

Research Article

Effect of Solar Drying and Vinegar Pretreatment on the Antioxidant Properties and Bioactive Compounds of Sliced Ginger

Roseline Esi Amoah ¹, Sureshkumar Kalakandan ², Faustina Dufie Wireko-Manu ³,
Ibok Oduro ⁴, Firibu Kwesi Saalia ⁵, William Otoo Ellis ⁶,
and Srinivasan Krishnamoorthy ²

¹Ghana Standards Authority, PMB MB 245, Accra, Ghana

²National Institute of Food Technology, Entrepreneurship (NIFTEM), Thanjavur, Tamil Nadu, India

³Department of Food Science and Technology, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana

⁴Department of Food Science and Technology, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana

⁵Department of Food Process Engineering, University of Ghana, P.O. Box LG 77, Accra, Ghana

⁶Department of Food Science and Technology, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana

Correspondence should be addressed to Roseline Esi Amoah; rosarchie@yahoo.com

Received 31 January 2022; Accepted 26 April 2022; Published 11 May 2022

Academic Editor: Shudong He

Copyright © 2022 Roseline Esi Amoah et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

A comparison of concrete solar dryer (CSD) to stainless steel solar dryer (SSSD) in terms of the effect of drying and 10% vinegar pretreatment on antioxidant activities of ginger rhizome using 1,1-diphenyl-2-picrylhydrazyl (DPPH) radical scavenging activity method, Ferric Reducing Antioxidant Power (FRAP) Assay, and total antioxidant methods was investigated. The effect of the two solar dryers and open-sun drying (OSD) on bioactive compound composition of the 10% vinegar pretreated sliced ginger using ethanol and aqueous extracts with GCMS/MS identification was also evaluated. The antioxidant activities of ethanol and aqueous extract of the 10% vinegar pretreated ginger using FRAP, DPPH, and total antioxidant methods were all higher than that of the dried samples, with CSD having the highest antioxidant activities among the dried methods. Drying reduced the main bioactive compound, which is gingerol, from 47.97% in the fresh sample to 32.49% in the OSD sample. The CSD sample demonstrated close likeness to the fresh sample with regard to retaining the highest gingerol and α -zingiberene. Hence, CSD can be adopted for commercial processing of ginger to reduce postharvest losses of the crop.

1. Introduction

Antioxidants are compounds needed in the human body to mitigate issues of oxidative stress which leads to various illnesses and for the preservation of foods against rancidity [1, 2]. Many consumers are seeking to replace synthetic antioxidants with antioxidants from natural sources because synthetic antioxidants such as butylated hydroxyanisole (BHA) and butylated hydroxytoluene (BHT) may cause liver swelling and kidney and lung diseases because they are potential carcinogens [2]. The natural sources of antioxidants are numerous including fruits, vegetables, medicinal plants, and spices such as ginger rhizome [2]. Ginger

(*Zingiber officinale* Roscoe) is the rhizome of the Zingiberaceae family used as a spice and herbal medicine [3–5]. It is well known for its importance as a medicinal spice due to its antioxidant properties. It has anti-inflammatory, antimicrobial, anticancer, antiemetic, and antiplatelet properties, as well as androgenic properties [6, 7].

Ginger rhizome's antioxidant activities and health potency are attributed to the main pungent compounds which are the gingerol [8, 9] and shogaol including related phenolic ketone derivatives [8]. The antioxidant activities of ginger have been well documented [7]. Afshari et al. [1], for example, demonstrated ginger extract's ability to decrease lipid peroxidation and increase plasma antioxidant capacity in

Wistar rats using Ferric Reducing Antioxidant Power (FRAP) Assay and thiobarbituric acid reactive substance (TBARS) measurement. It has also been shown that the dichloromethane extract of ginger rhizome exhibited a higher antioxidant activity than α -tocopherol, while the methanol extract showed almost the same pattern as α -tocopherol by ferric thiocyanate (FTC) method [10]. Thermal processing of fresh ginger beyond a temperature of 60°C can reduce the main compound that accounts for pungency, gingerol, to less potent compounds such as shogaol and zingerone [9, 11] and its like-derivatives that reduces the pungency and aroma intensity. However, ginger is mainly thermally treated to develop products such as dried ginger slices, powder, oleoresin, and ginger oil for international trade [9, 12]. Offei-Okyne et al. [9] compared the samples processed by different drying methods, namely, open sun drying, freeze-drying, and oven drying, to the fresh samples and revealed that freeze-dried samples had a better 1,1-diphenyl-2-picryl-hydrazyl (DPPH) activity than the other dried ones while open-sun-dried ginger also showed superior Ferric Reducing Antioxidant Power (FRAP) Assay to that of the other dried samples of 80% methanol ginger extract. Using the same drying and antioxidant methods but varying the temperatures of the hot air oven and age of maturity of the ginger rhizome, Chumroenphat et al. [13] found that oven drying at 60°C for the 9-month-old ginger rhizome had the highest total phenolic content as well as DPPH and FRAP activities. In their antioxidant activity studies on fresh ginger rhizome, dried vacuum oven samples, and sun-dried ginger samples, measuring Cupric Ion Reducing Antioxidant Capacity (CUPRAC), Gümü Say et al. [14] reported that the fresh samples had higher activity compared to the dried samples. An et al. [15] in a comparative study of five drying methods, viz., air drying (AD) at 60°C, infrared (IR) drying, freeze-drying (FD), Microwave drying (MD), and intermittent microwave and convective drying (IM&CD), using 2,2'-azino-bis-3-ethylbenzthiazoline-6-sulfonic (ABTS) radical cation decolorization assay, DPPH, and FRAP, concluded that IM&CD seemed the best drying method not only because of the high antioxidant activity but also because the drying method uses low energy. In the tropics, countries that enjoy sun energy could explore the use of solar drying to preserve ginger rhizome; however, this must be scientifically studied to ascertain the stability of the antioxidant properties and the phytochemical composition associated with the process. Ginger rhizomes differ in their phytochemical composition according to the maturity and the variety and variation in locality or microclimate [9, 16, 17] as well as the extraction method and method of analysis employed [17]. The aroma of the ginger rhizome also depends on its phytochemical composition. Quality attributes of exported ginger are based on both the aroma intensity and its pungency which is derived from phytochemicals in the volatile essential oils and nonvolatile oleoresin. These volatile compounds in the essential oils include α -zingiberene, α -curcumene, and α -farnesene [8, 9] while the nonvolatile pungent compounds contain the bioactive compounds such as gingerols, shogaols, zingerone, and paradols [7]. Thermal treatment affects both the

pungent and aroma compounds of ginger rhizomes. Some works on the aroma compounds of ginger have been done by many researchers. For instance, Van Beek et al. [18] investigated the Vietnamese ginger for its essential oil components; Onyenekwe and Hashimoto [19] studied the volatile oil composition of Nigerian ginger, while Chumroenphat et al. [13] compared essential oil composition of two ginger rhizome varieties (Bhaisa and Majulay) dried in a hot air oven at 50°C. All the studies used hydrodistillation method to extract the oil and had similar dominant phytochemical compounds such as α -zingiberene, β -sesquiphellandrene, α -farnesene, germacrene D, and geranial. However, the ethanol extract of fresh and dried ginger rhizome which contains both volatile and nonvolatile phytochemical compounds is yet to be assessed for its antioxidant activity and pungent bioactive compounds as well as volatile compounds. This study focused on assessing the effect of solar drying methods and 10% vinegar pretreatment on the antioxidant activities and phytochemical composition of the ethanol extract of the ginger rhizome using a tent-like concrete solar dryer (CSD) and stainless steel solar dryer (SSSD) compared with open sun drying (OSD).

2. Materials and Methods

2.1. Raw Materials. The Ghana yellow variety of fresh ginger rhizome (*Zingiber officinale* Roscoe) was purchased from the open market in Agbogbloshie, Accra, Ghana. The fresh ginger rhizome was transported to the laboratory of Ghana Standards Authority stored in jute sack and hand-cleaned of excess debris. It was divided into two parts; one part remained in Ghana, and the other part was couriered to the India Institute of Food Processing Technology (IIFPT) of Ministry of Food and Processing, India (MOFPI), Thanjavur, Tamil Nadu, and worked on.

2.2. Treatment of the Fresh Ginger. The fresh ginger was submerged into potable water for 2 hours to loosen the soil/debris. It was then thoroughly washed using a soft sponge to clear it of all debris before being rinsed again with water. The washed ginger rhizome was manually cut into slices of about 3–5 mm thickness using a kitchen knife. The sliced ginger was rinsed with water and pretreated by soaking in 10% vinegar for one (1) hour. The vinegar pretreated sliced ginger was spread on stainless steel drying trays (1 × 1 m in length and width). Each tray carried approximately 1 kg of sliced ginger.

2.3. Drying Methods. The 10% vinegar pretreated sliced ginger was divided into two parts; one lot was open-sun-dried (OSD), and the other lot was dried in a stainless steel box dryer (SSSD) in Theni, India. the same procedure was followed for processing ginger and the ginger was dried using a tent-like concrete solar dryer (CSD) located at the Ghana Atomic Energy, Ghana. The temperatures in the solar dryers ranged between 32 and 42°C, 44–58°C, and 25.5–36.6°C for CSD, SSSD, and OSD, respectively. The sample in the CSD dried in 5 days, while the sample in the

SSSD dried in 15 hours and that of the OSD took 3 days to dry. The moisture content was between 8.0 and 12% dry basis (db). The dried ginger samples were stored in a freezer at a temperature of -18°C until ready for the analysis.

The stainless steel box dryer (SSSD) uses indirect solar heating. It comprises a 1.2 m square-like drying chamber made of stainless steel. It has an inlet to allow aeration around the samples and outlet to let out the damp or moist air. Within the chamber are wire netted drying racks for drying the samples. On the inner roof and sides of the drying chamber are drying fans powered by electrical energy to help circulate the heated air. It also has a sensor to measure the drying temperatures. The drying chamber is connected to a solar panel with the dimensions 4.0 m by 2.0 m as shown in Figure 1(a).

The concrete solar dryer is a natural passive solar dryer that is tent-like, constructed with concrete and roofed with Perspex. The dryer has the dimensions of 4.24 m in width and 1.8 m in height. It has two sets of windows and a door to the front. The drying is done on concrete slabs on each side of the chamber with a walkway in between shown Figure 1(b).

2.4. Milling of Ginger Samples. The samples (fresh washed or dried ginger) were pulverized into paste and powder, respectively, using a Philips mill (HR 2113/05, China) at low speed for 30 s and then maximum speed for 60 s just before running each analysis.

2.5. Preparation of Ginger Extract for Antioxidant Analysis. Approximately 10 g of pulverized ginger was placed in a 250 mL conical flask containing 100 mL of either distilled water or absolute ethanol and allowed to stand at room temperature for 24 hrs. It was then filtered with Whatman No. 1 filter paper and centrifuged at 5000 rpm for 20 minutes. The supernatant was then concentrated to one-fourth of the original volume by boiling on a water bath and stored at -18°C in plastic vial for antioxidant analysis.

2.6. DPPH Photometric Assay. The DPPH was measured using the method of Mensor et al. [20]. One millilitre of 0.4 mM 1,1-diphenyl-2-picryl-hydrazyl (DPPH) prepared with ethanol was added to 2.5 mL of 100 $\mu\text{g}/\text{ml}$ of ginger extract. The mixture was first kept in a dark cabinet for 30 min, and the absorbance was read at 518 nm. 1,1-Diphenyl-2-picryl-hydrazyl (DPPH), butylated hydroxytoluene (BHT), and ascorbic acid were purchased from HiMedia (India) and used as positive standards at 100 $\mu\text{g}/\text{ml}$ concentrations. Blank samples contained 1 mL ethanol and 2.5 mL of 100 $\mu\text{g}/\text{ml}$ ginger extract; control sample contained 1 mL of 0.4 mM DPPH + 2.5 mL ethanol.

The antiradical activity (AA) was determined using the formula below:

$$\text{AA}\%_{(518\text{nm})} = \frac{(\text{Absorbance of sample} - \text{Absorbance of control})}{\text{Absorbance of control}} \times 100. \quad (1)$$

2.7. Ferric Reducing Antioxidant Power (FRAP) Assay. The reducing power of the aqueous and ethanol extracts of fresh and dried ginger rhizomes was measured using the method of Oyaizu [21]. 0.5 mL of extract (concentration of 100 $\mu\text{g}/\text{ml}$) was mixed with 2.0 mL of phosphate buffer (0.2 M, pH 6.6) and 2.5 mL of potassium ferricyanide (1%). The mixtures were incubated at 50°C for 20 min, and 2.5 mL of trichloroacetic acid (10% TCA) was added to stop the reaction after it had cooled to room temperature. The mixtures were centrifuged at 650 rpm for 10 min. Then, 2.5 mL of the supernatant was mixed with 2.5 mL of distilled water and 0.5 mL of ferric chloride. The mixture was incubated at room temperature for 10 min, and the absorbance was measured at 700 nm in a spectrophotometer (Shimadzu, UV-1800, Japan). Phosphate buffer was used as blank. Lower absorbance of the reaction mixture indicates greater reducing power. Ascorbic acid and BHT purchased from HiMedia, India, were used as control.

2.8. Total Antioxidants (Phosphomolybdenum Assay). A 0.3 mL volume of aqueous and ethanolic fresh and dried ginger extracts each was taken in a tube and mixed with 3 ml

of reagent solution containing 0.6 M sulphuric acid, 28 mM sodium phosphate, and 4 mM ammonium molybdate and incubated at 95°C for 90 min. The tubes were allowed to cool at room temperature, and absorbance was measured at 695 nm in a Shimadzu UV-spectrophotometer (UV-1800). Ascorbic acid was used as a reference standard. The absorbance of the mixture was then measured at 695 nm, with distilled water or ethanol as blank for the aqueous and ethanol extract, respectively, as described by Prieto et al. [22]. The antioxidant activity was expressed as the number of Gram equivalents of ascorbic acid.

2.9. Ginger Extract Preparation for Quantitative Phytochemical Analysis (GC-MS Method). Ten grams each of pulverized fresh and dried 10% vinegar ginger rhizome were dispersed in 20 mL of absolute ethanol (98% purity) and allowed to stand at room temperature for 24 hrs. The dispersion obtained was then filtered with blotting paper and Whatman No. 1 filter paper containing 5.0 g sodium sulphate to absorb the moisture. The filtrate was then concentrated to 1 ml by flushing nitrogen gas into it. The concentrated filtrate was used for GCMS/MS analysis.



(a)



(b)

FIGURE 1: (a) Pictorial representation of the stainless steel solar dryer (SSSD). (b) Pictorial representation of the tent-like concrete solar dryer (CSD).

2.10. GCMS/MS Analysis of the Phytochemical Composition of Ginger Extract. The phytochemical composition of the fresh and dried ginger extracts was analyzed by the method of Srinivasan and Kumaravel [23] and Ravichandran et al. [24]. The GCMS/MS used was a Bruker Scion 436-GC (United States of America) model coupled with a Triple quadruple mass spectrophotometer with fused silica capillary column BR-5MS (5% diphenyl/95% dimethyl polysiloxane). The column had a length of 30 m, internal diameter of 0.25 mm, and a thickness of 0.25 μm . Helium gas of 99.999% purity was used as the carrier gas at a constant flow rate of 1 mL/min, and an injection volume of 2 μl was employed (split ratio of 10:1). The column oven temperature was programmed as follows: 80°C, hold for 2 min; up to 160°C at the rate of 20°C/min, no hold; up to 280°C at the rate of 5°C/min, no hold; up to 300°C at the rate of 20°C/min, 10 min hold; and injector temperature of 280°C. Total GC running time was 36 min. This last increase was to clean the column from any residues. The mass spectrometer was operated in the positive electron ionization (EI) mode with ionization energy of 70 eV. The solvent delay was 0–3.0 min. A scan interval of 0.5 s and fragments from m/z 50 to 500 Da were programmed. The inlet temperature was set at 280°C, and source temperature was 250°C. The relative percentage amount of each component was calculated by comparing its average peak area to the total areas. MS Workstation 8 was adopted to handle mass spectra and chromatograms. The library database of National Institute of Standards and Technology (NIST) having more than 62,000 patterns (NIST Version 2.0) was used for identifying the chemical components. The spectrum of the unknown component was compared with the spectrum of the known components stored in the NIST library.

2.11. Statistical Analysis. One-Way Analysis of Variance (ANOVA) test at $p \leq 0.05$ was used to determine significant differences between treatments in antioxidant ability, in triplicate, using the JMP statistical software (from SAS). The pairwise comparison among means was done using Tukey–Kramer HSD Test.

3. Results and Discussion

3.1. Antioxidant Activities. The results of the antioxidant activity using 1,1-diphenyl-2-picryl-hydrazyl (DPPH),

Ferric Reducing Antioxidant Power (FRAP) Assay, and total antioxidant power (molybdenum method) assay of the ginger using both ethanol and aqueous extracts is shown in Table 1. The findings of this study showed that the DPPH scavenging ability, FRAP, and total antioxidant activities of the fresh sample were significantly ($p \leq 0.05$) higher, compared to the antioxidant activities of all the solar-dried samples irrespective of the solvent used for extraction. This agrees with the findings of Zhang et al. [25] and Jolad et al. [26], who reported that the major phenolic compound responsible for antioxidant activity in ginger rhizome, gingerol, reduces with heat treatment.

It was observed that there was no significant difference in the DPPH scavenging activity between the two solar-dried ginger samples, CSD and SSSD, although both solar-dried samples showed significant differences from OSD sample (Table 1). The pattern recorded by this study was different from the work done by Chumroenphat et al. [13] and Offei-Okyne et al. [9], who showed a higher DPPH and FRAP activity of the dried samples relative to the fresh sample. However, in their work, they did not state if the computation of results was done on dry basis to allow for a common level of comparison.

The DPPH activity of the ethanol extract of the fresh ginger rhizome was higher than that of both ascorbic acid and BHT, yet that of CSD and SSSD samples compared very well with ascorbic acid, corroborating the work done by Ziaur-Rehman et al. [27], who showed that the antioxidant activity of ginger rhizome at various concentrations exhibited almost equal abilities to those of BHT. Furthermore, these findings confirm that ginger rhizomes could be a better alternative to synthetic antioxidants that pose health problems to humans [8, 27].

The FRAP and total antioxidant analysis of the ethanol extract of CSD sample were significantly higher than those of the SSSD sample as well as the OSD sample. The total antioxidant ability of the aqueous extract of the CSD sample compared to the SSSD sample (0.07 ± 0.00 ; 0.08 ± 0.00) was not statistically different. The study shows that even though the CSD sample took a longer period (5 days) than OSD (3 days) and SSSD (15 hrs), the antioxidant activity was generally better than that of all the other dried samples.

The aqueous total antioxidant activity of the ginger rhizome followed the same pattern as the ethanol activity

TABLE 1: Antioxidant activity of ginger rhizome at an extract concentration of 100 $\mu\text{g/ml}$ on dry basis (db) using different solar drying methods compared to ascorbic acid and butylated hydroxytoluene at concentration of 100 $\mu\text{g/ml}$.

Treatment	DPPH ethanol%	FRAP (mg equivalence of AA or BHT)		Total antioxidant (mg equivalence of AA or BHT)	
		Ethanol	Aqueous	Ethanol	Aqueous
Fresh	104.45 \pm 0.35 ^a	0.55 \pm 0.01 ^a	0.23 \pm 0.01 ^a	0.33 \pm 0.01 ^a	0.22 \pm 0.01 ^a
SSSD	95.30 \pm 0.42 ^b	0.21 \pm 0.01 ^c	0.12 \pm 0.00 ^b	0.18 \pm 0.00 ^c	0.08 \pm 0.00 ^b
CSD	95.57 \pm 0.35 ^b	0.35 \pm 0.00 ^b		0.20 \pm 0.01 ^b	0.07 \pm 0.00 ^b
OSD	78.90 \pm 0.60 ^c	0.22 \pm 0.00 ^c	0.11 \pm 0.00 ^b	0.17 \pm 0.00 ^c	0.04 \pm 0.00 ^c
Ascorbic acid	95.30 \pm 0.42	0.92 \pm 0.00	0.79 \pm 0.02	0.49 \pm 0.00	0.57 \pm 0.00
BHT	85.51 \pm 0.70	0.49 \pm 0.00			

Data is represented as mean \pm standard deviation of three replicate readings. Means in a column with different superscripts are significantly different at $p \leq 0.05$. CSD: tent-like concrete solar-dried ginger rhizome. SSSD: stainless steel solar-dried ginger rhizome. OSD: open-sun-dried ginger rhizome. FRAP: Ferric Reducing Antioxidant Power Assay. DPPH: 2,2-diphenyl-1-picrylhydrazyl. AA: ascorbic acid. BHT: butylated hydroxytoluene.

where the fresh sample recorded the highest ability and was significant compared to all the solar drying methods except that there were no significant differences between the CSD and SSSD samples. Among the three dried ginger rhizome samples, the open-sun-dried sample had the least activity regarding the total antioxidant ability of the aqueous extract, which was significant compared to all the other drying samples.

The antioxidant activities of the aqueous extract were lower than that of the ethanol extract which was expected since gingerol, the main phenolic compound in ginger, is more soluble in ethanol than water. This is consistent with the findings of Offei-Okyne et al. [9], who showed that the increase in polarity of extraction solvent increases extract yield and largely increases antioxidant activities, and Yeh et al. [17], who demonstrated that ethanol extracts of ginger rhizomes were better antioxidants than aqueous extracts. The antioxidant analysis of the ginger extract was the lowest in the OSD sample irrespective of the extraction solvent and method of analysis used.

3.2. Phytochemical Composition of Ethanol Extract of Ginger Rhizome. The pungent and flavor compounds of the ethanol extract of the Ghana yellow ginger rhizome isolated by gas chromatography mass spectrometry/mass spectrometry (GCMS/MS) and identified using NIST library (version 2.0) are presented in Table 2, and the chromatograms are provided in Figure 2. There were 34, 32, 38, and 41 peaks identified for the fresh, CSD, SSSD, and OSD samples, respectively; however, there was an unknown peak for all the drying methods. Apart from the CSD sample, the other two drying methods recorded more compounds than the fresh sample confirming the findings of Baokang et al. [28] and Ding et al. [29] that drying results in the presence or absence of certain flavors.

All the different drying methods recorded gingerol as the major component of the ethanol extract of the ginger rhizome. The fresh sample recorded the highest amount of gingerol (47.97%) which has been shown to be the main pungent and phenolic compound than the percentage fractions recorded by the dried samples, corroborating Zhang et al. [25], Balladin et al. [30], and Jolad et al. [26] regarding the reduction of gingerol during heat treatment.

The CSD sample recorded the second highest gingerol fraction (34.98%) as shown in Table 2, with SSSD and OSD having a similar percentage fraction. The SSSD sample had the least gingerol percentage fraction (32.49%) which could be due to the high drying temperature. This explains the high antioxidant activity in the fresh sample as compared to the dried products irrespective of the antioxidant method and solvent employed. Furthermore, the CSD sample has slightly higher antioxidant activities generally compared to SSSD and OSD, which is attributed to the same reason of a higher gingerol [7, 31]. Apart from gingerol, the fresh sample exhibited an extensive difference in its first five dominant compounds compared to those of the dried samples—showing compounds such as 1-(2,4-dihydroxyphenyl)-2-(4-methoxy-3-nitrophenyl)ethanone; 7-oxabicyclo[4.1.0]heptane, 1-(1,3-dimethyl-1,3-butadienyl)-2,2,6-trimethyl-(E)-; 6-(3,5-dimethyl-furan-2-yl)-6-methyl-hept-3-en-2-one; and α -citral; α -zingiberene *cis-Z*- α -bisabolene epoxide; β -sesquiphellandrene; and zingerone in the dried samples. Conversely, the first 5 dominant components of the dried samples differed slightly with the different drying methods. Gingerol and α -zingiberene were the first two compounds isolated for all 3 drying methods. Besides, CSD recorded *cis-Z*- α -bisabolene epoxide, β -sesquiphellandrene, and zingerone as the other 3 top compounds. SSSD recorded β -sesquiphellandrene, α -himachalene, and α -curcumene, while OSD sample showed the other 3 dominant compounds as zingerone, β -sesquiphellandrene, and 1-(2,4-dihydroxyphenyl)-2-(4-methoxy-3-nitrophenyl)ethanone. The fresh sample showed vast differences in the first 5 compounds as compared to studies done by Bartley and Jacobs [32], Toure and Xiaoming [33], and Nogueira de Melo et al. [34], with the identification of compounds such as α -curcumene (59%), β -myrcene (14%), 1,8-cineol (8%), citral (7.5%), α -zingiberene, α -farnesene, geranial, and β -sesquiphellandrene as the top 5 compounds in their studies. Most of these studies isolated α -zingiberene as the chief flavor component with a percentage in the range of 13.44–31.1% which is higher than the percentages recorded in the Ghana yellow variety (2.07%). Moreover, the Ghana fresh yellow ginger showed similar compounds with both Chinese and Guinean ginger rhizome extracted with hydrodistillation such as linalool, borneol, terpineol, decanal, citral, γ -elemene, and β -phellandrene in different

TABLE 2: Pungent and flavor compounds identified from the ethanol extract of Yellow ginger using different drying methods on dry basis (db).

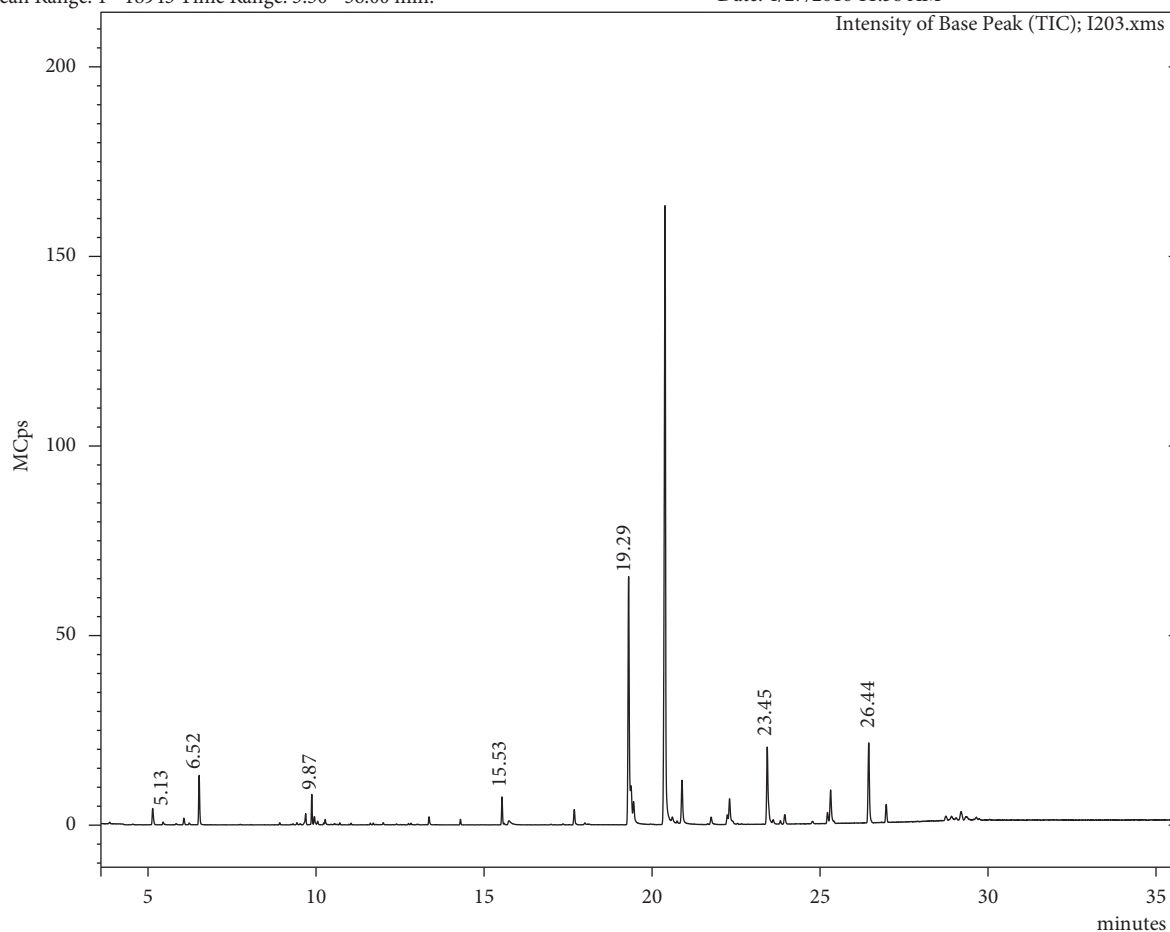
Retention time (min)	Phytochemicals identified	Mol. formula/ wt	Fraction (%)			
			Fresh	CSD	SSSD	OSD
3.58	Linalool	C ₁₀ H ₁₈ O (154)	0.78	—	0.15	0.07
5.14	<i>endo</i> -Borneol	C ₁₀ H ₁₈ O (154)	0.76	1.0	0.64	1.23
5.45	α -Terpineol	C ₁₀ H ₁₈ O (154)	0.45	0.13	0.29	0.16
5.53	Decanal	C ₁₀ H ₂₀ O (156)	—	0.24	0.29	0.12
6.07	β -Citral	C ₁₀ H ₁₆ O (152)	0.95	0.40	0.36	0.41
6.22	2,6-Octadien-1-ol, 3,7-dimethyl-, (Z)-	C ₁₀ H ₁₈ O (154)	0.19	—	—	—
6.52	α -Citral	C ₁₀ H ₁₆ O (152)	3.29	1.08	0.46	1.04
8.29	<i>alfa</i> -Copaene	C ₁₅ H ₂₄ (204)	—	—	0.26	0.15
8.45	Cyclohexane, 1-ethenyl-1-methyl-2,4-bis(1-methylethenyl)-, [1S-(1 α , 2 β , 4 β)]-	C ₁₅ H ₂₄ (204)	—	—	0.47	0.14
8.61	<i>trans</i> - α -Bergamotene	C ₁₅ H ₂₄ (204)	—	—	0.18	0.11
9.02	γ -Elemene	C ₁₅ H ₂₄ (204)	0.18	—	0.44	0.15
9.25	<i>cis</i> - β -Farnesene	C ₁₅ H ₂₄ (204)	0.17	—	0.39	0.16
9.43	Spiro[5.5]undec-2-ene, 3,7,7-trimethyl-11-methylene-, (-)-	C ₁₅ H ₂₄ (204)	0.51	—	—	—
9.51	Alloaromadendrene	C ₁₅ H ₂₄ (204)	—	—	0.26	0.09
9.69	α -Curcumene	C ₁₅ H ₂₂ (202)	1.76	1.72	3.40	2.29
9.78	Germacrene D	C ₁₅ H ₂₄ (204)	—	0.61	1.4	0.62
9.95	Guaia-1(10), 11-diene	C ₁₅ H ₂₄ (204)	1.6	—	—	—
9.96	α -Farnesene	C ₁₅ H ₂₄ (204)	—	2.98	—	—
9.97	α -Zingiberene	C ₁₅ H ₂₄ (204)	2.07	19.02	18.47	15.77
10.06	<i>alpha</i> -Himachalene	C ₁₅ H ₂₄ (204)	0.70	2.43	7.30	2.54
10.11	γ -Muurolene	C ₁₅ H ₂₄ (204)	—	—	—	—
10.18	(+)- <i>epi</i> -Bicyclosquiphellandrene	C ₁₅ H ₂₄ (204)	—	0.31	—	—
10.33	β -Sesquiphellandrene	C ₁₅ H ₂₄ (204)	0.82	3.68	11.07	3.82
10.71	1,6,10-Dodecatrien-3-ol, 3,7,11-trimethyl-, (E)-	C ₁₅ H ₂₆ O (220)	0.33	—	0.65	0.32
10.88	4-((1E)-3-Hydroxy-1-propenyl)-2-methoxyphenol	C ₁₀ H ₁₂ O ₃ (180)	—	1.30	—	0.61
11.61	α -Acorenol	C ₁₅ H ₂₆ O (222)	0.37	—	—	—
11.70	1H-Cycloprop[e]azulene, 1a,2,3,4,4a,5,6,7b-octahydro-1,1,4,7-tetramethyl-, [1aR-(1a α ,4 α ,4a β ,7b α)]-	C ₁₅ H ₂₄ (204)	0.41	—	—	—
11.77	Unknown	—	—	12.71	0.04	5.30
12.04	2-Naphthalenemethanol, decahydro- $\alpha,\alpha,4a$ -trimethyl-8-methylene-, [2R-(2 $\alpha,4\alpha,8a\beta$)]-	C ₁₅ H ₂₆ O (222)	0.76	0.22	0.86	0.25
12.28	<i>cis</i> -Sesquisabinene hydrate	C ₁₅ H ₂₆ O (222)	—	0.30	1.05	0.35
12.40	1H-3a,7-Methanoazulen-5-ol, octahydro-3,8,8-trimethyl-6-methylene-	C ₁₅ H ₂₄ O (220)	0.27	0.19	0.55	0.24
13.37	2S,4aS,5R,8aS)-2-Allyl-5-((Z)-pent-2-en-4-yn-1-yl) decahydroquinoline	C ₁₇ H ₂₅ N (243)	0.45	—	—	—
13.74	<i>cis</i> -Z- α -Bisabolene epoxide	C ₁₅ H ₂₄ O (220)	—	3.64	0.77	0.23
14.07	4-(1-Hydroperoxy-2,2-dimethyl-6-methylene-cyclohexyl)-pent-3-en-2-one	C ₁₄ H ₂₂ O ₃ (238)	—	—	0.67	0.23
14.29	Phthalic acid, isobutyl octyl ester	C ₂₀ H ₃₀ O ₄ (334)	0.05	—	—	—
15.52	Geranyl-p-cymene	C ₂₀ H ₃₀ (270)	0.74	0.14	0.28	2.64
15.60	n-Hexadecanoic acid	C ₁₆ H ₃₂ O ₂ (256)	0.36	—	—	—
15.74	Anthrone	C ₁₄ H ₁₀ O (194)	0.81	—	—	—
15.87	Geranyl- α -terpinene	C ₂₀ H ₃₂ (272)	—	0.09	0.42	0.09
16.58	1,6,10,14-Hexadecatetraen-3-ol, 3,7,11,15-tetramethyl-, (E,E)-	C ₂₀ H ₃₄ O (290)	—	0.11	0.42	0.09
17.67	(-)-Nortrachelogenin	C ₂₀ H ₂₂ O ₇ (374)	0.66	—	—	—
17.99	9,12-Octadecadienoic acid (Z, Z)-	C ₁₈ H ₃₂ O ₂ (280)	0.03	—	—	—
18.30	<i>trans</i> -Sesquisabinene hydrate	C ₁₅ H ₂₆ O (222)	—	0.10	0.56	0.09
19.25	Zingerone	C ₁₁ H ₁₄ O ₃ (194)	2.77	2.96	2.31	8.15
19.44	3-Decanone, 1-(4-hydroxy-3-methoxyphenyl)-	C ₁₇ H ₂₆ O ₃ (278)	—	1.05	0.78	0.99
22.30	2-Heptanone, 6-(3,5-dimethyl-2-furanyl)-6-methyl-	C ₁₄ H ₂₂ O ₂ (222)	1.25	—	—	—
21.92	Gingerol	C ₁₇ H ₂₆ O ₄ (294)	47.97	34.98	32.49	33.33
23.10	3-Benzofuranmethanol, 2,3-dihydro-2-(4-hydroxy-3-methoxyphenyl)-5-(3-hydroxy-1-propenyl)-7-methoxy-	C ₂₀ H ₂₂ O ₆ (358)	—	0.60	1.00	0.73

TABLE 2: Continued.

Retention time (min)	Phytochemicals identified	Mol. formula/ wt	Fraction (%)			
			Fresh	CSD	SSSD	OSD
23.43	7-Oxabicyclo[4.1.0]heptane, 1-(1,3-dimethyl-1,3-butadienyl)-2,2,6-trimethyl-, (E)-	C ₁₅ H ₂₄ O (220)	7.79	1.33	1.56	2.12
24.81	Benz[e]azulene-3,8-dione,3a, 4,6a,7,9,10,10a,10b-octahydro-3a,10a-dihydroxy-5-(hydroxymethyl)-7-(1-hydroxy-1-methylethyl)-2,10-dimethyl-, [3aR-(3aα,6aα,7α,10β,10aβ,10bβ)]-	C ₂₀ H ₂₈ O ₆ (364)	1.35			
24.85	Aspidinol	C ₁₂ H ₁₆ O ₄ (224)	—	2.20	2.58	2.51
25.31	2,4-Dihydroxyphenylbenzyl ketone		1.74			
26.58	6-(3,5-Dimethyl-furan-2-yl)-6-methyl-hept-3-en-2-one	C ₁₄ H ₂₀ O ₂ (220)	7.56	2.78	3.02	4.10
27.10	1-(2,4-Dihydroxyphenyl)-2-(4-methoxy-3-nitrophenyl)ethanone	C ₁₅ H ₁₃ NO ₆ (303)	10.35	2.38	2.03	4.27
27.81	2H-Pyran, 2-(7-heptadecynloxy) tetrahydro-	C ₂₂ H ₄₀ O ₂	—	0.24	0.31	0.13
31.02	Cannabinol, trifluoroacetate	C ₂₃ H ₂₅ F ₃ O ₃ (406)	—	—	—	0.29
31.92	Spiro[3-cyclohexene-1,2'-[2H]furo[3,2-f][1]benzopyran]-2,5-dione, 1',7'-dihydro-3,4,4',5',7',7'-hexamethyl-1'-(2-methylpropenyl)-	C ₂₆ H ₃₀ O ₄ (406)	—	—	—	0.30
31.92	2H-3,9a-Methano-1-benzoxepin, octahydro-2,2,5a,9-tetramethyl-,[3R-(3α,5αα,9α,9αα)]-	C ₁₅ H ₂₆ O (222)	—	0.33	0.77	1.44
31.94	2(3H)-Furanone, dihydro-3,4-bis[(4-hydroxy-3-methoxyphenyl)methyl]-, (3R-trans)-	C ₂₀ H ₂₂ O ₆ (358)	—	0.71	1.00	2.31

File: c:\brukerws\data\april 2016\27.04.2016\i203.xms
 Sample: I203
 Scan Range: 1 - 18943 Time Range: 3.50 - 36.00 min.

Operator: IICPT
 Date: 4/27/2016 11:58 AM

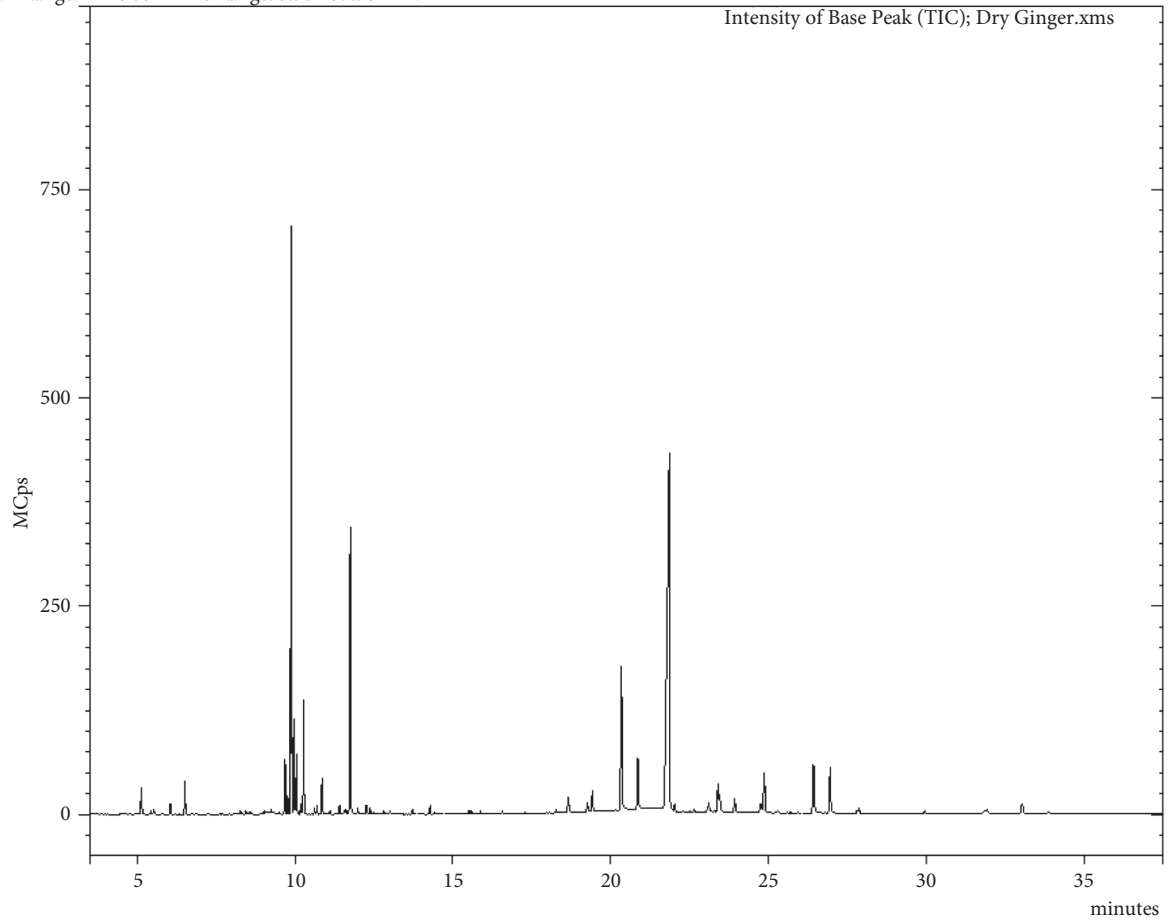


(a)

FIGURE 2: Continued.

File: c:\brukerws\data\march 2016\11.03.2016\dry ginger.xml
Sample: Dry Ginger
Scan Range: 1 - 19662 Time Range: 3.50 - 37.50 min.

Operator: IICPT
Date: 3/11/2016 12:37 PM

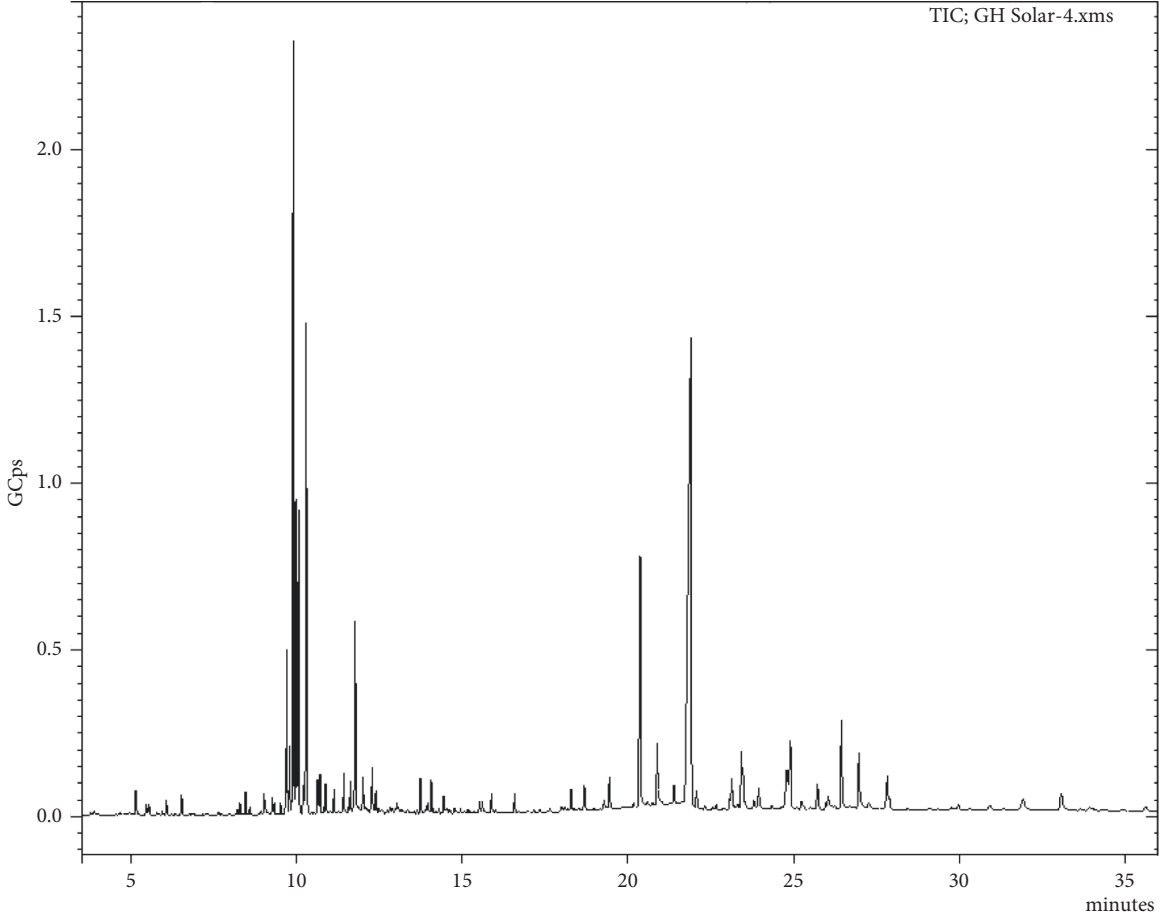


(b)

FIGURE 2: Continued.

File: c:\brukerws\data\may 2016\18.05.2016\gh solar-4.xms
Sample: GH solar-4
Scan Range: 1 - 18265 Time Range: 3.50 - 36.00 min.

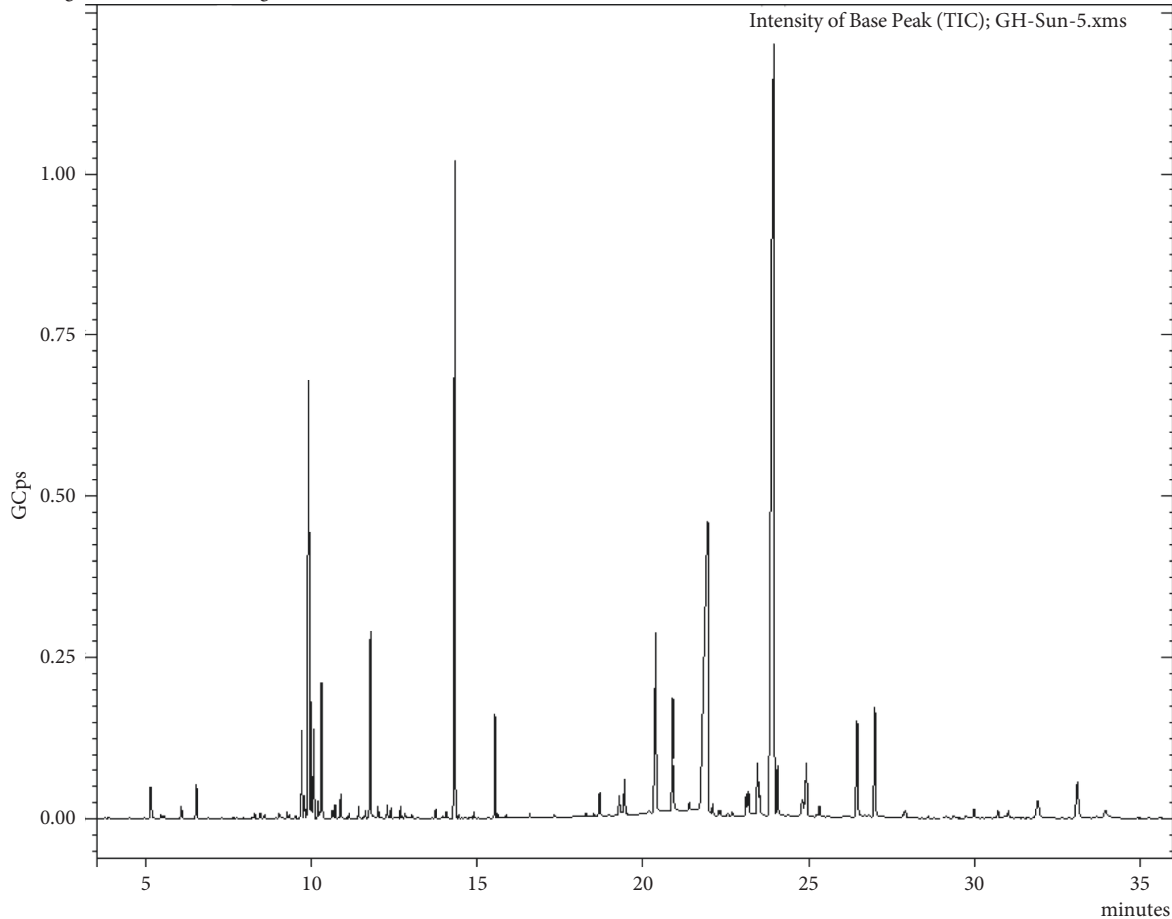
Operator: IICPT
Date: 5/18/2016 5:30 PM



(c)
FIGURE 2: Continued.

File: c:\brukerws\data\may 2016\18.05.2016\gh-sun-5.xms
 Sample: GH-Sun-5
 Scan Range: 1 - 18262 Time Range: 3.50 - 36.00 min.

Operator: IICPT
 Date: 5/18/2016 6:13 PM



(d)

FIGURE 2: (a) Chromatograms of the volatile and bioactive compounds of the ethanol extract of fresh ginger rhizome. (b) Chromatograms of the volatile and bioactive compounds of the ethanol extract of CSD ginger rhizome. (c) Chromatograms of the volatile and bioactive compounds of the ethanol extract of SSSD ginger rhizome. (d) Chromatograms of the volatile and bioactive compounds of the ethanol extract of OSD ginger rhizome.

quantities [33]. The fresh ginger rhizome in this study also showed a remarkable difference between the isolated compounds from two varieties of fresh ginger rhizomes grown in Ghana, in which geranial, neral, and α -zingiberene were chiefly isolated as the main components for variety 2 and zerumbone for variety 1 [35]. The dried samples, on the other hand, exhibited similar compounds to those in the work done by Van Beek et al. [18] on Sri Lankan ginger variety and Onyenekwe and Hashimoto [19] on Nigerian ginger variety where zingiberene (29.5%), sesquiphellandrene (18.4%), farnesene (6.46%), germacrene D (3.58%), and geranial (3.46%) were isolated just as Bartley and Jacobs [32] from Australian ginger. However, gingerol and zingerone were not among the top five compounds in their work compared to this study; the difference could be attributed to the differences in extract used. The extract used for this study contains both volatile and nonvolatile compounds [17]. The terpene or volatile components of ginger which are responsible for its aroma include α -zingiberene,

β -bisabolene, α -farnesene, β -sesquiphellandrene, and α -curcumene, while the nonvolatile compounds responsible for ginger rhizome pungency include gingerol, paradols, and/or zingerone [9]. Van Beek et al. [18], Onyenekwe and Hashimoto [19], Bartley and Jacobs [32], Juliani et al. [35], and Toure and Xiaoming [33] examined ginger oil extracted by hydrodistillation; hence, the identified compounds are largely terpene or volatile compounds as opposed to this study examining the alcoholic extract of ginger rhizome which contains both volatile and nonvolatile compounds.

Drying may also cause the appearance or disappearance of certain compounds as well as increasing or decreasing the percentage fractions of isolated compounds as shown in Table 2. From the fresh sample, the following were isolated, notably: 2,6-octadien-1-ol, 3,7-dimethyl-, (Z)-; spiro[5.5]undec-2-ene, 3,7,7-trimethyl-11-methylene-, (-)-; guaia-1(10),11-diene; n-hexadecanoic acid; anthrone; (-)-nor-trachelogenin; 2-heptanone, 6-(3,5-dimethyl-2-furanyl)-6-methyl-; benz[e]azulene-3,8-dione, 3a, 4,6a,7,9,10,10a,10b-o

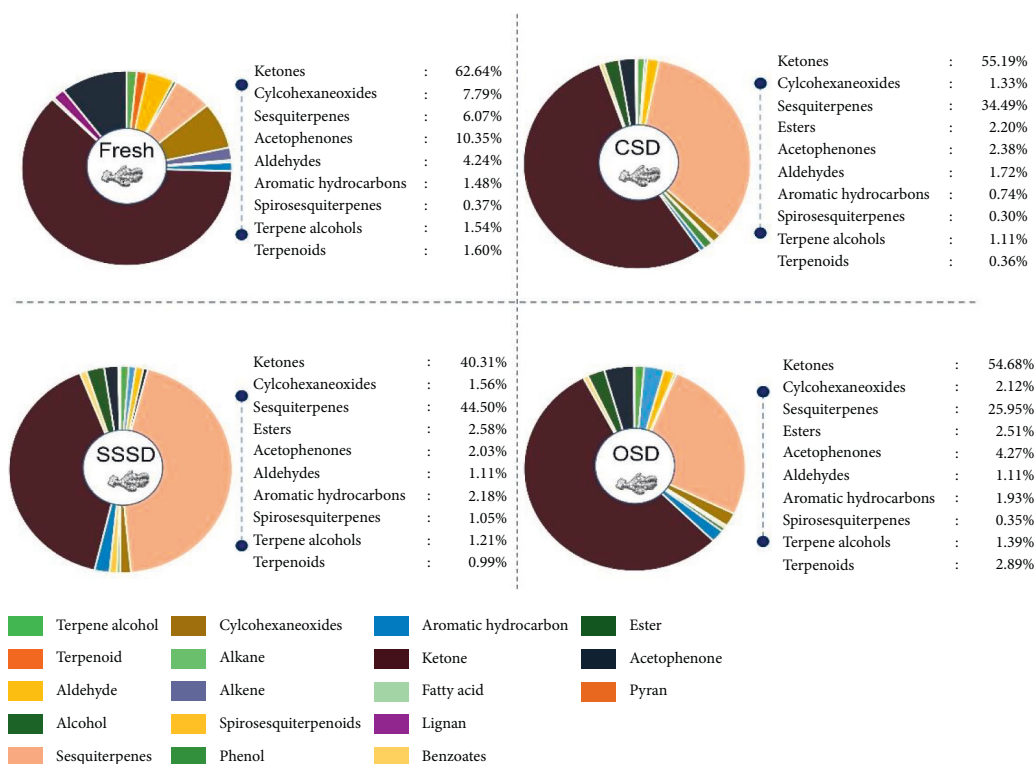


FIGURE 3: Categorization of the Pungent and flavor compounds from the fresh and dried ginger slices.

ctahydro-3a,10a-dihydroxy-5-(hydroxymethyl)-7-(1-hydroxy-1-methylethyl)-2,10-dimethyl-, [3aR-(3 α ,6 α ,7 α ,10 β ,10 α ,10 β)]-; and 2,4-dihydroxyphenylbenzyl ketone; these were not isolated in any of the dried samples. These may account for the unique flavor characteristics of the Ghana yellow fresh ginger rhizome.

Compounds such as *trans*- α -bergamotene, α -copaene, alloaromadendrene, and 4-(1-hydroperoxy-2,2-dimethyl-6-methylene-cyclohexyl)-pent-3-en-2-one were also isolated in only SSSD and OSD samples and not the fresh or CSD sample. In this study, the CSD sample had the highest α -zingiberene (19.02%) component among the drying methods which is the major aroma compound of ginger with OSD sample having the least content (15.77%). α -Farnesene is an indication of typical ginger oil [33]; its isolation in only CSD sample being as high as 2.98% is another indication of CSD being a good drying method for preserving ginger aroma. Both α -citral and β -citral are compounds responsible for the “citrus-like” flavor of fresh ginger the same as geranial and neral [36]; however, even though they were all isolated in all samples, the percentage fractions were greatly reduced in the dried samples (fresh, 3.29, 0.95%; CSD, 1.08, 0.40%; SSSD, 0.46, 0.36%; OSD, 1.04, 0.41%), with CSD sample having a slightly higher percentage fraction among the dried samples. The low amount (<5.0%) of α -curcumene and high amount of α -zingiberene recorded in this study suggest that the drying and extraction processes were not too harsh to cause high oxidative decomposition of α -zingiberene to higher fractions of α -curcumene [36]. The highest α -curcumene (3.40%) was found in SSSD because the temperature for drying was higher than the other two drying temperatures (Table 2).

As explored in previous studies [37], the GCMS/MS analysis revealed that ketones and sesquiterpenes are the two dominant volatile chemical groups in ginger rhizomes. Fresh ginger sample on a wet basis is characterized by a diverse class of compounds such as ketones, acetophenones, cyclohexane oxides, sesquiterpenes, aldehydes, terpenoids, and terpene alcohols (Figure 3). However, the major compounds of dried ginger rhizomes were mainly ketones (40.13–55.19%; zingerone, gingerol, and furanone) and sesquiterpenes (25.95–34.49%; α -copaene, γ -elemene, and α -farnesene), accounting for more than 80% of the total compounds (Figure 1). Flavor compounds such as aldehydes were reduced, while esters, alkane, and benzoate compounds were newly formed such as aspidinol, cyclohexane, and benzofuranmethanol, respectively, to a different extent during the dehydration process. The higher antioxidant activity of the CSD ginger sample reported in this study apart from gingerol can be related to many bioactive chemical species such as acetophenones (2',4'-dihydroxy- α -4-methoxy-3-nitrophenyl), aromatic hydrocarbons (2-naphthalenemethanol), terpene alcohols (linalool and *endo*-borneol), terpenoids (α -terpineol and 1H-cycloprop[e] azulene), and spirosesquiterpene (α -acorenil) in varying proportions.

Overall, even though SSSD and OSD samples have more isolated compounds than CSD sample, CSD is a better drying method in retaining the pungent and aroma compounds of ginger comparable to the fresh ginger. It is also relatively less expensive compared to hot air oven that uses electrical energy, vacuum dryer, and microwave dryer. The tent-like concrete solar dryer (CSD) could be explored for

commercial production of dried ginger which will preserve its bioactive compounds.

4. Conclusion

The antioxidant activities of the ethanol and aqueous extract of the Ghana yellow variety using FRAP, DPPH, and total antioxidant showed that fresh ginger had a better antioxidant activity than dried ginger irrespective of the solvent or antioxidant method employed. Drying reduced the main phenolic compound, which is gingerol, resulting in reduced antioxidant activity as compared to the fresh ginger rhizome. The use of passive tent-like concrete solar dryer (CSD) showed a better antioxidant activity in the ginger rhizomes compared to the stainless steel solar dryer (SSSD) and the open sun dryer (OSD). The phytochemical components showed gingerol as the main component for all the samples, fresh or dried. Drying reduced the flavor and pungent compounds as compared to the fresh ginger. Among the dried samples, CSD sample exhibited close resemblance to the fresh sample with respect to retaining ginger flavor compounds as well as pungency. Thus, CSD can be adopted for commercial drying of ginger to preserve its volatile and bioactive components [38–41].

Data Availability

Data are available upon request from the corresponding author.

Conflicts of Interest

The authors declare that they do not have any conflicts of interest.

Acknowledgments

This work was done through a fellowship program of the Research Training Fellowship for Developing Country Scientists (RTF-DCS) in the India Institute of Food Processing Technology (IIFPT) of Ministry of Food Processing, India (MOFPI), Thanjavur, Tamil Nadu.

References

- [1] A. T. Afshari, A. Shirpoor, A. Farshid et al., "The effect of ginger on diabetic nephropathy, plasma antioxidant capacity and lipid peroxidation in rats," *Food Chemistry*, vol. 101, no. 1, pp. 148–153, 2007.
- [2] H. Anwar, G. Hussain, and I. Mustafa, *Antioxidants in Foods and its Applications*, IntechOpen Book Series, London, UK, 2018.
- [3] R. E. Amoah, F. D. Wireko-Manu, I. Oduro, F. K. Saalia, and W. O. Ellis, "Effect of pretreatment on physicochemical, microbiological, and aflatoxin quality of solar sliced dried ginger (*Zingiber officinale* Roscoe) rhizome," *Journal of Food Science and Nutrition*, vol. 8, pp. 5934–5942, 2020.
- [4] R. E. Amoah, K. Sureshkumar, F. D. Wireko-Manu, I. Oduro, F. K. Saalia, and E. Owusu, "The effect of vinegar and drying (Solar and Open Sun) on the microbiological quality of ginger (*Zingiber officinale* Roscoe) rhizomes," *Journal of Food Science and Nutrition*, vol. 8, no. 11, pp. 1–8, 2020.
- [5] M. Gupta and J. Tennyson, *Diseases of Ginger*, IntechOpen, 2020.
- [6] D. T. Leal, G. G. Fontes, J. K. D. Villa et al., "Zingiber officinale formulation reduces hepatic injury and weight gain in rats fed an unhealthy diet," *Annals of the Brazilian Academy of Sciences*, vol. 91, no. 4, Article ID e20180975, 2019.
- [7] Q. Mao, X., X. Xu, S. Cao et al., "A review: bioactive compounds and bioactivities of ginger (*Zingiber officinale* roscoe)," *Foods*, vol. 8, p. 185, 2019.
- [8] F. O. Balogun, S. T. AdeyeOluwa, and A. O. A. Ashafa, "Ginger cultivation and its antimicrobial and pharmacological potentials," *Pharmacological Potentials of Ginger*, IntechBook Series, London, UK, 2019.
- [9] R. Offei-Okyne, J. Patterson, L. T. Walker, and M. Verghese, "Processing effects on phytochemical content and antioxidative potential of ginger," *Zingiber officinale*. *Journal of Food and Nutrition Sciences*, vol. 6, pp. 445–451, 2015.
- [10] H. Kikuzaki and N. Nakatani, "Antioxidant effects of some ginger constituents," *Journal of Food Science*, vol. 58, no. 6, pp. 1407–1410, 1993.
- [11] D. A. Balladin, O. Headley, I. Chang-Yen, and D. R. Mcgaw, "High pressure liquid chromatographic analysis of the main pungent principles of solar dried west Indian ginger (*Zingiber officinale*)," *Journal of Renewable Energy*, vol. 13, no. 4, pp. 531–536, 1998.
- [12] M. Kaushal, A. Gupta, D. Vaidya, and M. Gupta, "Postharvest management and value addition of ginger (*zingiber officinale* roscoe): a review," *International Journal of Environment, Agriculture and Biotechnology*, vol. 2, no. 1, 2017.
- [13] T. Chumroenphat, I. Khanprom, and L. Butkhup, "Antioxidant properties in ginger (*Zingiber officinale* Roscoe) rhizome with different drying methods," *Journal of Herbs, Spices, and Medicinal Plants*, vol. 4, pp. 361–374, 2011.
- [14] O. A. Gümü Say, A. A. Borazan, N. Ercal, and O. Demirkol, "Drying effects on the antioxidant properties of tomatoes and ginger," *Journal of Food Chemistry*, vol. 173, pp. 136–162, 2015.
- [15] K. An, D. Zhao, Z. Wang, J. Wu, Y. Xu, and G. Xiao, "Comparison of different drying methods on Chinese ginger (*Zingiber officinale* Roscoe): changes in volatiles, chemical profile, antioxidant properties, and microstructure," *Journal of Food Chemistry*, vol. 197, 2015.
- [16] N. Damenu, B. Jayasundara, and P. Arampath, "Effect of variety, location and maturity stage at harvesting, on essential oil, chemical composition, and weight yield of *Zingiber officinale* roscoe grown in Sri Lanka," *Heliyon*, vol. 7, Article ID e06560, 2021.
- [17] H. Yeh, C. Chuang, H. Chen, C. Wan, T. Chen, and L. Lin, "Bioactive components analysis of two various ginger (*Zingiberofficinale* Roscoe) and antioxidant effect of ginger extracts," *LWT-Journal of Food Science and Technology*, vol. 55, pp. 329–334, 2014.
- [18] T. A. Van Beek, M. A. Posthumus, G. P. Lelyveld, H. V. Phiet, and B. T. Yen, "Investigation of the essential oil of Vietnamese ginger," *Journal of Phytochemistry*, vol. 26, no. 11, pp. 3005–3010, 1987.
- [19] P. C. Onyenekwe and S. Hashimoto, "The composition of the essential oil of dried Nigerian ginger (*Zingiber officinale* Roscoe)," *Journal of European Food Research and Technology*, vol. 209, no. 6, pp. 407–410, 1999.
- [20] L. L. Mensor, F. S. Menezes, G. G. Leital et al., "Screening plant extracts for antioxidant activity by the use of DPPH free

- radical method," *Journal of Phytotherapy Research*, vol. 15, pp. 127–130, 2001.
- [21] M. Oyaizu, "Studies on product of browning reaction—antioxidant activities of products prepared from glucosamine," *Japanese Journal of Nutrition*, vol. 44, pp. 307–315, 1986.
- [22] P. Prieto, M. Pineda, and M. Aguilar, "Spectrophotometric quantitation of antioxidant capacity through the formation of a phosphomolybdenum complex: specific application to the determination of vitamin E," *Journal of Analytical Biochemistry*, vol. 269, pp. 337–341, 1999.
- [23] K. Srinivasan and S. Kumaravel, "A comparative study: the impact of solvent extraction on phytochemical profiling of *adhatoda vasica*," *International Journal of Pharma Research and Health Sciences*, vol. 3, no. 6, pp. 874–879, 2015.
- [24] K. Ravichandran, S. Krishnamoorthi, M. Pakkirisamy, P. Pandiyarajan, S. Sekar, and S. Shanmugam, "Organochlorine and organophosphorus pesticide residues analysis by GCMS/MS in raw cow milk," *International Journal of Agricultural and Life Sciences- IJALS*, vol. 1, no. 4, 2015.
- [25] X. Zhang, W. T. Iwaoka, A. S. Huang, S. T. Nakamoto, and R. Wong, "Gingerol decreases after processing and storage of ginger," *Journal of Food Science*, vol. 59, pp. 1338–1340, 1994.
- [26] S. D. Jolad, R. C. Lantz, A. M. Solyom, G. J. Chen, R. B. Bates, and B. N. Timmermann, "Fresh organically grown ginger (*Zingiber officinale*): composition and effects on LPS-induced PGE2 production," *Journal of Phytochemistry*, vol. 65, pp. 1937–1954, 2004.
- [27] Z.-U. Rehman, A. M. Salariya, and F. Habib, "Antioxidant activity of ginger extract in sunflower oil," *Journal of the Science of Food and Agriculture*, vol. 83, no. 7, pp. 624–629, 2003.
- [28] H. Baokang, W. Guowei, C. Zhiyong, and Q. Luping, "Effect of oven drying, microwave drying, and silica gel drying methods on the volatile components of ginger (*zingiber officinale roscoe*) by HS-SPME-GC-MS, drying Technology," *International Journal*, vol. 30, no. 3, pp. 248–255, 2012.
- [29] S. H. Ding, K. J. An, C. P. Zhao, Y. H. Guo, and Z. F. Wang, "Effect of drying methods on volatiles of Chinese ginger, (*Zingiber officinale Roscoe*)," *Journal of Food and Bioproduct Processing*, vol. 90, pp. 515–524, 2012.
- [30] D. A. Balladin, O. Headley, I. Chang-Yen, and D. R. McGaw, "High pressure liquid chromatographic analysis of the main pungent principles of solar dried West Indian ginger (*Zingiber officinale Roscoe*)," *Renewable Energy*, vol. 13, no. 4, pp. 531–536, 1998.
- [31] J. B. Johnson, J. S. Mani, S. White, P. Brown, and M. Naiker, "Pungent and volatile constituents of dried Australian ginger," *Journal of Current Research in Food Science*, vol. 4, pp. 612–618, 2021.
- [32] J. P. Bartley and A. L. Jacobs, "Effects of drying on flavour compounds in Australian-grown ginger (*Zingiber officinale*)," *Journal of the Science of Food and Agriculture*, vol. 80, no. 2, pp. 209–215, 2000.
- [33] A. Toure and Z. Xiaoming, "Gas chromatographic analysis of volatile components of Guinean and Chinese ginger oils (*Zingiber officinale*) extracted by steam distillation," *Journal of Agronomy*, vol. 6, no. 2, pp. 350–355, 2007.
- [34] G. A. Nogueira de Melo, R. Grespan, J. P. Fonseca et al., "Inhibitory effects of ginger (*Zingiber officinale Roscoe*) essential oil, on leukocyte migration in vivo and in vitro," *Journal of Natural Medicines*, vol. 65, pp. 241–246, 2011.
- [35] H. R. Juliani, A. R. Koroch, J. E. Simon, J. Asante-Dartey, and D. Acquaye, "Chemistry and quality of fresh ginger varieties (*Zingiber officinale*) from Ghana. ISHS Acta Horticulturae," *International Symposium on Medicinal and Nutraceutical Plants*, vol. 756, 2007.
- [36] J. P. Bartley and P. Foley, "Supercritical fluid extraction of Australian-grown ginger (*Zingiber officinale*)," *Journal of the Science of Food and Agriculture*, vol. 66, no. 3, pp. 365–371, 1994.
- [37] I. Sasidharan, V. V. Venugopa, and A. N. Menon, "Essential oil composition of two unique ginger (*Zingiber officinale Roscoe*) cultivars from Sikkim," *Natural Product Research*, vol. 26, no. 19, pp. 1759–1764, 2012.
- [38] H. A. Baldreldin, G. Bluden, M. O. Tanira, and A. Nemmar, "Some phytochemical, pharmacological and toxicological properties of ginger (*Zingiber officinale Roscoe*): a review of recent research," *Journal of Food and Chemical Toxicology*, vol. 46, pp. 409–420, 2008.
- [39] I. F. Benzie and J. J. Strain, "The ferric reducing ability of plasma (FRAP) as a measure of "antioxidant power": the FRAP assay," *Analytical Biochemistry*, vol. 239, pp. 70–76, 1999.
- [40] N. S. Mashhadi, R. Ghiasvand, G. Askari, M. Hariri, L. Darvishi, and M. R. Mofid, "Anti-oxidative and anti-inflammatory effects of ginger in health and physical activity: review of current evidence," *International Journal of Preventive Medicine*, vol. 4, pp. 36–42, 2013.
- [41] Z. Yang, W. Yang, Q. Peng et al., "Volatile phytochemical composition of the rhizome of ginger after extraction by headspace solid-phase microextraction, petroleum ether extraction and steam distillation extraction," *Bangladesh Journal of Pharmacology*, vol. 4, pp. 136–143, 2009.