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EFFECT OF DRYING METHODS ON THE ESSENTIAL OIL COMPONENTS AND ANTIOXIDANT POTENTIAL OF RHIZOMES OF THE SPICE *ZINGIBER OFFICINALE* ROSCOE.(ZINGIBE RACEAE)

AABHA[1], GEETA TEWARI[1 *], CHITRA PANDE[1], NEETA NEGI[1], MAMTA BISHT[2], BHAWANA KANYAL[1], SHALINI SINGH[3] AND OM PRAKASH[4]

[1]Department of Chemistry, D. S. B. Campus, Kumaun University, Nainital - 263001, Uttarakhand, INDIA
[2]Department of Chemistry, School of Applied and Life Sciences, Uttaranchal University,Dehradun -248007 , Uttarakhand , INDIA
[3]Department of Chemistry, Uttarakhand Open University, Haldwani - 263139,Uttarakhand.
[4]Department of Chemistry, C.B.S.H., G.B.P.U.A. and T. Pantnagar -263145 , Uttarakhand, INDIA.
e-mail: geeta_k@rediffmail.com
ORCID ID:htpp://orcid.org/0000-0003-0063-8672

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***Corresponding author**

ABSTRACT

Zingiber officinale Roscoe., belonging to the Zingiberaceae family is one of the world's most popular spices. The aim of the current study was the assessment of drying effects on the essential oil composition of *Z. officinale* Roscoe. rhizomes that were harvested at the maturity stage from the Betalghat region, Nainital, Uttarakhand. The GC and GC/MS analysis of the oils showed the presence of geranial (18.35-22.26%), neral (13.89-16.43%), β -phellandrene (10.18-11.91%), geraniol (7.25-10.99%), geranyl acetate (3.76-7.74%), camphene (5.36-8.96%), and zingiberene (3.10-5.17%) as the most prevalent components in the oil. All of the samples of essential oils had a high percentage of oxygenated monoterpenes. The amount of neral, β -phellandrene, and camphene increased with all types of drying conditions. α -Pinene, linalool, α -(*E*, *E*)-farnesene, and β -sesquiphelland rene were the minor constituents in the oil samples. The results depicted that the oven-dried sample at 30ºC had the highest antioxidant activity and oil yield.

INTRODUCTION

Culinary professionals are constantly looking for new spices and flavorings ingredients because of the growing global demand for authentic and cross-cultural. Consumers are increasingly looking for natural foods and preservatives to live healthier lifestyles and prevent illnesses naturally and thus, there is a need for the preservation techniques of culinary herbs like *Zingiber officinale*. Ginger belongs to the Zingiberaceae family, which has around 45 genera and 800 species; its scientific name is *Zingiber officinale* Roscoe. Its cultivation is thought to have begun in China and expanded to India, West Africa, and Southeast Asia (Tarfaoui *et al.,* 2022).

This medicinal plant has been utilized in Chinese, Ayurvedic, and Tibb-Unani herbal treatments (Ahmed *et al.,* 2023). In herbal medicine practice, it has been used to treat arthritis, rheumatological diseases, and muscular discomfort. Other illnesses for which ginger has been proposed, include atherosclerosis, migraine headaches, rheumatoid arthritis, high cholesterol, ulcers, depression, and impotence. In addition to its therapeutic properties, ginger is widely used as a cooking spice and is thought to help with common colds, flu-like symptoms, and even painful menstrual periods (Tarfaoui *et al.,* 2022). It is regarded as a safe herbal treatment with few and minimal negative side effects (Bellik 2014). This spice has high antioxidant capacity and can be used to create novel natural antioxidants as well as flavoring agents for usage in a variety of food products (Tarfaoui *et al.,* 2022).

Besides medicinal purposes, ginger rhizome oil is also one of the essential oils prized for its pleasant aroma that can range from sweet, warm, to camphoraceous or citrus-like depending on the relative essential elements that determine the oil's quality and industrial usage (Dhanik *et al.,* 2017). Furthermore, ginger plants are commonly utilized in the extraction of essential oils, rich in monoterpenes and sesquiterpenes. Because of their established antibacterial and antifungal qualities, essential oils are used as natural preservatives in addition to their applications in cosmetics,cleaning goods,Fragrances and aromatherapy (Ivanovic *et al.,* 2021).

The food sector is currently faced with issues in keeping the quality of fruit and vegetable products after processing. Because of its multiple health-promoting characteristics, ginger rhizome processing has recently received a lot of attention (Ravindran *et al.,* 2005). Ginger dehydration is the most commonly used

processing method for inhibiting microbial development and delaying deteriorative biochemical reactions. It is also an important processing procedure for creating novel products. Dried ginger can be used to make ginger spices, medication, and cosmetics, as well as ginger-flavored foods such as soft drinks and candies. However, drying can cause thermal damage as well as significant changes in the physical, chemical, and organoleptic aspects of aromatic plants.As a result, selecting a drying procedure is critical (An *et al.,* 2016). Thus, the present work idea was created to find the impact of different drying conditions on the *Z. officinale* essential oil composition and its antioxidant activity.

Drying is a significant processing procedure for fresh ginger that is required for its use in many products and long-term preservation. Fresh ginger has a relatively high moisture content (85-95% on a wet basis), resulting in a reduced shelf life due to microbial deterioration (Ghafoor *et al.,* 2020). Before deciding on an appropriate process for commercial drying of ginger, the quality of dried ginger obtained from various driers has to be examined. A few studies on the impact of post-harvest techniques on ginger have been undertaken so far by Jayashree *et al.,* 2014; Aabha *et al.,* 2022 ; Kamal *et al.,* 2023. Jayashree *et al.,*2014; found the effect of dying methods (open sun drying and solar tunnel drying) and Kamal *et al.* (2023) found the effect of oven drying and sun drying conditions on essential oil composition, but to the best of our knowledge, no work has been reported on the effect of drying techniques (shade drying, oven drying, and blower drying) on the essential oil composition and antioxidant activity of *Z. officinale*. As a result, the current study was done to investigate the effect of drying procedures on the essential oil composition and antioxidant potential of *Z. officinale*.

MATERIALS AND METHODS

Plant collection

Rhizomes *Z. officinale* were collected at the maturation stage from the Betalghat region (29º56'N, 79º30'E) at an altitude of 775m of Uttarakhand in December 2022. The specimen's plant samples were collected and properly identified.

Extraction of essential oil

The freshly collected rhizomes of the plant were soaked in water to loosen the soil present in the rhizomes. Then these were washed under tap water and sliced into small pieces. These were divided into six batches of 1 kg for applying different drying methods including fresh, sun drying, blower drying, shade

drying, oven drying at 30ºC and 50ºC). Clevenger apparatus was utilized to extract the oil from the fresh and dried rhizomes. The extraction process was done for 6 hours (Clevenger, 1928; Aabha *et al.,* 2022). The process of hydrodistillation was replicated three times. Sodium sulphate was used to dry the extracted oil and the oil was stored at 4ºC until further testing.

Analysis of essential oil

Gas chromatography flame ionization detector (GC-FID)

All three essential oil sample were run on the Shimadzu 2010 GC having Rtx-5 column (30m*0.25mm) and flame ionization detector. Nitrogen was used as carrier gas at 30mL/min column flow. The column temperature programming was 50ºC for 2 min hold time, 210ºC for 2 min., and 280ºC for 6 min. The injector flow rate temperature was set to 260ºC and the detector temperature was 280ºC. The split ratio was 1:10 (Aabha *et al.,* 2022).

Gas chromatography-mass spectrometry (GC/MS)

The Shimadzu 2010 GC has an Rtx-5 column (30m*0.25mm) and flame ionization detector. The column temperature was 50ºC the ion source temperature was 220ºC and the interface temperature 270ºC. The pressure was 69 kPa, column flow 1.21mL/min with a total of 125.2 mL/min. The split ratio was 1:100. The scanning mass range m/z was 40-600 (Aabha *et al.,* 2022).

Identification and quantification of the compounds

The retention index (RI), based on homologous n-alkane C9-C33 series under analogous experimental settings, was calculated to identify the distinct constituents of essential oils. Then the mass spectra were matched with WILEY (7th edition) and NIST (version 4.1) libraries. By using the techniques of Zheljazkov *et al.,* 2008 the amount of each chemical was determined.The identification of each compounds was completed by examining and contrasting the fragmentation pattern of the mass spectral data with those reported in the literature (Adams, 2017).

Antioxidant activity

Several *in vitro* tests were conducted to assess the essential oils antioxidant activity, and the results were presented as the mean ± SD of three measured value.

DPPH free radical scavenging activity

To investigate the antioxidant potential against DPPH (2,2'-diphenyl-1- picrylhydrazyl) the method applied by Rani *et al.,* 2022 and Kanyal *et al.,* 2023 was used. Each sample and standard (Butylated hydroxytoluene: BHT) received 5 mL of DPPH in a 0.004% methanol solution at different ranges of concentration (5- 25μg/mL). The absorbance at 517 nm was measured in triplicate after 30 minutes in the dark at room temperature using a UV-visible spectrophotometer (Thermo Scientific Evolution-201).

Iron metal chelating activity

The metal chelating activity was investigated using the technique described by Kanyal *et al.,* 2023. To make a final volume of 5mL, different test samples and standard (L-ascorbic acid) concentrations (5-25μg/mL) were combined with 0.1 mL of 2mM $FeCl_2$, 0.2 mL of 5mM ferrozine, and 4.7 mL of methanol. The solution was then incubated at room temperature for 10 minutes. After shaking and 30 minutes of room temperature incubation, the solution's absorbance at 562 nm was measured using a UV-visible spectrophotometer (Thermo Scientific, Evolution-201).

Hydrogen peroxides radical scavenging activity

The H_2O_2 radical scavenging activity of the investigated materials was determined using the previously reported method by Kanyal *et al.,* 2023. The test solution consisted of 0.4 mL of methanolic solution containing essential oils or standards (BHT) at varied concentrations (5-25 μg/mL) in phosphate-buffered saline (PBS; 0.1 M; pH 7.4) and 0.6 mL of

H_2O_2 solution (40 mM) in PBS. The solution was incubated at room temperature for ten minutes. The solution was incubated at room temperature for ten minutes. The solution was incubated at room temperature for ten minutes. The absorbance at 230 nm was measured in comparison to a blank of methanol.

Statistical analysis

The data on the percentage variance in the components of essential oils was statistically assessed using SPSS 16.0 for one-way ANOVA and cluster analysis . The findings were calculated and displayed as mean value standard deviation using MS-Excel 2019 (Aabha *et al.,* 2022).

RESULTS AND DISCUSSION

Effect of drying condition on the moisture content, essential oil content, and essential oil composition

Moisture content

The moisture content of fresh *Z. officinale* rhizomes was 80%. The constant weight took 36 hours to attain, and the moisture content after sun drying was 8.32%. Blower-dried rhizomes had a moisture level of 4.4% and took 47 hours to achieve a consistent weight. Shade drying revealed a moisture content of 10.3%, which took 28 days to achieve a consistent weight. The moisture content of oven-dried rhizomes at 30ºC and 50ºC was 12.22% and 12.84%, respectively. When different drying circumstances were compared, it was discovered that sun drying required the least amount of time, and shade drying took the most time to dry the moisture content.

Essential oil content

The fresh *Z. officinale* rhizomes had 0.18% (v/w) essential oil content. Sun-dried and shade-dried rhizomes had 0.78% and 0.56% (v/w) oil content. The oven-dried rhizomes at 30ºC and 50ºC and blower-dried rhizomes had 0.70% (v/w) essential oil content. In the dried samples the highest oil yield was obtained from the sun-dried sample (Govindarajan and Connell, 1983). The oil yield of ginger oil may range from 1.0 to 3.0 %, depending on the location from where the rhizomes are harvested (Mahboubi, 2019. Ginger had an oil yield of 2.4 %, 0.17 % according to Famurewa *et al.,* 2011 and Kubra and Rao, 2012 while Pino *et al.,* 2014 showed that fresh *Z. officinale* yielded 0.11% essential oil.

The oil yield of fresh ginger, according to Jayasundra and Arampath *et al.,* 2021 was 1.26%. While Famurewa *et al.,* 2011 investigated that the yields of ginger oil from oven and sun-dried ginger were 1.36% and 0.81%, respectively.Bellik *et al.,* 2013 stated that the essential oil produced by *Z. officinale* rhizomes is pale yellow to light amber and can be extracted with a yield ranging from 1.5 to 3.0%, depending on crop quality. Jayashree *et al.,* 2014 showed that sun drying promotes the production of essential oils. The drying technique had a substantial impact on the essential oil yield and chemical composition of ginger rhizomes. It has been proven that drying the rhizomes at temperatures lower than 70 degrees Celsius increases the output of ginger oil (Mahboubi *et al.,* 2019).

Essential oil composition

The essential oil composition of fresh *Z. officinale*

The essential oil composition of fresh and dried rhizomes *Z. officinale* is represented in Table 1. The GC and GC/MS analysis of fresh *Z. officinale* essential oil showed the presence of 51 compounds representing 96.79% of the compounds (Figure 1).Geranial (20.13%), neral (13.89%), geraniol (10.99%), β -phellandrene (10.61), geranyl acetate (7.74%), camphene (5.36%) and zingiberene (5.17%) were identified as the major compounds while α-(*E,E*)-farnesene(2.33%), β- sesquiph ellandrene (2.30%) and α-pinene (2.05%) were present as the minor components having percentage more than 2%. The essential oils consisted primarily mono and sesquiterpenoids, the most important of which were geranial, neral, 1,8-cineole, zingiberene, bisabolene, and β-sesquiphellandrene (Ekundayo *et al.,* 1988).

The most prevalent constituents in ginger oil were borneol, neral, geraniol, geranyl acetate, ar-curcumene, α-(E, E)-farnesene,zingiberene, β-bisabolene,and β -sesquiphella ndrene (Wohlmuth *et al.,* 2006).According to Gupta *et al.,* 2011, the oil of freshly harvested ginger rhizomes from the northwestern Himalayas included high concentrations of 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%). The primary components of the fresh ginger essential oil from China were zingiberene (28.12%), (*E*)-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%) (Ren *et al.,* 2012). The major compounds present in the essential oil of ginger from Mysore, India were 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%) (Kubra and Rao, 2012).

Nampoothiri *et al.,* 2012 also investigated the essential oil of fresh ginger and reported geranial (20.07%), neral (9.44%), ar-curcumene (6.56%), (*E, E*)-farnesene (6.29%), β-sequiphellandrene (6.17%), β-bisabolene (5.91%), and zingiberene (5.74%) as the marker components of the rhizome oil. According to Sasidharan *et al.,* 2012, ginger Bhaisa variety oil was rich in geranyl acetate (18.8%), zingiberene (16.3%), and geranial (8.2%), while zingiberene (19.8%) and geranial (16.5%) were found in Majulay oil. Zingiberene (27.8%), β-phellandrene (12.9%), β-sesquiphellandrene (10.4%), geranial (6.6%), ar-curcumene (5.7%), and β-bisabolene (5.7%) were identified as major components in a different study from China (Huang *et al.,* 2012).

According to Mesomo*et al.,* 2013, the most abundant compounds in the oil obtained by hydrodistillation were α-curcumene, geranial, and camphene. The Algerian ginger had two primary components which were zingiberene (17.07%) and citral (30.8%) (Meliani *et al.,* 2014). (*E*)-Citral (10.5%), zingiberene(10.5%),ar-curcumene (9.8%), β -sesquiphe llandrene (7.1%), (*Z*)-citral (7.0%), camphene (6.1%), α-farnesol (5.8%), and (*E, E*)-farnesene (5.1%) by Raina *et al.,* 2015 which had resemblance to the present study (Raina *et*

Table1: Compounds present in *Z. officinale* under different drying conditions

S.No.	Compound	RT	RI (Calculated)	RI (Adams)	HSF	HSS	HSB	HSSH	HSOV30	HSO V50
1)	Hexanal	5.088	801	801	ND	0.26	ND	0.21	0.19	0.2
2)	Heptanone	7.77	889	889	ND	0.09	0.08	0.11	0.07	0.07
3)	Heptanol	8.188	904	894	0.06	0.26	0.19	0.33	0.21	0.22
4)	Tricyclene	8.961	919	921	0.08	0.13	0.12	0.08	0.08	0.07
5)	α-pinene	9.417	930	932	2.05	2.47	2.32	1.83	1.92	1.81
6)	Camphene	10.121	947	946	5.36	8.96	8.32	6.21	5.86	5.46
7)	Sabinene	11.029	969	969	0.15	0.1	0.11	0.11	0.11	0.12
8)	β- pinene	11.233	974	974	0.32	0.3	0.28	0.24	0.3	0.3
9)	Hepten-2-one -6-methyl-5	11.561	986	981	0.57	1.74	1.18	1.6	1.26	1.5
10)	Myrcene	11.782	990	988	1.53	1.53	1.44	1.29	1.45	1.39
11)	β-phellandrene	12.371	1005	1002	0.24	0.23	0.23	0.26	0.23	0.26
12)	Carene-´-3	12.497	1007	1008	0.29	0.22	0.26	0.24	0.24	0.24
13)	β- phellandrene	13.723	1032	1025	10.61	10.18	11.17	11.91	10.79	11.2
14)	2-heptanol acetate	13.997	1039	1038	0.08	0.11	0.1	0.1	0.08	0.1
15)	2- (E) - octenal	14.884	1058	1054	0.13	0.01	0.12	0.12	0.01	0.11
16)	Terpinolene	16.172	1084	1086	0.27	0.26	0.26	0.24	0.25	0.25
17)	2-nonanone	16.431	1091	1087	0.1	0.27	0.28	0.25	0.17	0.18
18)	Linalool	16.984	1105	1095	1.72	2.78	2.75	2.69	2.15	2.19
19)	Trans-pinene hydrate	18.124	1125	1119	0.1	0.14	0.15	0.16	0.12	0.13
20)	Citronellal	19.361	1153	1148	0.27	0.25	0.26	0.28	0.2	0.23
21)	(Z) -Isocitral	19.828	1163	1160	0.73	0.43	0.71	0.52	0.33	0.45
22)	Borneol	20.394	1174	1165	0.48	2.34	1.8	0.12	1.34	1.26
23)	(E) - Isocitral	20.729	1181	1177	1.19	0.98	1.12	1.07	0.75	0.91
24)	α - terpineol	21.496	1197	1186	0.72	1.31	1.24	1.35	1.21	1.23
25)	Nerol	23.082	1231	1227	0.32	0.06	0.7	ND	0.05	0.98
26)	Neral	23.722	1245	1235	13.89	14.34	16.01	16.43	14.85	14.97
27)	Geraniol	24.584	1264	1249	10.99	7.9	7.25	9.09	9.99	10.97
28)	Geranial	25.222	1277	1264	20.13	18.35	21.63	22.26	20.18	19.74
29)	Bornyl acetate	25.646	1287	1284	0.25	0.44	0.34	0.31	0.29	0.28
30)	Undecanone-2	26.006	1294	1293	0.13	0.26	0.24	0.21	0.16	0.16
31)	-elemene	27.85	1336	1335	0.05	0.02	ND	0.02	0.02	ND
32)	Citronellyl acetate	28.493	1350	1350	0.36	0.32	0.25	0.28	0.3	0.31
33)	Neryl acetate	28.875	1359	1359	0.05	0.02	ND	0.02	0.03	ND
34)	Geranyl acetate	29.902	1382	1379	7.74	4.2	3.76	4.15	5.72	5.67
35)	β - elemene	30.258	1390	1389	0.21	0.14	0.13	0.11	0.14	0.16
36)	Funebrene	30.803	1403	1402	0.03	0.02	ND	0.01	0.02	ND
37)	(E)-(β)-Caryop hyllene	31.525	1420	1417	0.1	0.07	0.08	0.04	0.09	0.21
38)	E-isoeugenol	32.925	1453	1448	0.14	0.07	0.17	0.04	0.29	0.07
39)	Caryophyllene-9-epi-(E)	33.208	1459	1464	0.11	0.05	ND	0.03	0.06	0.03
40)	Curcumene	34.11	1481	1479	1.5	1.5	1.09	0.8	1.29	1.35
41)	Zingiberene	34.785	1497	1493	5.17	3.11	3.09	2.01	3.1	2.91
42)	α - (E,E)-Farnesene	35.16	1507	1505	2.33	1.17	1.13	0.77	1.5	1.36
43)	β- sesquiphellan drene	35.911	1526	1521	2.3	1.37	1.18	0.85	1.32	1.24
44)	α - elemol	36.883	1550	1548	0.59	0.64	0.7	0.67	0.66	0.75
45)	Germacrene-B	37.242	1559	1559	0.16	0.12	0.07	0.07	0.13	0.1
46)	(E) - Nerolidol	37.368	1563	1561	0.88	0.94	0.82	0.69	0.98	0.84
47)	Germacrene-D-4-ol	37.801	1574	1574	0.01	0.01	0.07	0.07	ND	ND
48)	β- epi-eudesmol	39.727	1623	1622	0.4	0.37	0.37	0.35	0.43	0.42
49)	β- eudesmol	41.003	1657	1649	0.55	0.93	0.87	0.74	0.94	0.05
50)	α – bisabolol	42.215	1689	1685	0.51	0.75	0.57	0.56	0.68	0.63
51)	Shyobunol	42.519	1697	1688	0.43	0.43	0.31	0.42	0.54	0.49
52)	Farnesal (2E,6Z)	42.952	1709	1713	0.07	0.06	0.07	0.06	0.08	0.05
53)	Farnesal (2E,6E)	43.944	1737	1740	0.13	0.1	0.12	0.1	0.13	0.1
	Total				96.79	93.23	95.73	92.69	93.39	93.92

The bold characters indicated the major constituents of the essential oils.

ND = Not detected;Class of compounds;MH = Monoterpene hydrocarbons (4-8, 10-13,16);OM = Oxygenated monoterpenes (18-28,34);SH = Sesquiterpene hydrocarbons (31,35-43,45);OS = Oxygenated sesquiterpenes (44,46-53);OT = Others (1-3,9, 14,15,17,29,30,32,33);RI[a] = Retention indices according to the literature /Adams RI;RI[b] = Retention indices experimental (calculated);RT = Retention time

Table 2: Major Compounds present in *Z. officinale*

Compounds	HSF	HSS	HSB	HSSH	HSOV30	HSOV50
Camphene	$5.36^{a} \pm 0.02$	$8.96^{f} \pm 0.03$	$8.32^{e} \pm 0.02$	$6.21^{d} \pm 0.06$	$5.86^{c} \pm 0.04$	$5.46^{b} \pm 0.05$
β- phellandrene	$10.61^{b} \pm 0.07$	$10.18^{a} \pm 0.03$	$11.17^{d} \pm 0.06$	$11.91^{f} \pm 0.05$	$10.79^{c} \pm 0.04$	$11.2^{e} \pm 0.03$
Neral	$13.89^{a} \pm 0.07$	$14.34^{b} \pm 0.06$	$16.01^{e} \pm 0.05$	$16.43^{f} \pm 0.04$	$14.85^{c} \pm 0.03$	$14.97^{d} \pm 0.02$
Geraniol	$10.99^{f} \pm 0.05$	$7.9^{b} \pm 0.03$	$7.25^{a} \pm 0.04$	$9.09^{c} \pm 0.03$	$9.99^{d} \pm 0.04$	$10.97^{e} \pm 0.07$
Geranial	$20.13^{c} \pm 0.07$	$18.35^{a} \pm 0.08$	$21.63^{e} \pm 0.06$	$22.26^{f} \pm 0.05$	$20.18^{d} \pm 0.04$	$19.74^{b} \pm 0.07$
Geranyl acetate	$7.74^{f} \pm 0.03$	$4.20^{c} \pm 0.05$	$3.76^{a} \pm 0.02$	$4.15^{b} \pm 0.07$	$5.72^{e} \pm 0.02$	$5.67^{d} \pm 0.06$
Zingiberene	$5.17^{d} \pm 0.01$	$3.11^{c} \pm 0.03$	$3.09^{b} \pm 0.01$	$2.01^{a} \pm 0.02$	$3.1^{c} \pm 0.03$	$2.91^{b} \pm 0.02$

al., 2005). Camphene, sabinene, α -curcumene, zingiberene, α-farnesene, β -sesquiphellandrene, neral, and geranial were the major components of the essential oil (Yeh *et al.,* 2014). Citral (geranial and neral), α -zingiberene, camphene, α -farnesene, and β -sesquiphellandrene were observed to be the predominant components of the essential oil (Hofrel *et al.,* 2015).

An *et al.,* 2016 discovered that zingiberene (22.76%), geranial (14.50%), β -phellandrene(12.40%),and β -sesquiphellandrene (7.01%), were the primary components of fresh ginger oil. The primary components of the essential oil from fresh rhizomes, according to a recent study by Kumar Poudel *et al.,* 2022 from Nepal, were ar-curcumene (3.0%-10.3%), neral (0.6%-11.8%), geranial (1.0%-17.4%), camphene (7.2%-12.8%), β -phellandrene(3.8%-10.1%),and β -sesquiphellandrene (3.7%-9.7%).

These findings suggested that the variation in volatile elements could be attributable to geographical differences.

The essential oil composition of sun-dried *Z. officinale*

A total of fifty-two compounds representing 93.23% of compounds were identified in sun-dried *Z. officinale* essential oil. geranial (18.35%), neral (14.34%), β -phellandrene (10.18%), camphene (8.96%) and geraniol (7.90%), were the major compounds and geranyl acetate (4.20%), zingiberene (3.11%), α -pinene (2.47%), linalool (2.78%) and borneol (2.34%) as minor compounds. The sun-dried rhizomes had 0.78% (v/w) oil yield. To get the constant dried weight of rhizomes, it took 34 hours (Figure 2; Table 1).

According to Aabha *et al.,* 2022 sun-dried *Z. officinale* rhizomes had geranial (24.60%), neral (17.30%), geranyl acetate (11.87%), geraniol (10.19%) and β -phellandrene (9.84%) as major constituents. The major compounds identified in the essential oil of Thailand SD ginger were 3-carene (13.50%), acorenone (4.14%), caryophyllene (18.89%), o-Cymene (5.58%), sabinol (6.44%), ā-himachalene (3.94%), β -santalol (5.23%), and geranyl- α -terpinene (2.10%) (Kamal *et al.,* 2023).

The essential oil composition of blower-dried *Z. officinale*

The analysis of blower-dried oil showed the presence of 48 compounds which represented 95.73% composition of the oil. The essential oil composition of sun-dried rhizomes showed the presence of geranial (21.63%), neral (16.01%), β-phellandrene (11.17%), camphene (8.32%), and geraniol (7.25%) as the predominant compounds. Oil had also the presence of minor components such as borneol (3.80%), geranyl acetate (3.76%), zingiberene (3.09%), linalool (2.75%),

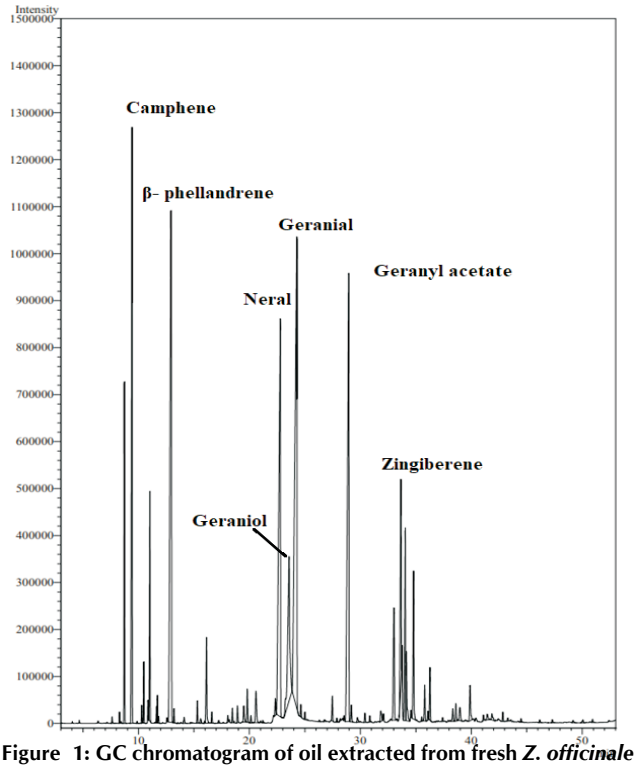

Figure 1: GC chromatogram of oil extracted from fresh *Z. officinale* rhizomes

and α -pinene (2.32%), and 20 hours were taken to get the constant weight (Figure 3;Table 1).

The essential oil composition of shade-dried *Z. officinale*

A total fifty-two compounds were identified showing 92.69% composition. The shade-dried *Z. officinale* had the presence of geranial (22.26%), neral (16.43%),β -phellandrene (11.91%), geraniol (9.09%), and camphene (6.21%) as the major components. The minor compounds identified were geranyl acetate (4.15%), linalool (2.69%), zingiberene (2.01%), and α -pinene (1.83%). The oil yield observed under this drying condition was 0.56%. The highest time was taken to get the constant dried weight under this drying. The highest geranial content was retained by shade drying (Figure 4; Table 1)

The essential oil composition of oven-dried *Z. officinale* at 30°C

The *Z. officinale* dried at 30°C had the presence of 52 compounds representing 93.38%. This rhizome essential oil had 0.70% (v/w) oil yield and showed the presence of major compounds such as geranial (20.18%), neral (14.85%),β - phellandrene (10.79%), geraniol (9.99%), camphene (5.86%)

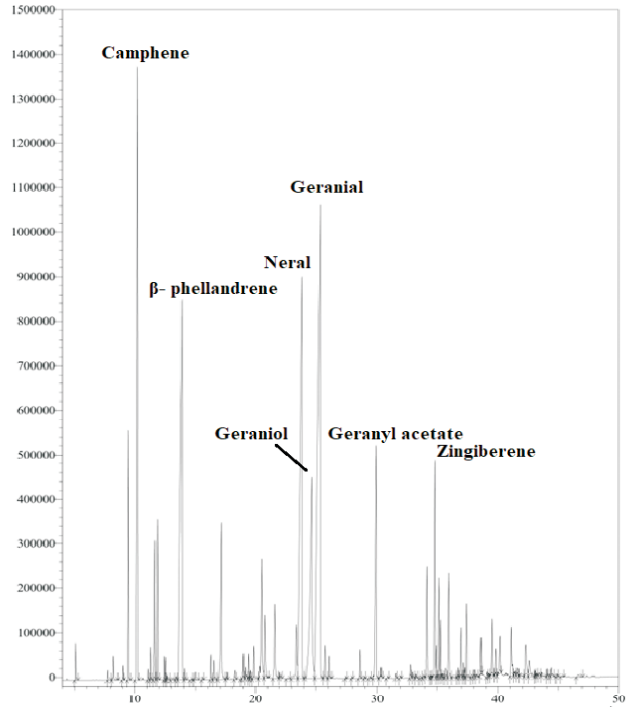

Figure 2: GC chromatogram of oil extracted from sun dried *Z. officinale* rhizomes

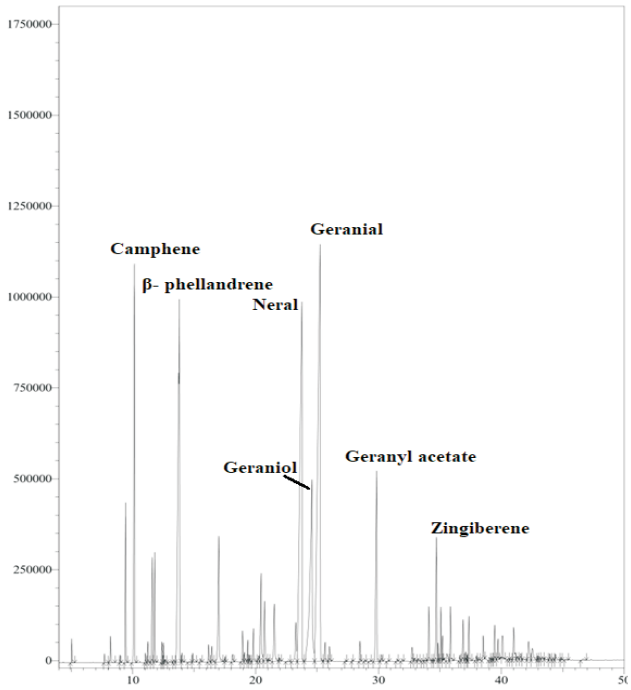

Figure 4: GC chromatogram of oil extracted from shade dried *Z. officinale* rhizomes

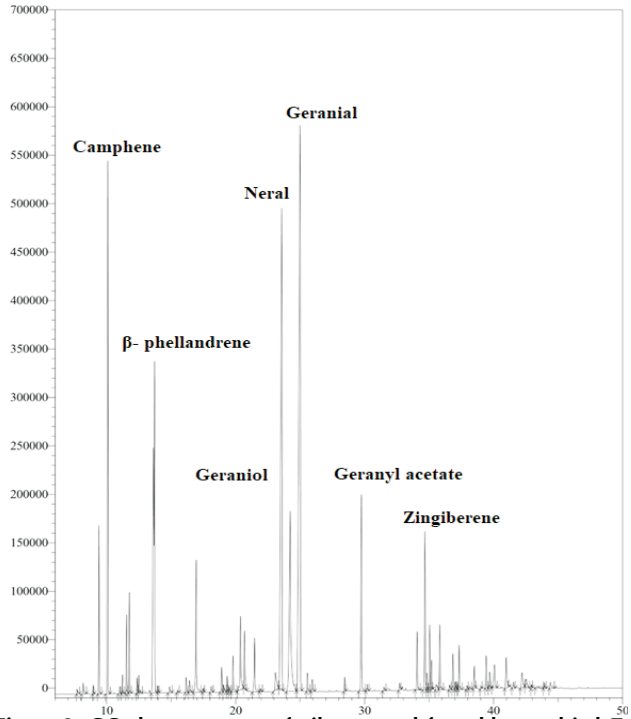

Figure 3: GC chromatogram of oil extracted from blower dried *Z. officinale* rhizomes

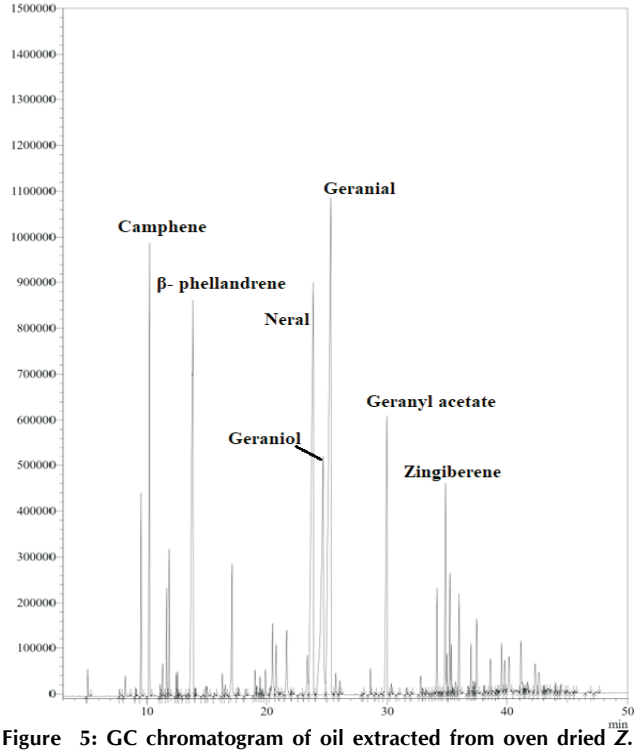

Figure 5: GC chromatogram of oil extracted from oven dried *Z. officinale* rhizomes at 30ºC

and geranyl acetate (5.72%). On the other hand, zingiberene (3.10%) and linalool (2.15%) were observed as minor compounds. Thirty-six hours were required to get the constant weight under this drying method (Figure 5; Table 1).

The essential oil composition of oven-dried *Z. officinale* at 50°C

The analysis of oven-dried rhizomes at 50ºC showed the presence of a total of forty-nine compounds out of which

Table 3: Effect of different drying conditions on the antioxidant activity of *Z. officinale*

S.No.	Samples	DPPH Activity IC_{50} with SD (¼g/mL ± SD)	Metal chelating Activity IC_{50} with SD (¼g/mL ± SD)	H_2O_2 Activity IC_{50} with SD (¼g/mL ± SD)
1.	HSF	$5.09^{c} \pm 0.18$	$4.09^{c} \pm 0.02$	$4.71^{b} \pm 0.02$
2.	HSS	$5.81^{f} \pm 0.11$	$5.83^{f} \pm 0.05$	$5.58^{e} \pm 0.25$
3.	HSB	$5.33^{e} \pm 0.17$	$5.27^{e} \pm 0.23$	$5.56^{d} \pm 0.03$
4.	HSSH	$4.48^{b} \pm 0.15$	$4.01^{b} \pm 0.11$	$4.67^{a} \pm 0.26$
5.	HSOV30	$4.26^{a} \pm .01$	$3.99^{a} \pm 0.02$	$4.66^{a} \pm 0.01$
6.	HSOV50	$5.15^{d} \pm 0.15$	$4.56^{d} \pm 0.21$	$4.84^{c} \pm 0.03$
7.	BHT	8.38	-	13.05
8.	Ascorbic Acid	-	20.66	-

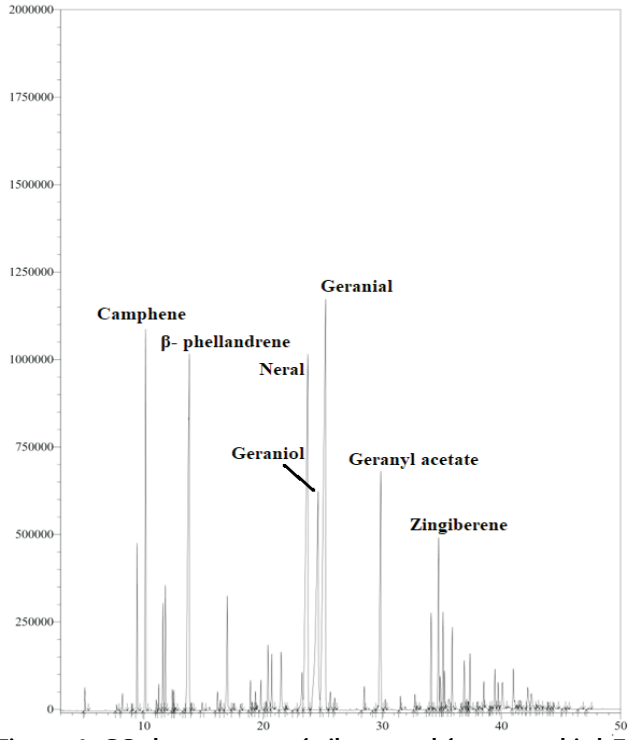

Figure 6: GC chromatogram of oil extracted from oven dried *Z. officinale* rhizomes at 50ºC

93.92% composition was identified by 48 components. The essential oil composition of oven-dried rhizomes showed the presence of geranial (19.74%), neral (14.97%), β-phellandrene (11.20%), geraniol (10.97%), camphene (5.46%), and geranyl acetate (5.67%). Oil also had the presence of minor components such as zingiberene (2.91%), linalool (2.75%), linalool (2.19%), and α-pinene (1.81%). The oil yield under this drying method was 0.70%. To get the constant dried weight of rhizomes, it took 21 hours during drying (Figure 6; Table 1). The primary components of oven-dried essential oil of Chinese variety were α-pinene (8.87%), limonene (16.11%), cis-thujopsene (3.50%), isoaromadendrene (3.47%),

isolongifolol (6.35%), and phytol (3.52%) (Kamal *et al.,* 2023)

Variation in the major compounds

The current investigation found that under all drying settings, the amount of camphene content rose. However, sun drying (8.96%) and blower drying (8.23%) exhibited the greatest camphene contents. Neral content was the highest in the shade-dried sample (16.43%), then at 50ºC (14.97%) and 30ºC in the oven-dried samples (14.85%) respectively (Figure 7; Table 2).

Geraniol concentration in the fresh oil was 10.99%, and all drying methods except oven drying at 50ºC reduced it to 10.97% (non-significantly). However, fresh material showed the highest levels of geranial content (20.13 %). However, fresh material showed the highest levels of geranial content (20.13 %). Bartley and Jacobs, (2000) found that the percentage of *β* –phellandrene increased from 1.30% to 4.68%. Geraniol% was found to decrease after drying in tests conducted in Australia and Tamil Nadu, India respectively (Bartley and Jacobs, 2000); Jayashree *et al.,* 2014).

Bartley and Jacobs, 2000 discovered a similar trend in the neral content of dried ginger from Australia. Aabha *et al.,* 2022 found that fresh oil had the lowest neral concentration (12.47%), whereas shade-dried ginger had the greatest neral level (24.59%) which was found to similar to the present study (13.89-16.43 %)). In comparison to the oil from fresh ginger, the ginger essential oil from the dried rhizomes had less citral content (Jeena *et al.,* 2013), which shows contrasting results from the present study.

Aabha *et al.,* 2022 also found that the geranial content of the shade-dried plant material was determined to be the highest among all dried samples which was in support of the present results. They also found that the geranyl acetate content in fresh rhizome oil was reduced over time (fresh: 12.23 % to

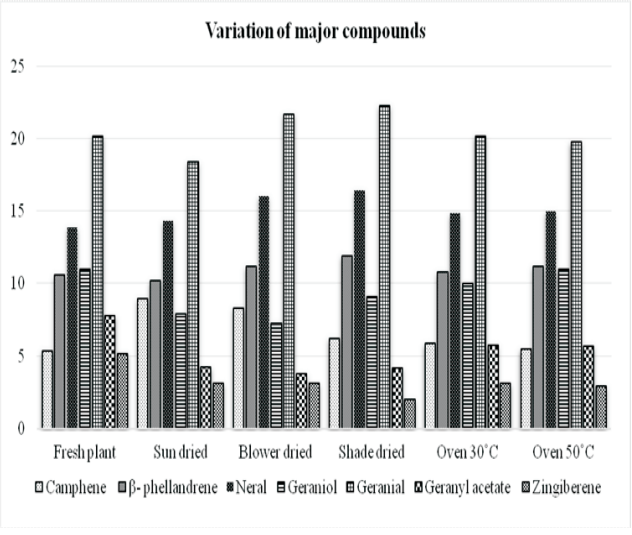

Figure 7: Effect of drying on the major components in *Z. officinale*

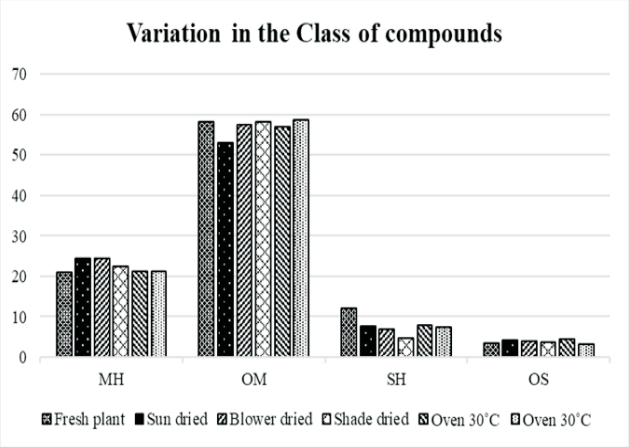

Figure 8: Effect of drying on the class of compounds in *Z. officinale*

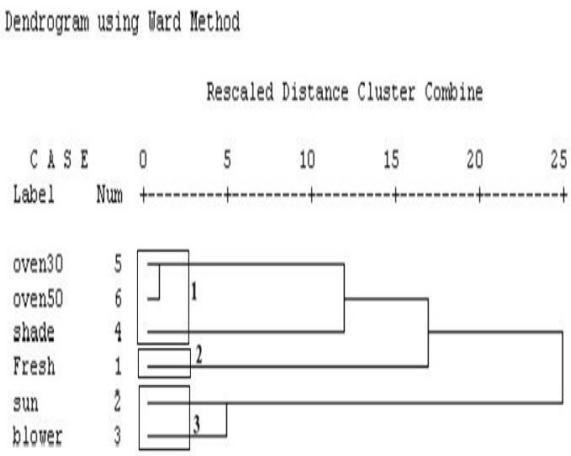

Figure 9: Cluster analysis of drying conditions on the basis of major components

11.87 %,11.45 %,10.93 %,10. 16 % and 1.33% respectively) under different types of drying conditions and shade dried rhizome oil has the least amount (1.33%) of geranyl acetate. Similarly, in the present study, this component was reduced from 7.74 % in fresh to 3.76 % under blower drying conditions.

By the effect of drying, zingiberene content dropped in a prior report from Tamil Nadu, India, (Jayashree *et al.,* 2014) which was in accordance with the present study (5.17 % to 2.01 %). Reports from Australia (Bartley and Jacobs, 2000), China (Huang *et al.,* 2013) and India (Aabha *et al.,* 2022) noticed a considerable rise in zingiberene content (13.44 to 24.58%), (8.8 % to 30.2 %) and 3.19 % to 5.24 % respectively which were in contrast to the present investigation (5.17 % to 2.01 %). Kanyal *et al.,* 2023 also showed the high presence of oxygenated monoterpenes in oven drying at 40ºC.

The essential oil of fresh, oven-dried, and sun-dried ginger samples of Chinese origin were the following compounds: α-pinene, camphene, limonene, longicyclene, copaene, longifolene, β -sesquiphellandrene, alloaromadendrene, α-muurolene, α-curcumene, α -farnesene, and citral (Kamal *et al.,* 2023).

Gururani *et al.,* 2023 showed the presence of hedycaryol (8.7%), α -zingiberene (13.5%), α -santalene (13.5%) curlone (14%), eucalyptol (26.4%) and turmerone (44.3%) as major components in Curcuma longa collected from Kumaun region of Uttarakhand. A study from Maharashtra showed that 1,8-cineole and α-terpinyl acetate are the major component of cardamom essential oil (Sontakke *et al.,* 2019)

Class of compounds

The concentration of oxygenated monoterpenes, monoterpene hydrocarbons, and sesquiterpene hydrocarbons was high in all the essential oil samples (fresh and dried material). In comparison to the other samples, the oven-dried sample at 50°C contained the highest oxygenated monoterpenes (58.73 %). Different types of drying conditions raised the amounts of monoterpene hydrocarbons (21.10 % to 24.51 %), which were lowest in fresh samples (20.90 %) (Figure 8). However, the amount of sesquiterpene hydrocarbons decreased by the effect of drying (12.10% in fresh to 4.75 % in shade dried).

Ginger oil included a high concentration of sesquiterpene hydrocarbons as described by El-Baroty *et al.,* 2010. Sharma *et al.,* 2016 from Ghaziabad, Uttar Pradesh suggested that the essential oil of fresh ginger included a significant concentration of sesquiterpenes (66.66%), monoterpenes (17.28%), and aliphatic chemicals (13.58%). Zingiberene (46.71%) was the most abundant sesquiterpene, followed by valencene (7.61%), β-funebrene (3.09%), and selina-4(14),7(11)-diene (1.03%). Zaid *et al.,* 2022 from Malaysia also observed that monoterpene hydrocarbons (19.7-25.5%), oxygenated monoterpenes (23.6-33.7%), sesquiterpene hydrocarbons (21.3-35.6%), oxygenated sesquiterpenes (1.5-3.9%), and other minor groups of chemicals (0.7-2.7%) were present in four varieties of *Z. officinale* collected from Malaysia.

Cluster analysis

The cluster analysis showed the presence of three clusters:

Cluster I had the presence of shade drying and two drying conditions in the oven at 30ºC and 50ºC. Cluster II had the presence of fresh plant material. However, Cluster III had the presence of Sun and blower drying conditions.

Cluster I: Geranial (19.74-22.26 %), neral (14.85-16.43 %), β-phellandrene (10.79-11.91%), geraniol (9.09-10.97 %), camphene (5.46-6.21 %), geranyl acetate (4.15-5.72 %), zingiberene (2.01-3.10 %)

Cluster II: Geranial (20.13%), neral (13.89%), geraniol (10.99%), β-phellandrene (10.61%), geranyl acetate (7.74%), camphene (5.36%) and zingiberene (5.17%)

Cluster III: Geranial (18.35-21.63%), neral (14.34-16.01%), β-phellandrene (10.18-11.17%), camphene (8.23-8.96%), geraniol (7.25-7.9), geranyl acetate (3.76-4.2 %) and zingiberene (3.09-3.11%).

Activity

According to the DPPH assay, the oven-dried essential oil sample (HSOV30) exhibited the highest antioxidant activity (IC_{50} = 4.26 μg/mL), followed by the HSSH, HSF, HSOV50, HSB, and HSS samples (IC_{50} = 4.48 μg/mL, 5.09 μg/mL, 5.15 μg/mL, 5.33 μg/mL and 5.81 μg/mL, respectively). Metal chelating activity, H_2O_2 and DPPH IC_{50} values were below the standard IC_{50} value (Table 3). The six oil samples demonstrated stronger antioxidant activity (4.26 to 5.81 μg/mL) than the standard, according to their IC_{50} values, which were 8.38 μg/mL for the standard.

For reducing power assay, the order of activity was as follows:

In reducing power assay, samples from the HSSOV30 (IC_{50} = 3.99 μg/mL), HSSH (IC_{50} = 4.01 μg/mL), HSF (IC_{50} 4.09 μg/mL), HSOV50 (IC_{50} = 4.56 μg/mL), HSB (IC_{50} = 5.27 μg/mL) and HSS (IC_{50} = 5.83 μg/mL), groups were examined. Ascorbic acid had an IC_{50} value of 20.66 μg/mL, which was greater than all of the samples of evaluated essential oils (Table 3).

Oven-dried sample at 30°C had the lowest minimum inhibitory concentration (IC_{50}) for the H_2O_2 assay HSOV30 (IC_{50} = 4.66 μg/mL), followed by samples from HSSH (IC_{50} = 4.67 μg/mL), HSF ($IC_{50\,HH}$ = 4.71 μg/mL), HSOV50 (IC_{50} = 4.84 μg/mL), HSB (IC_{50} = 5.56 μg/mL and). HSS (IC_{50} = 5.58 μg/mL), BHT's IC_{50} value was 13.05 μg/mL, the highest (Table 3).

Due to the body's production of free radicals and their connection to various human ailments, scientists' interest in natural antioxidants has grown. Ginger's antioxidant potential is often assumed to be transported by the rhizomes, Rhizomes are therefore, predicted to have greater antioxidant activity than other plant parts (Chan *et al.,* 2011). The essential oil's *in vitro* antioxidant activity of ginger oil, as measured by IC_{50}, followed the order: hydroxyl radical ($OH^{\bullet}$) scavenging > chelating capacity > 2,2-azino-bis-3-ethylbenzothiazoline-6-sulfonic acid radical cation ($ABTS^{\bullet+}$) scavenging (Hofrel *et al.,* 2015). According to the DPPH method, oleoresin had the highest antioxidant activity (72.19% inhibition), followed by essential oil (62.15% inhibition) and crude extract (40.06% inhibition), with BHA serving as a control for comparison (Hofrel *et al.,* 2015). It could be a rich source of natural antioxidants.

Mohd Sahardi and Makpol,2019 suggested that *Z. officinale* could be a possible source of natural antioxidants and can be useful as therapeutic agents in preventing or reducing the progression of aging and age-related oxidative stress-related degenerative illnesses.

In the ABST assay, ginger essential oil also showed antioxidant activity. The radical scavenging activity of 0.87 to 869.2 μg/mL essential oil was 12.1-80.53% versus 7.5-69.3% for 0.08-0.6 μg/mL ascorbic acid. The IC_{50} of ABST (μg/mL) for ginger essential oil was 1.82 ± 0.034 μg/mL. In general, oleoresin had greater antioxidant activity (IC_{50} = 1.82 ± 0.034 mg/mL) than the essential oil (IC_{50} = 110.14 ± 8.44 μg/mL) (Bellik*et al.,* 2014).

Ginger rhizomes utilizing oven and freeze-drying processes may result in an increased content of bioactive components and antioxidant activity. Correlation tests for the biochemical makeup of ginger rhizomes revealed that total phenolics were strongly linked with antioxidant activity ($r = 0.973$, $p < 0.001$) (Ghafoor *et al.,* 2020). The antioxidant assays (ABTS and FRAP) revealed that turmeric essential oil from the same family exhibited the highest antioxidant capacity, while cardamom essential oil had the lowest (Ivanovic *et al.,* 2021). Another study by Kanyal *et al.,* 2023 showed that oven drying at 40°C had high antioxidant activity for *C.glanduliferum*.

CONCLUSION

The present work was designed to find the methods of drying for obtaining high-quality essential oil at the maturity stage. We deduced from the experiment's findings that the drying conditions had a substantial impact on the essential oil composition. When comparing the different drying techniques, it was discovered that sun drying was the quickest and that shade drying required more time for dehydration. Shade drying had a high retention of major components which showed that it is the best method to get quality essential oil. These major compounds of *Z. officinale* can be used for various commercial and industrial purposes. The study showed that oven-dried at 30°C had a high antioxidant potential.

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