21

ZOD_1 = Fresh; ZOD_2 = Sun drying; ZOD_3 = Blower drying; ZOD_4 = Shade drying; ZOD_5 = Oven drying at 30ºC; ZOD_6 = Oven drying at 50ºC

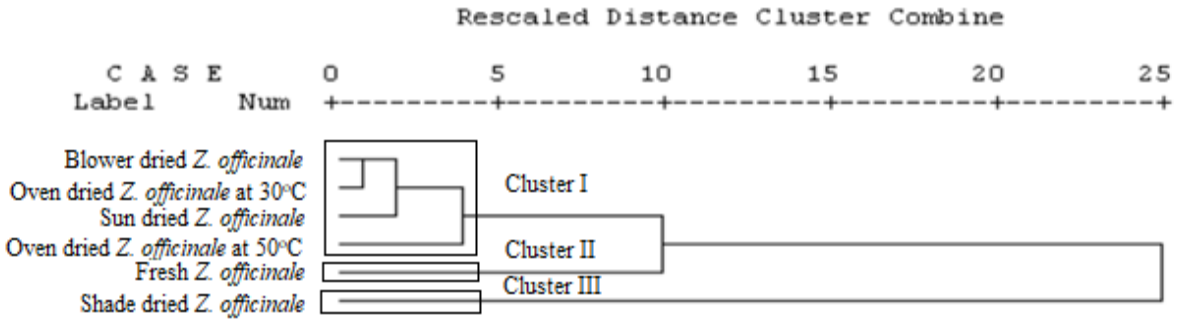

Figure 8. Dendrogram of to the essential oils of *Z. officinale* dried under different drying onditions

of oil obtained from blower drying, oven drying at 30ºC, sun drying and oven drying at 50ºC conditions. Cluster II consisted of essential oil obtained from fresh plant while Cluster III contained the essential oil obtained from shade drying.

Cluster I: Geranial (18.74-24.60%), neral (17.18-18.00%), geranyl acetate (10.16-11.45%), β-phellandrene (9.84-12.10%), geraniol (7.54-10.19%), camphene (4.23-5.93%), zingiberene (2.70-5.24%)

Cluster II: Geranial (17.53%), β-phellandrene (14.12%), neral (12.47%), geranyl acetate (12.23%), camphene (7.87%), geraniol (5.43%), Cluster III: Geranial (35.24%), neral (24.59%), β-phellandrene (13.21%), geraniol (5.56%), camphene (4.45%)

Clusters were observed to be formed on the basis of the effect of air on the plant secondary metabolite. Cluster I consisted of drying conditions that were affected by high temperatures, direct sunlight and hot air flow. However, Cluster II and Cluster III were not affected by any types of high temperatures or air flow.

Discussion

Effect of drying on the essential oil content

Present study aimed at determining the most suitable method of drying to obtain quality essential oil. The moisture content, oil yield and essential oil composition were determined.

In the present study, the fresh ginger oil sample yielded 0.20% (v/w) oil while the oil yield of dried samples ranged between 0.48% to 0.62%. The oven dried ginger rhizomes at a temperature of 30ºC showed the highest oil yield 0.62% among the dried samples followed by the blower dried sample 0.61% (Figure 1).

The essential oil yield of fresh *Z. officinale* was 0.11% obtained by Pino *et al.*[19], 0.17% by Famurewa *et al.*[27] and 0.17% by Kubra and Rao [21]. However, the oil yield of fresh ginger as reported by Jayasundra *et al.*[28] was 1.26%. According to Famurewa *et al.*[27], oven dried and sun-dried ginger oil yield was 1.36% and 0.81%,

respectively. Jayashree *et al.*[22] observed that sun drying leads to an increase in essential oil yield. Thus, the oil yield of fresh sample was found to be more significant and there was an increase in the oil yield when it underwent by the drying conditions.

Chemical composition of fresh Z. officinale

The major components of the fresh ginger oil in the study were geranial, neral, β-phellandrene, geraniol, geranyl acetate, camphene and zingiberene. Onyenekwe and Hashimoto observed that the predominant components in the fresh ginger oil were zingiberene (29.54%) and β-sesquiphellandrene (18.42%) [10]. According to Raina *et al.*, (*E*)-citral, (10.5%), zingiberene (10.5%), *ar*-curcumene (9.8%), β-sesquiphellandrene (7.1%), (*Z*)-citral (7.0%), camphene (6.1%), β-farnesol (5.8%) and β-farnesene (5.1%) were the major components in the fresh ginger rhizome oil [13]. Gupta *et al.* reported that the oil of fresh ginger rhizomes collected from north west Himalayas was rich in geraniol (14.5%), 1,8-cineole (10.9%), geranial (9.5%), neral (8.1%), geranyl acetate (6.3%), borneol (5.6%) and *trans*-dimethoxy citral (5.0%) [14]. The major components identified in the fresh ginger essential oil from China were zingiberene (28.12%), (*E*)-α-citral (15.71%), *β*-sesquiphellandrene (7.65%), β-phellandrene (7.53%), farnesene (6.91%), camphene (6.66%), eucalyptol (5.66%) and β-citral (5.65%) [19]. A previous study by Kubra and Rao *et al.*[21] from Mysore, India suggested the presence of zingiberene (23.5%), α-farnesene (12.0%), β-sesquiphellandrene (10.3%), β-phellandrene (9.3%), geranial (6.4%), camphene (6.2%) and ar-curcumene (5.5%) as the major components in the fresh oil of ginger. Nampoothiri *et al*. reported geranial (20.07%), neral (9.44%), ar-curcumene (6.56%) (E, E)-α-farnesene (6.29%), β-sequiphellandrene (6.17%), β-bisabolene (5.91%) and zingiberene (5.74%) as the marker compounds of fresh ginger rhizome oil from north west Himalayan region [15]. In another study from China, zingiberene (27.8%), β-phellandrene (12.9%), sesquiphellandrene (10.4%), geranial (6.6%), ar-curcumene (5.8%) and β-bisabolene (5.7%) were present in significant amount in the fresh *Z. officinale* oil [5]. An *et al*. showed the presence of zingiberene (22.76%), β-phellandrene (12.40%), β-sesquiphellandrene (7.01%) and geranial (14.50%) as the prime components in the fresh ginger oil [9]. A recent study by Poudel et al. from Nepal reported that the essential oil from fresh rhizomes contained α-zingiberene (8.6%-24.1%), camphene (7.2%-12.8%), β-phellandrene (3.8%-10.1%), neral (0.6%-11.8%), geranial (1.0%-17.4%), ar-curcumene (3.0%-10.3%), and β-sesquiphellandrene (3.7%- 9.7%) as the major compounds [17]. These results showed that the variation in the volatile constituents might be due to the different geographical locations.

Essential oil composition influenced by different drying methods

Based on the present investigation, we observed that drying conditions had a profound effect on the essential oil composition. On comparing different drying conditions, it was noticed that sun drying took the least time and shade drying took more time to dry the moisture content. Shade drying retained the high amount of geranial content. Five minor components namely α-thujene, β-(*E*)-ocimene, octanol acetate, δ-elemene and geranyl linalool which were present in the fresh oil, were observed to be absent in the oil derived from dried samples. On the other hand, myrtenyl acetate and shyobunol content retained in the oven dried samples. p-Cymene and citronellol were absent in the fresh oil and appeared in the shade dried samples. Absence of some components in the fresh samples and appearance in the dried samples have been reported in some previous investigations [29-33]. This might be attributed to some chemical conversions or transformations of the components during the drying process. Variation in the major compounds of *Z. officinale* by different drying conditions is discussed further in the following sub sections.

The present results are found to differ from the previous studies from India as well as from other countries.

Variation in the content of camphene

The results suggested that in the fresh oil,

camphene content was high (7.87%). Camphene content was observed to be minimum under oven drying conditions at 50ºC (4.23%) while maximum under oven drying condition at 30ºC (5.93%) (Table 3; Figure 9). Camphene content was observed to increase from 1.08% to 2.89% in dried ginger collected from Australia [34]. However the present study showed high camphene content, which was noted to decreased significantly on drying.

Variation in the content of β-phellandrene

The content of β-phellandrene was highest (14.12%) in the fresh oil followed by shade drying (13.21%) and oven drying at 30ºC (12.10%). The β-phellandrene content was found lowest for sun dried (9.84%) ginger oil (Table 3; Figure 9). Huang *et al*. also noted the decrease in the β-phellandrene content in the ginger rhizome oil from 12.9% to 10.0% on oven drying [5]. On the contrary, Bartley and Jacobs observed increase in the percentage of β-phellandrene from 1.30% to 4.68% [34]. Present results are found to be similar to the study by Huang *et al* from China which suggested that β-phellandrene content decreased significantly on drying.

Variation in the content of neral

It was observed that the fresh oil contained the lowest neral content (12.47%) while the highest neral content was present in the shade dried ginger (24.59%) (Table 3; Figure 9). Bartley and Jacobs observed the similar trend of neral content in dried ginger from Australia [34]. In contrast, a previous report from Iran on the effect of drying methods in the essential oil composition of *Lippia citriodora* revealed a decrease in the percentage of neral with the rise in temperature [16]. Pirbalouti *et al*.[31] and Hanaa *et al*.[35] also reported that the content of neral decreased significantly when lemongrass and basil were oven dried. The present study indicated that the percentage of neral was found to increase under different drying conditions.

Variation in the content of geraniol

The fresh ginger oil had the lowest geraniol content 5.43% which increased under the effect of drying conditions. It also showed that the retention of geraniol content was maximum under sun drying (10.19%) conditions followed by oven drying at 50ºC (10.04%) (Table 3; Figure 9). On the contrary, in previous studies

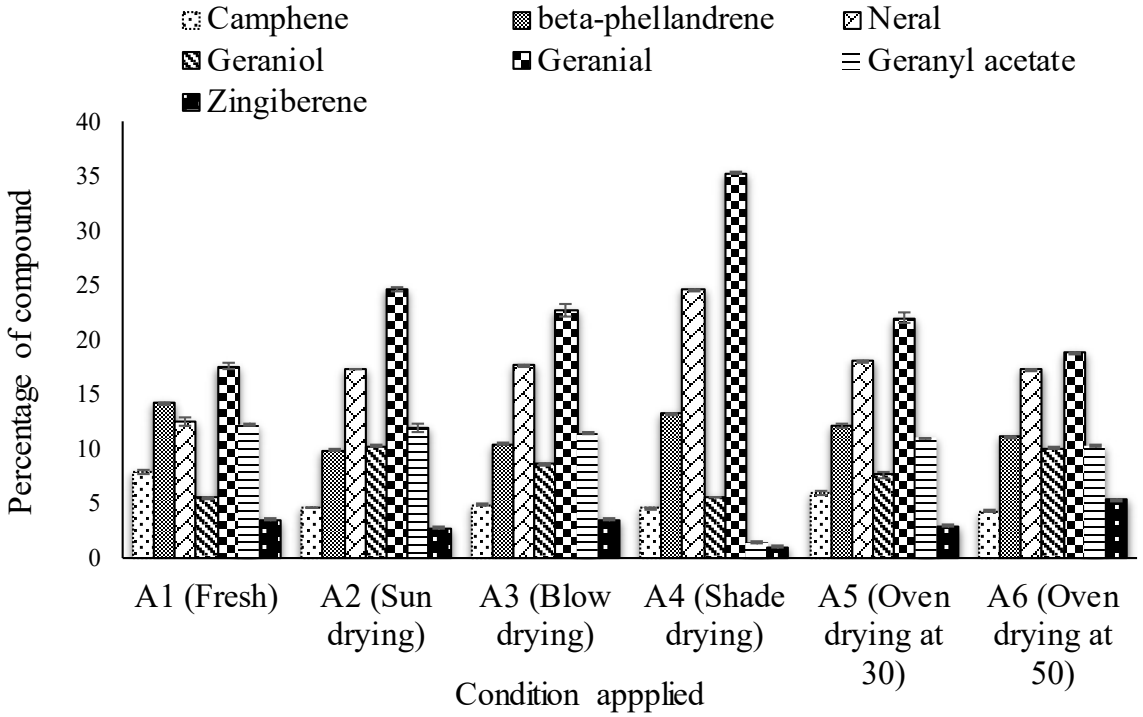

Figure 9. Variation in the major compounds in *Z. officinale* under different drying conditions

from Australia [22] and Tamil Nadu, India [34] it was observed that geraniol percentage decreased upon drying [22 34]. The present study was found contrary to the above studies. Thus, the high geraniol content can be obtained by drying.

Variation in the content of geranial

17.53% geranial content was observed in the fresh oil, which was found to be the lowest when compared to that obtained under all drying conditions. The geranial content was found to be the highest for the shade dried plant material (35.24%) and decreased in the order of sun drying (24.60%), blower drying (22.63%), oven drying at 30ºC (21.94%) and oven drying at 50ºC (18.74%) (Table 3; Figure 9). No change in the geranial percent was observed by Huang *et al.*[5]. In contrast to the present study, Shahhoseini *et al*.[16], Pirbalouti *et al*.[31], Bartley *et al*.[34] and Hanaa *et al*.[35] observed the negative impact of temperature on the content of geranial in the essential oil of *Lippia citriodora,* basil, ginger and lemongrass. However, the pPresent investigation suggested the positive impact of drying conditions on the geranial content.

Variation in the content of geranyl acetate

The content of geranyl acetate was 12.23% in the fresh rhizome oil and decreased in the following order of drying conditions: sun drying, blower drying, followed by oven drying at 30ºC and 50ºC (Table 3; Figure 9). The lowest geranyl acetate content was observed for the shade dried rhizome oil. The percentage of geranyl acetate increased in the essential oil of ginger from Australia [34] and *Melissa officinalis* L. from Egypt [1] on drying. Contrasting results were observed, that geranyl acetate content decreased on drying.

Variation in the content of zingiberene

The oven dried rhizomes at 50ºC had the maximum zingiberene content (5.24%) whereas the shade dried material contained the lowest content (0.92%). The fresh oil had 3.19% zingiberene which increased on blower drying but decreased on sun drying (Table 3; Figure 9). Bartley *et al*.[34] observed a significant increase (13.44 to 24.58%) in the content of zingiberene upon drying. However, in previous reports from Tamil Nadu, India and China, the content of zingiberene decreased upon oven drying [5,22], In the present investigation, the percent of zingiberene was observed to significantly increase upon oven drying at 50ºC and decrease upon other drying processes which is different from the other studies.

Conclusion

In this research work, methods of drying for obtaining the high-quality essential oil at maturity stage were explored. The amount of neral, geranial and geraniol content increased whereas the content of camphene, β- phellandrene, and geranyl acetate decreased by drying. Zingiberene content was highest for oven dried material at 50ºC. The study suggested that shade drying of *Z. officinale* rhizomes is more suitable for getting the high content of biologically active and industrially important β-phellandrene, neral and geranial. Thus, shade drying can be a promising method for food products like ginger as there is no energy consumption and yet good retentions of compounds. The highest oil yield was obtained by drying ginger in oven at 30ºC. This research can be helpful in further exploration of the biological activities of the dried ginger rhizome oil (antioxidant activity, antibacterial activity and antifeedant activity).

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