Food Chemistry: X 21 (2024) 101227

Contents lists available at ScienceDirect

Food Chemistry: X

journal homepage: www.sciencedirect.com/journal/food-chemistry-x

Developing the procedure-enhanced model of ginger-infused sesame oil based on its flavor and functional properties

Li-Yun Lin [a], Chih-Wei Chen [b,1], Hsin-Chun Chen [c,2], Tai-Liang Chen [a], Kai-Min Yang [d,3,*]

[a] Department of Food Science and Technology, Hung Kuang University, Taichung 433, Taiwan
[b] Bachelor Degree Program in Food Safety/Hygiene and Laboratory Science, Chang Jung Christian University, Tainan City 711, Taiwan
[c] Department of Cosmeceutics, China Medical University, Taichung 406, Taiwan
[d] Department of Food Science, National Quemoy University, Kinmen 892, Taiwan

ARTICLE INFO

Keywords:
Ginger
Infused sesame oil
Gingerol
Antioxidant capacity

ABSTRACT

Ginger-infused sesame oil enriches the nutrition and provides enhanced flavor for the foods. An original processing procedure and module for evaluation were established in this study, using different raw materials (Guangdong and Chu ginger) and treatments (ginger powder, extract, and both). The quality, functionality, and flavor of the infused oils were evaluated. Ginger-infused sesame oil contained 0.58–3.22 μg/g of 6-gingerol, 0.21–0.88 μg/g of 6-shogaol. The number range of volatile compounds from 48 to 55 identified by gas chromatography-mass spectrometry varies depending on different process procedures. Agglomerative hierarchical clustering analysis revealed the flavor profiles were clustered by different varieties, while gingerol and phytosterol was by different treatments. In conclusion, sesame oil was an appropriate carrier for gingerol and phytosterol, which are characterized by higher antioxidant capacities ($p < 0.05$). These results show the benefits of developing infused oil products with enhanced functional and sensory properties.

1. Introduction

Over the past few years, the increase of eating disorders has been noted. Frequent consumption of unbalanced meals has led to an increased risk of metabolic disorders, for instance, diabetes, obesity, or dyslipidemia (Albert Perez, Poveda González, Martínez-Espinosa, Molina Vila, & Reig Garcia-Galbis, 2019; Lee, Shin, & Kim, 2021). Dietary intervention is crucial for treating such conditions. Functional foods, that have received attraction as a result, provide health-promoting effects that go beyond their nutritional properties. Functional foods can be natural foods or fortified ones, and when ingested to a proper dosage, can achieve health-promoting benefits (Vecchio & Cavallo, 2019; Parks, Stern, Fricke, Clausen, & Yaroch, 2020). The growth of functional foods is fueled by industrial innovation, the increasing demands made by health-conscious consumers, and by varying health claims. Products such as fermented diary drinks, plant-based milk, propolis, fish oil, and leutein supplements has received commercial success across the globe (Vecchio & Cavallo, 2019).

The application of natural products as therapeutic agents was common in history. Currently, there is rising interest in the exertion of natural products for treating a variety health conditions such as inflammation. Ginger (Zingiber officinale Rosc.) is a plant used in food, medicine, and cosmetics. Due to the refreshing aroma and spicy, pungent taste, the addition of ginger rhizome enhances the sense of heat and has been widely used as a dietary supplement in traditional medicine (Jang, Han, Park, Jhon, & Seo, 2004; Koga, Beltrame, & Pereira, 2016; Maghraby, Labib, Sobeih, & Farag, 2023). Numerous studies have demonstrated ginger (Fam. Zingiberaceae) to be a promising contemporary remedy as it contains gingerol, curcumin, phytosterols, terpenoids, and zerumbone and therefore may prevent cardiovascular diseases and associated pathologies (e.g., diabetes, obesity, and metabolic syndrome) that act as risk factors for cardiovascular diseases (Jang, Han, Park, Jhon, & Seo, 2004; Yeh et al., 2014; Lal, Begum, Munda, & Pandey, 2021). Sesame (Sesamum indicum L.), a member of the Pedaliaceae family, is one of the earliest oil crops domesticated and consumed by humans. Sesame oil is an aromatic oil produced by cold

* Corresponding author.
E-mail addresses: lylin@hk.edu.tw (L.-Y. Lin), ccwlly@mail.cjcu.edu.tw (C.-W. Chen), d91628004@ntu.edu.tw (H.-C. Chen), ykmin@nqu.edu.tw (K.-M. Yang).
[1] 0000-0002-9640-3503.
[2] 0000-0002-6076-3611.
[3] 0000-0003-0270-3511.

https://doi.org/10.1016/j.fochx.2024.101227
Received 1 November 2023; Received in revised form 4 February 2024; Accepted 11 February 2024
Available online 16 February 2024

Table 1
Oxidation stat, color and browning index values of ginger-infused sesame oil.

	AV* (mg KOH/g)	POV (meq/kg)	TBA (μmole/g)	L	a	b	ΔE**	BI***
So	1.74	11.96	10.05	23.82*	0.82	1.70	–	188.04
GuEx-So	1.81	13.25	10.14	31.06	4.59	11.01	12.38	231.70
GuP-So	1.78	12.16	10.12	22.91	0.18	1.40	1.15	185.07
GuExP-So	1.78	12.11	9.98	30.09	7.14	11.29	13.09	241.32
ChEx-So	1.76	13.12	10.07	33.79	6.03	15.51	17.81	250.66
ChP-So	1.82	12.07	9.98	22.87	0.62	1.67	0.97	187.69
ChExP-So	1.81	12.13	9.76	31.61	6.01	12.96	14.64	243.39

Data presented are in triplicate mean.
*AV: acid value; POV: peroxide value; TBA: thiobarbituric acid.
**ΔE:The comprehensive color difference represented.
$\Delta E = [(\Delta L^*)2 + (4a^*)2 + (4b^*)2]^{1/2}$.
*** BI: browning index.

pressing roasted sesame seeds and is traditionally used as an edible oil. Sesame oil is rich in linoleic and linolenic acids and contains high amounts of biologically active substances such as lignans (338.1–1153.6 mg/100 g), vitamin E (53.4–81.1 mg/100 g), and phytosterols (411.8–488.6 mg/100 g) (Shi et al., 2018, Yin, Ma, Li, Liu, & Shi, 2021).

Infused oils are convenient food products consumed worldwide, which are used as dressings in various foods, increasing their attractiveness and tastiness. Nowadays, there is high demand for innovative and specialized products of high nutritional quality and with different sensory characteristics (Khatri et al., 2023). Herb-infused oils seem to derive from ancient processing and conservation practices, in which the oils acquired the flavor of the aromatic herbs used and were later used in the preparation of dishes and salads. Infused oils come with advantages, such as versatility, handiness, and rich flavors has turned them into cupboard staples around the world. The aromatic herbs used to infuse the oils not only improve their sensory and nutritional properties but also extend their expiration date and counteract free radicals because of their antioxidant and antimicrobial activities (Díaz-Montaña, Aparicio-Ruiz, & Morales, 2023). In recent research, the addition of essential oils derived from herbs and spices could provide pleasant flavors and improve the oxidative stability in vegetable oils (Abo et al., 2014; Lim, Hamdan, David Chua, & Lim, 2021).

Ginger-infused sesame oil is often used as a food therapy and medicinal diet therapy in Asia, since ginger has properties described as “interior-warming and cold-dispelling” and sesame oil is said to be “Yin-tonifying (in terms of Qi)” and “replenishing”, combination the benefits are enhanced, making it the ultimate recipe for activating blood circulation in the concept of Traditional Chinese Medicine, which also claims it the best for post-partum women. The objective of this study was to develop a new manufacturing process for ginger-infused sesame oil to promote its functional and flavor properties. Analyses of the quality, functionality, and volatiles of the ginger-infused oil were conducted.

2. Materials and methods

2.1. Materials

The chemicals and solvents used in this research were provided by Merck (Darmstadt, Germany), Sigma-Aldrich (St. Louis, MO, USA), and Chemical Co., Ltd. (Miaoli, Taiwan), including 6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid (Trolox), 1,1-diphenyl-2-picrylhydrazyl (DPPH), 2,4,6-tripyridyl-S-triazine (TPTZ), 2,2′-azinobis-(3-ethylbenzothiazoline-6-sulfonate) (ABTS), gallic acid, quercetin, Folin–Ciocalteu reagent, 6-gingerol, 6-shogaol, 8-gingerol, 10-gingerol, curcumin, and sesame. All solvents were of HPLC grade.

2.2. Production of ginger-infused sesame oil

Guangdong ginger (Gu) and Chu ginger (Ch) were purchased from three different markets in Nantou County (Taiwan) in September 2020 to achieve three biological replicates. All ginger were mixed then made into powder according to the following description. Sample preparation of this study were listed as following: (1) Ginger powder preparation: The ginger was washed and cut into slices, dried with a hot air at 50 °C for 18 h, ground, and passed through a 40-mesh sieve. (2) Ginger extract preparation: 50 g of ginger powder was mecerated with eight times its volume of ethanol and collected after 3 h, concentrated into a syrup form under a vacuum, then diluted to 10 mL with sesame oil. (3) Ginger-infused sesame oil preparation: (a) Gu/ChEx-So, 10 mL of ginger extract was added to 200 mL of sesame oil in an airtight glass jar; (b) Gu/ChP-So, 200 mL of sesame oil was added into a stainless-steel pot with 50 g of ginger powder, infused for 10 min at 150 °C, and canned in an airtight glass jar; (c) Gu/ChExP-So, 200 mL of sesame oil was added into a stainless-steel pot with 25 g of ginger powder and infused for 10 min at 150 °C. After cooling, 5 mL of ginger extract was added and canned in an airtight glass jar. (4) Sample of control preparation: (d) So, 200 mL of sesame oil (FWUSOW INDUSTRY CO., LTD.) was added into a stainless-steel pot and heated to 150 °C then held in this temperature for 10 min and canned in an airtight glass jar.

2.3. Quality analysis

The peroxide value (POV) of each oil sample was determined as prescribed by the official analytical methods of the Mariotti (2014). The acid value (AV) of the samples was determined by titration with a 0.1 N potassium hydroxide alcoholic solution. The thiobarbituric acid (TBA) content of the samples was measured according to Ghani, Barril, Bedgood, and Prenzler (2017).

The color of each oil sample was measured using a colorimeter (NE-4000, Nippon Denshoku Industries Co. Ltd., Tokyo, Japan). After the instrument was standardized with a white plate ($L0 = 97.51$, $a0 = -0.16$, and $b0 = 1.75$), the colors of the samples were evaluated at room temperature. The Hunter L, a, and b values correspond to lightness, greenness (−a) or redness (+a), and blueness (−b) or yellowness (+b), respectively. The browning index (BI) was calculated using the following.

Equation:

$$Browningindex = [100 \times (x - 0.312)]/0.172.$$

where $x = (a + 1.75L)/(5.645L + a - 3.012b)$.

2.4. Functional component analysis

This study used standard solutions to investigate the functional components, including 6-gingerol, 6-shogaol, 8-gingerol, 10-gingerol, curcumin, and sesamol. To determine standards quantitatively, we followed the method of Yeh et al. (2014) and used high-performance liquid chromatography (HPLC) with a Hitachi L-2130 pump and L-2400 UV detector from Hitachi, Japan. Sample solutions were filtered through a

Table 2
Analyzed gingerols and sesamols of ginger-infused sesame oil.

	6-gingerol (μg/g)	6-shogaol (μg/g)	8-gingerol (μg/g)	10-gingerol (μg/g)	Curcumin (μg/g)	Sesamol (μg/g)
So	-	-	-	-	-	0.62 ± 0.04 c
GuEx-So	0.99 ± 0.08 a*	0.22 ± 0.01 a	0.06 ± 0.01 a	0.05 ± 0.01 a	0.31 ± 0.03 b	0.54 ± 0.03 c
GuP-So	3.22 ± 0.18 d	0.81 ± 0.06 c	0.19 ± 0.02 c	0.11 ± 0.02 b	1.02 ± 0.06 d	0.39 ± 0.03 a
GuExP-So	2.51 ± 0.21 c	0.57 ± 0.03 b	0.14 ± 0.01 b	0.08 ± 0.02 b	0.66 ± 0.07 c	0.42 ± 0.02 ab
ChEx-So	0.58 ± 0.06 a	0.21 ± 0.01 a	0.08 ± 0.01 a	n.d.**	0.11 ± 0.01 a	0.45 ± 0.04 b
ChP-So	2.11 ± 0.18 c	0.88 ± 0.04 b	0.27 ± 0.01 d	n.d.	0.51 ± 0.05 c	0.38 ± 0.02 a
ChExP-So	1.42 ± 0.12 b	0.54 ± 0.05 c	0.21 ± 0.01 c	n.d.	0.27 ± 0.01 b	0.42 ± 0.03 ab

* Data presented are in mean ± SD (n = 3) which with different letters are significantly different at $p < 0.05$.
** n.d.: not detected.
a-d: Date with identical letters in the same column are not significantly different ($p < 0.05$).

0.45 μm filter (3 mm; Millex Filter, Millipore), and 20 μL of the filtrate was analyzed. We built calibration curves of the standards by plotting the peak area vs. each corresponding concentration and used them to quantify the functional components.

The remaining procedures were carried out as previously reported (Yang, Cheng, Ye, Chu, & Chen, 2022), using an Agilent 6890 GC equipped with a DB-1 fused-silica capillary column (60 m × 0.25 mm i.d., 0.25 μm film thickness, Agilent Technologies) coupled to an Agilent 5973 N MSD mass spectrometer (MS). We used Helium as the carrier gas at a 1 mL/min flow rate and maintained the injector temperature at 250 °C. The GC conditions were identical for both GC/MS and GC analysis. GC analyzed the derivatized phytosterol extracts by an injection with 1:30 split ratio at 260 °C. The content of individual sterols was expressed as the percentage of the PS fraction obtained using 5α-Cholestane as an internal standard.

2.5. Antioxidant property assay

DPPH, ABTS, and FRAP tests were carried out to evaluate the antioxidant activity in triplicate (Olszowy & Dawidowicz, 2016). A solution of 1 mL of DPPH methanol was mixed with 0.5 mL of the sample and allowed to stand for 30 min. The mixture was mixed vigorously and incubated for 30 min at ambient temperature without exposure to the light, and the mixture was measured under 517 nm. ABTS radical cation-scavenging activity using method was measured and compared with standard materials' results. ABTS + radicals were produced by reacting the ABTS solution (7 mM, 25 mL) with potassium persulfate (1.4 mM, 0.44 mL), and the mixture was kept in the dark at room temperature for 12–16 h. The sample (1.0 mL) was added to the ABTS + solution (2.5 mL) and mixed vigorously. After reacting at room temperature for 5 min, the absorbance was measured at 734 nm. FRAP using method was measured and compared with standard materials' results. Each oil sample was diluted with an acetone/methanol (2:8) solution to 2 mg/mL and mixed with the FRAP reagent (containing acetate buffer, $FeCl_3$ solution, and TPTZ by the ratio of 10:1:1). With vigorous vortex, the mixture was incubated at ambient temperature for 10 min following with the measurement at 595 nm. The Trolox was selected as the positive control.

2.6. Volatile analysis

To isolate the volatile components of ginger-infused sesame oil, we used simultaneous distillation–extraction (SDE) with a modified Likens-Nickerson apparatus (Lin, Tseng, Li, & Mau, 2008). We added 100 g of ginger-infused sesame oil and 1000 ml of deionized water to the apparatus. Then, we used a solvent mixture of *n*-pentane and diethyl ether (1:1, v/v) as the extractant. We repeated this process three times and concentrated the filtered extract at 40 °C to 100 ml, which we then stored at −20 °C until analysis using a Vigreux column (i.d. 1.5 × 100 cm; Tung Kwan Glass Co., Hsinchu, Taiwan).

To identify the volatile components of the oil sample, we used the Agilent 6890 GC with the DB-1 column and coupled it to the Agilent 5973 N MSD MS. We identified the constituents by matching their spectra with those recorded in an MS library (Wiley 7 N), and we confirmed them using the Kovats indices or by comparing the GC retention time data with those of authentic standards or published in the literature. The linear RIs were calculated from the retention times of *n*-alkanes (C_5-C_{25}) run under the same chromatographic conditions.

2.7. Statistical analysis

The measurement was obtained in triplicate (n = 3) for each sample and expressed as means ± SD (standard deviation). The data were subjected to a hierarchical cluster analysis (HCA) with squared Euclidean distances. Subsequently, the data were analyzed using principal components analysis (PCA) combined with varimax rotation. The

Table 3
Analyzed phytosterols of ginger-infused sesame oil.

	Brassicasterol (μg/g)				Campesterol (μg/g)				Stigmasterol (μg/g)				β-sitosterol (μg/g)			
So	133.65	±	9.68	a	25.84	±	1.66	a	18.96	±	1.22	a	98.69	±	5.63	a
GuEx-So	211.23	±	14.38	c	44.43	±	2.31	c	38.92	±	2.91	d	205.70	±	13.95	b
GuP-So	162.51	±	12.86	b	32.57	±	2.26	b	30.23	±	2.83	c	157.48	±	11.66	c
GuExP-So	179.61	±	14.37	b	37.27	±	3.57	b	33.52	±	2.64	cd	174.81	±	12.95	d
ChEx-So	211.67	±	15.72	c	50.03	±	2.13	d	30.09	±	2.19	c	188.35	±	13.42	d
ChP-So	163.54	±	11.41	b	34.99	±	2.91	b	24.03	±	1.85	b	141.26	±	10.63	b
ChExP-So	177.19	±	13.56	b	33.36	±	2.15	b	27.91	±	1.93	b	145.31	±	12.37	b

Data presented are in mean ± SD (n = 3) which with different letters are significantly different at $p < 0.05$.
a-d: Date with identical letters in the same column are not significantly different ($p < 0.05$).

Table 4
Antioxidant property of ginger-infused sesame oil.

	DPPH (%)				ABTS (%)				FRAP (Trolox μg/g)			
So	55.61	±	2.36	a	61.45	±	3.25	b	82.04	±	6.12	b
GuEx-So	62.57	±	3.74	b	56.64	±	2.13	a	73.21	±	5.75	a
GuP-So	72.99	±	2.83	c	62.72	±	3.21	b	72.26	±	4.51	a
GuExP-So	74.14	±	3.18	c	72.59	±	3.69	c	82.90	±	6.32	ab
ChEx-So	63.79	±	2.96	b	57.71	±	2.36	a	75.01	±	6.11	a
ChP-So	77.63	±	3.85	cd	68.01	±	2.11	bc	80.27	±	5.93	ab
ChExP-So	80.26	±	4.12	d	73.37	±	4.62	c	88.24	±	3.68	b

Data presented are in mean ± SD (n = 3) which with different letters are significantly different at $p < 0.05$.
a-d: Date with identical letters in the same column are not significantly different ($p < 0.05$).

XLSTAT software (version 2010.2.01, Addinsoft Deutschland, Andernach, Germany) was used for the AHC and PCA analyses.

3. Results and discussion

3.1. Quality profile

The thermal processing of ginger-infused sesame oil can impart unique flavors, colors, and textures to foods and increase nutrient digestibility or reduce antinutritional elements (Aydeniz-Guneser, 2021). Heat treatment can also lead to adverse outcomes, such as oil oxidation (Yin et al., 2021). We used the POV, AV, and TBA to evaluate the oxidation state of sesame oil and ginger-infused sesame oil. In this study, the POVs were in the range of 11.96–13.25 meq/kg, the AVs were in the range of 1.74–1.82 mg KOH/g, and the TBAs were in the range of 9.76–10.12 μmole/g (Table 1). The results show that the oil is of sufficient quality and no safety concerns exist.

The color of ginger-infused sesame oil is highly associated with consumer acceptance of this product. The color difference (ΔE) compares the L, a, and b values of the infused samples to those of plain sesame oil. The ΔE of GuEx-So, GuP-So, GuExP-So, ChEx-So, ChP-So, and ChExP-So were 12.38, 1.15, 13.09, 17.81, 0.97, and 14.64, respectively (Table 2). An important aspect of the quality of ginger-infused sesame oil subjected to heat is its browning index (BI). The BIs of GuEx-So, GuP-So, GuExP-So, ChEx-So, ChP-So, and ChExP-So were 231.70, 185.07, 241.32, 250.66, 187.69, and 243.39, respectively (Table 2). The results show that the addition of ginger extract enhanced the Maillard reaction. The tendency to darken the color of the ginger-infused sesame oil is related to its chemical composition (Ahmad et al., 2021).

3.2. Functionality profile

Ginger rhizomes with numerous bioactive compounds showed beneficial properties, especially pharmacologically. Among these compounds, gingerol is considered as the most potent and rich component. (Jang et al., 2004; Yeh et al., 2014). The combination of gingerol derivatives, including 6-gingerol, 8-gingerol, and 10-gingerol not only provided therapeutic effects but also its unique flavor and aroma (Yeh et al., 2014; Koga et al., 2016). Previous study showed Gu and Ch contains 6.11 and 5.54 mg/100 g (dry weight) of total gingerol with 6-gingerol and 6-shogaol making up most of the content (Yeh et al., 2014). In this study, the ginger-infused sesame oil contained 0.58–3.22 μg/g of 6-gingerol, 0.21–0.88 μg/g of 6-shogaol, 0.06–0.27 μg/g of 8-gingerol, 0.0.5–0.11 μg/g of 10-gingerol, and 0.11–1.02 μg/g of curcumin (Table 2). The presence of heat or storage for long time, gingerols may transformed into shogaols (Zagórska, Czernicka-Boś, Kukula-Koch, Iłowiecka, & Koch, 2023). Bacterial metabolism also played a vital role, converting 6-Shogaol into 6-paradol, while both showed similar anti-inflammatory and antioxidant properties. Sesame lignans are the main active ingredients in sesame seeds and have strong antioxidant activity (Nayak, Dash, Rayaguru, & Krishnan, 2016).

Lipid soluble bioactive compounds are often limited of their performance in most cooking processes and upon direct consumption. Edible oils have been effective carriers for said compounds. Sesamol was 0.62 μg/g in sesame oil and had a concentration of 0.38–0.54 μg/g in ginger-infused sesame oil (Table 3). Phytosterols also provide health benefits, and they can increase the stability of oils in storage. Δ-5-avenasterol for instance, exhibits anti-polymerization properties, which protects oil compounds from oxidation during heat treatment (Winkler & Warner, 2008; Zhang, Saleh, Chen, & Shen, 2012). Ginger-infused sesame oil contains 163.54–211.67 μg/g of brassicasterol, 32.57–50.03 μg/g of campesterol, 24.03–38.92 μg/g of stigmasterol, and 141.26–205.7 μg/g of β-sitosterol. These results show that ginger can effectively increase the phytosterol content in ginger-infused sesame oil, and the ginger extract is better than the ginger powder for this purpose.

Antioxidants hindered the oxidation of oils, including their reaction with free radicals and peroxy or alkoxy radicals, which then led to the propagation step of oxidation (Endo, 2018). The results showed that ginger-infused sesame oil had a better DPPH-scavenging effect, which was 62.57–80.26 % compared to 55.61 % for sesame oil. The ABTS-scavenging effect of ginger-infused sesame oil was 56.64–73.3 % compared to 61.45 % for sesame oil (Table 4). The relevant literature showed that the antioxidant capacity is correlated with the chemical structure of free radicals. Specifically, ABTS presents cationic properties that behave as a proton acceptor or an electron. Hence, ABTS can cope

Table 5
Volatile compounds of ginger-infused sesame oil.

Compound	M.W	RI	Odor description**
Monoterpene Hydrocarbone			
camphene	136	943	camphoraceuos, cooling,
α-phellandrene	136	994	citrus, slightly green
α-terpinolene	136	1077	sweet, fresh, citrus
Sesquiterpene Hydrocarbone			
δ-elemene	204	1331	herbal, waxy, fresh
(+)-cycloisosativene	204	1363	–
α-copaene	204	1371	woody, spicy, honey
β-elemene	204	1383	herbal, waxy, fresh
α-zingiberene *	204	1396	spicy, fresh, sharp
β-cubebene	204	1421	herbal, waxy
trans-β-farnesene	204	1431	woody, green, floral
δ-selinene	204	1441	herbal
aromadendrene	204	1452	–
α-curcumene *	202	1466	–
germacrene D	204	1470	–
(-)-isoledene	204	1476	–
β-zingiberene	204	1483	spicy, fresh, sharp
γ-cadinene	204	1490	woody
β-bisabolene	204	1496	balsamic, woody
E,E-α-farnesene	204	1498	woody, green, herbal
β-sesquiphellandrene	204	1510	herbal, fruity, woody
trans-γ-bisabolene	204	1518	woody, citrus, fruity
germacrene B	204	1546	woody, earthy, spicy
Oxygenated Sesquiterpene			
butylated hydroxy toluene	220	1488	camphoreous
elemol	222	1532	green, woody, spicy
zingiberenol *	222	1597	ginger, metallic
Alcohol			
pentanol	88	746	musty, fusel, alcoholic
1-octen-3-ol *	128	964	earthy, green, oily
guaiacol	124	1061	phenolic, smoky, spicy
cumic alcohol	150	1080	spicy, herbal
linalool *	154	1084	orange, floral
borneol	154	1148	earthy, minty, camphoreous
4-terpineol	154	1160	musty
α-terpineol	154	1171	pine, terpenic, lilac
β-citronellol	156	1208	rose, oily
geraniol *	154	1235	sweet, floral, fruity
Ketones			
3-octen-2-one	126	1013	earthy, oily
acetophenone	120	1035	sweet, pungent
2-nonanone	142	1070	fruity, sweet, waxy
camphor	152	1117	camphoreous
5-nonanone	142	1074	fruity, sweet, waxy
pulegone	152	1158	peppermint, camphor
2-undecanone	170	1279	waxy, fruity, fatty
Aldehydes			
hexanal	100	800	fresh, green, fatty
heptanal	114	900	fresh, green, fatty
benzaldehyde *	106	930	almond, fruity
benzeneacetaldehyde	120	1006	honey, sweet, floral
2-octenal	126	1032	sweet, fatty,
nonanal	142	1082	waxy, aldehydic
neral *	152	1122	sweet, citral
citronellal	154	1130	sweet, floral
myrtenal	150	1160	sweet, spicy, cinnamon
geranial	152	1211	citrus
2,4-decadienal	152	1287	fatty, chicken, aldehydic
Esters			
bornyl acetate	196	1266	woody, herbal
geranyl acetate	196	1357	waxy, green, floral
Hydrocarbon			
toluene	92	751	sweet
butyl benzene	134	1042	–
pentyl benzene	148	1142	–
dodecane	170	1196	–
Nitrile			
methyl pyrazine	94	795	nutty, cocoa, roasted
2,5-dimethyl pyrazine	108	884	nutty, musty, earthy
2-ethyl-6-methyl-pyrazine	122	972	nutty, roasted
2,5-dimethyl-3-ethylpyrazine	136	1056	nutty, roasted
3,5-diethyl-2-methyl pyrazine	150	1133	nutty, roasted
Miscellaneous compounds			
2-pentylfuran	138	978	fruity, green, earthy
2-acetyl-5-methylfuran	124	1003	sweet, musty, nutty
1,8-cineole	154	1018	eucalyptus,herbal

RI: Retention index; cidentified via comparison of the mass spectra with the RI; RI obtained from literature.
*compared with standard compound;**compared with information from The Good Scents Company Information System (https://www.thegoodscentscompany.com); - no odor description to be found.

with DPPH which contains an unpaired electron. (Nhu-Trang, Nguyen, Cong-Hau, Anh-Dao, & Behra, 2023). The FRAP of ginger-infused sesame oil was 72.26–88.24 Trolox μg/ml compared to 82.04 Trolox μg/mL for sesame oil (Table 4). The FRAP values quantify the ability of the antioxidant compounds to donate electrons and, thus, reduce the oxidized species. The reducing power of a compound is an indicator of its potential antioxidant activity. Ginger exhibits excellent antioxidant activity and is a source of natural antioxidants that regulate lipid peroxidation and reduce the production of reactive oxygen species (Abdel-Azeem, Hegazy, Ibrahim, Farrag, & El-Sayed, 2013; Nayak et al., 2016; Zagórska et al., 2023).

3.3. Flavor profile

Oil infusing is a process of transferring scent, flavor, and functional ingredients into a carrier oil. This process can be done to add flavor to cooking oils. Here, we identified the volatiles of So, GuEx-So, GuP-So, GuExP-So, ChEx-So, ChP-So, and ChExP-So have 31, 55, 53, 49, 48, 57, and 55 compounds, respectively (Table 5). Nitrile compounds contributed to the special aroma of sesame oil (Abdel-Azeem et al., 2013), and various compounds were found, including 2-ethyl-6-methyl-pyrazine, 2,5-dimethyl pyrazine, 2,5-dimethyl-3-ethylpyrazine, 3,5-diethyl-2-methyl pyrazine and methyl pyrazine in this study. Hexanal, nonanal, benzaldehyde, and benzeneacetaldehyde exhibited the highest odor activity value in sesame oil (Jia et al., 2019). Terpene hydrocarbons, including β-sesquiphellandrene, α-curcumin, β-bisabolene, and zingiberene, are the main components that provide a distinct aroma and taste to ginger (Yeh et al., 2014). In this study, ginger-infused sesame oil contained 5.41–23.57 mg/kg of zingiberene, 2.01–8.21 mg/kg of β-sesquiphellandrene, 1.83–5.48 mg/kg of α-curcumin, and 0.94–3.97 mg/kg of β-bisabolene. The experimental results show that bamboo ginger oil exhibits ginger's most notable volatile characteristics, containing both borneol (cooling) and bornyl acetate (piney).

Heating can cause unpleasant flavors in condiments due to biochemical reactions such as the Maillard reaction, caramelization, and fat oxidation. These reactions can be inconvenient for consumers and are associated with furan production, linked to Maillard reactions and unsaturated fatty acid oxidation (Ludwig et al., 2021; Ni et al., 2022). Additionally, 2,4-Decadienal is a lipid oxidation product that creates a cooked-like aroma (Brewer, 2011). Research has shown that thermal stability of terpenes relate to their structures, and sesquiterpenes exhibit better thermal stability as they increase oxygen-containing moieties through heat-induced oxidation (e.g., zingiberene → zingiberenol and β-elemene → elemol) rather than monoterpenes facing degradation of the terpene skeleton upon the introduction of heat (Yang & Chiang, 2019).

3.4. Chemometricprofile

Several studies have utilized chemometrics to assess the impact of processing on the quality of ginger-infused sesame oil (Yang & Chiang, 2019; Santos et al., 2021; Chiang, Yang, Wang, & Chen, 2022; Yang et al., 2022; Nhu-Trang et al., 2023). By using multivariate statistical analyses (PCA and AHC), the chemometric profiles of the samples were

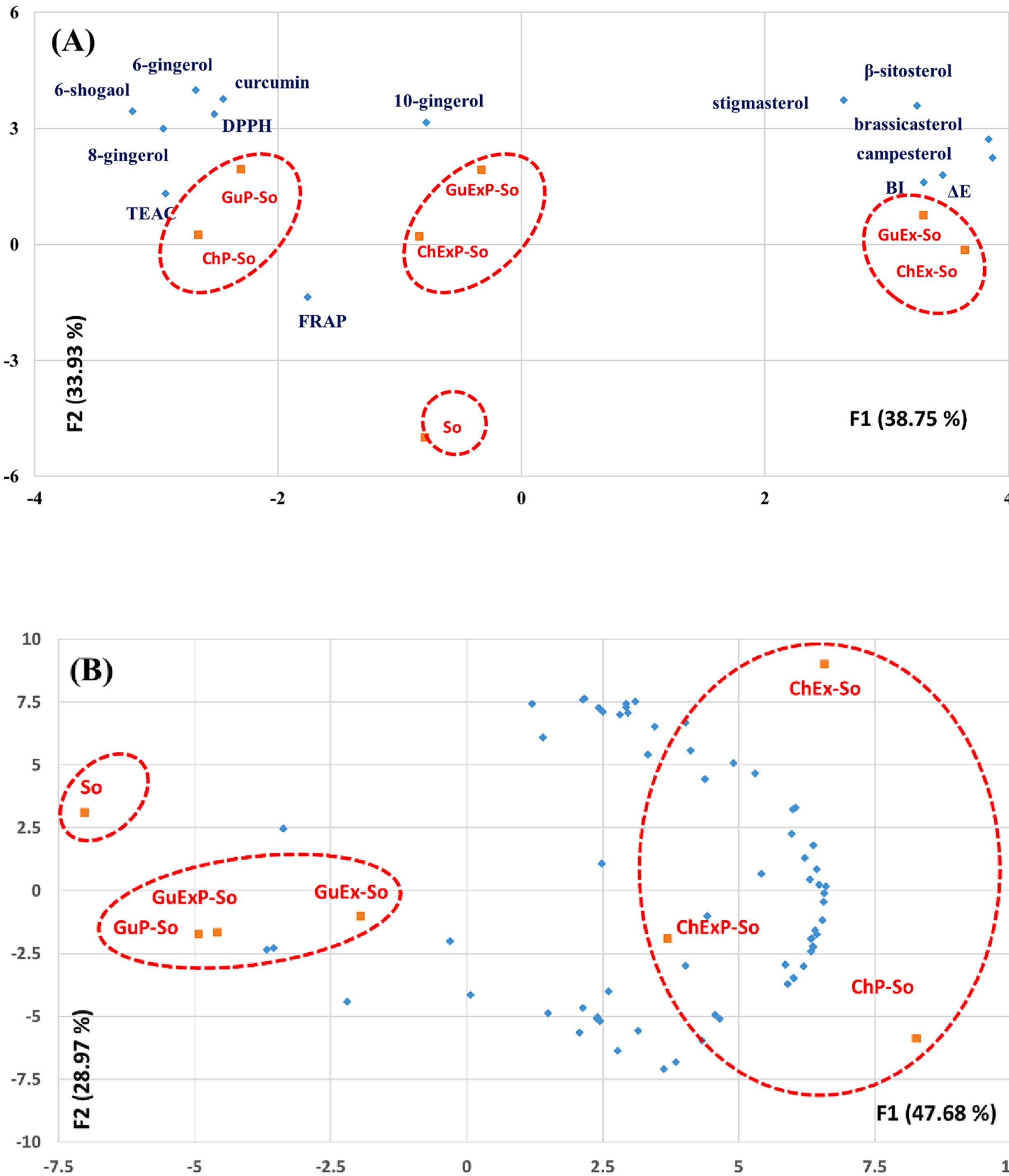

Fig. 1. PCA and AHC plots of the (a)functionality and (b) flavor of ginger-infused sesame oil.

evaluated. The PCA analysis revealed the relationship between the processing of ginger-infused sesame oil and its functionality (Fig. 1-A). Two principal components accounted for 38.75 % and 33.93 % of the variance, respectively, resulting in a cumulative variance of 72.68 %. The results indicated that the presence of 8-gingerol (R: 0.941), 6-shogaol (R: 0.869), and 6-gingerol (R: 0.723) in ginger-infused sesame oil was effective in clearing DPPH. We then conducted AHC analysis and identified four main clusters: Cluster 1 included GuP-So and ChP-So, Cluster 2 contained GuExP-So and ChExP-So, Cluster 3 comprised GuEx-So and ChEx-So, and Cluster 4 contained only So. We discovered a significant correlation between various treatments and functional performance. The stability and solubility of the functional components in carrier oils played a crucial role in this relationship.

We also used PCA to analyze the connections between factors, such as ginger-infused sesame oil and flavor. The two principal components displayed a total variance of 76.76 %, with percentage variances of 47.68 % and 28.97 %, as shown in Fig. 1-B. Then, we employed AHC analysis to identify flavor clusters and identified three main clusters: Cluster 1 contained only So, Cluster 2 included GuEx-So, GuP-So, and GuExP-So, while Cluster 3 comprised ChEx-So, ChP-So, and ChExP-So. Our findings indicate that different raw materials significantly influence flavor performance.

Conclusion

By incorporating natural ingredients sourced from food into everyday foods or condiments, we can help tackle nutritional inequalities. One way to do this is by altering the formulation of ginger-infused sesame oil through material selection and different treatment procedures, which can replicate traditional functional foods. Incorporating a combination of ginger powder and the extract is an innovative and promising strategy that enhances the active substance of functional ginger-infused sesame oil. This study offers helpful references and methods for developing functional foods and conditions. However, further research is necessary to explore issues such as consumer acceptance and activity methods of ginger-infused sesame oil, which are critical factors to consider for the future.

CRediT authorship contribution statement

Li-Yun Lin: Writing – review & editing, Writing – original draft, Formal analysis, Data curation, Conceptualization. **Chih-Wei Chen:** Writing – original draft, Methodology, Formal analysis, Data curation. **Hsin-Chun Chen:** Formal analysis, Data curation, Conceptualization. **Tai-Liang Chen:** Project administration, Methodology. **Kai-Min Yang:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

References

Abdel-Azeem, A. S., Hegazy, A. M., Ibrahim, K. S., Farrag, A. R. H., & El-Sayed, E. M. (2013). Hepatoprotective, antioxidant, and ameliorative effects of ginger (Zingiber officinale Roscoe) and vitamin E in acetaminophen treated rats. *Journal of dietary supplements, 10*(3), 195–209.

Abo, B., Bevan, J., Greenway, S., Healy, B., McCurdy, S. M., Peutz, J., & Wittman, G. (2014). Acidification of garlic and herbs for consumer preparation of infused oils. *Food Protection Trends, 34*(4), 247–257.

Ahmad, S. N. S., Tarmizi, A. H. A., Razak, R. A. A., Jinap, S., Norliza, S., Sulaiman, R., & Sanny, M. (2021). Selection of vegetable oils and frying cycles influencing acrylamide formation in the intermittently fried beef nuggets. *Foods, 10*(2), 257.

Albert Perez, E., Poveda González, M., Martínez-Espinosa, R. M., Molina Vila, M. D., & Reig Garcia-Galbis, M. (2019). Practical guidance for interventions in adults with metabolic syndrome: diet and exercise vs. changes in body composition. International journal of environmental research and public health, 16(18), 3481.

Aydeniz-Guneser, B. (2021). Investigation of stability of olive oils aromatized with some local plants. *Turkish Journal of Agriculture-Food Science and Technology, 9*(9), 1658–1668.

Brewer, M. S. (2011). Natural antioxidants: Sources, compounds, mechanisms of action, and potential applications. *Comprehensive reviews in food science and food safety, 10*(4), 221–247.

Chiang, S. H., Yang, K. M., Wang, S. Y., & Chen, C. W. (2022). Enzymatic treatment in black tea manufacturing processing: Impact on bioactive compounds, quality, and bioactivities of black tea. *LWT, 163*, Article 113560.

Díaz-Montaña, E. J., Aparicio-Ruiz, R., & Morales, M. T. (2023). Effect of flavorization on virgin olive oil oxidation and volatile profile. *Antioxidants, 12*(2), 242.

Endo, Y. (2018). Analytical methods to evaluate the quality of edible fats and oils: The JOCS standard methods for analysis of fats, oils and related materials (2013) and advanced methods. *Journal of oleo science, 67*(1), 1–10.

Ghani, M. A., Barril, C., Bedgood, D. R., Jr, & Prenzler, P. D. (2017). Measurement of antioxidant activity with the thiobarbituric acid reactive substances assay. *Food chemistry, 230*, 195–207.

Jang, D. S., Han, A. R., Park, G., Jhon, G. J., & Seo, E. K. (2004). Flavonoids and aromatic compounds from the rhizomes of Zingiber zerumbet. *Archives of Pharmacal Research, 27*, 386–389.

Jia, X., Zhou, Q., Wang, J., Liu, C., Huang, F., & Huang, Y. (2019). Identification of key aroma-active compounds in sesame oil from microwaved seeds using E-nose and HS-SPME-GC× GC-TOF/MS. *Journal of food biochemistry, 43*(10), e12786.

Khatri, P., Rani, A., Hameed, S., Chandra, S., Chang, C. M., & Pandey, R. P. (2023). Current understanding of the molecular basis of spices for the development of potential antimicrobial medicine. *Antibiotics, 12*(2), 270.

Koga, A. Y., Beltrame, F. L., & Pereira, A. V. (2016). Several aspects of Zingiber zerumbet: A review. *Revista Brasileira de Farmacognosia, 26*, 385–391.

Lal, M., Begum, T., Munda, S., & Pandey, S. K. (2021). Identification of high rhizome and essential oil yielding variety (Jor Lab ZB-103) of Zingiber zerumbet (L.) Roscoe ex Sm. *Journal of Essential Oil Bearing Plants, 24*(5), 1010–1025.

Lee, J. W., Shin, W. K., & Kim, Y. (2021). Food security status is not associated with increased risk of metabolic syndrome in Korean adults. *Metabolic Syndrome and Related Disorders, 19*(4), 192–199.

Lim, S. F., Hamdan, A., David Chua, S. N., & Lim, B. H. (2021). Comparison and optimization of conventional and ultrasound-assisted solvent extraction for synthetization of lemongrass (Cymbopogon)-infused cooking oil. *Food science & nutrition, 9*(5), 2722–2732.

Lin, L. Y., Tseng, Y. H., Li, R. C., & Mau, J. L. (2008). Quality of shiitake stipe bread. *Journal of food processing and preservation, 32*(6), 1002–1015.

Ludwig, V., Berghetti, M. R. P., Ribeiro, S. R., Rossato, F. P., Wendt, L. M., Thewes, F. R., & Wagner, R. (2021). The effects of soybean storage under controlled atmosphere at different temperatures on lipid oxidation and volatile compounds profile. *Food Research International, 147*, Article 110483.

Maghraby, Y. R., Labib, R. M., Sobeih, M., & Farag, M. A. (2023). Gingerols and shogaols: A multi-faceted review of their extraction, formulation, and analysis in drugs and biofluids to maximize their nutraceutical and pharmaceutical applications. *Food Chemistry, X*, Article 100947.

Mariotti, M. (2014). Virgin olive oil: Definition and standards. *The Extra-Virgin Olive Oil Handbook*, 11–19.

Nayak, P. K., Dash, U. M. A., Rayaguru, K., & Krishnan, K. R. (2016). Physio-chemical changes during repeated frying of cooked oil: A review. *Journal of Food Biochemistry, 40*(3), 371–390.

Nhu-Trang, T. T., Nguyen, Q. D., Cong-Hau, N., Anh-Dao, L. T., & Behra, P. (2023). Characteristics and relationships between total polyphenol and flavonoid contents, antioxidant capacities, and the content of caffeine, gallic acid, and major catechins in wild/ancient and cultivated teas in Vietnam. *Molecules, 28*(8), 3470.

Ni, Z. J., Wei, C. K., Zheng, A. R., Thakur, K., Zhang, J. G., & Wei, Z. J. (2022). Analysis of key precursor peptides and flavor components of flaxseed derived Maillard reaction products based on iBAQ mass spectrometry and molecular sensory science. *Food Chemistry: X, 13*, Article 100224.

Olszowy, M., & Dawidowicz, A. L. (2016). Essential oils as antioxidants: Their evaluation by DPPH, ABTS, FRAP, CUPRAC, and β-carotene bleaching methods. *Monatshefte für Chemie-Chemical Monthly, 147*, 2083–2091.

Parks, C. A., Stern, K. L., Fricke, H. E., Clausen, W., & Yaroch, A. L. (2020). Healthy food incentive programs: Findings from food insecurity nutrition incentive programs across the United States. *Health Promotion Practice, 21*(3), 421–429.

Santos, K. L., Alves, C. A. N., de Sousa, F. M., Gusmão, T. A. S., Alves Filho, E. G., & de Vasconcelos, L. B. (2021). Chemometrics applied to physical, physicochemical and sensorial attributes of chicken hamburgers blended with green banana and passion fruit epicarp biomasses. *International Journal of Gastronomy and Food Science, 24*, Article 100337.

Shi, L., Zheng, L., Zhang, Y., Liu, R., Chang, M., Huang, J., & Wang, X. (2018). Evaluation and comparison of lipid composition, oxidation stability, and antioxidant capacity of sesame oil: an industrial-scale study based on oil extraction method. *European Journal of Lipid Science and Technology, 120*(10), 1800158.

Vecchio, R., & Cavallo, C. (2019). Increasing healthy food choices through nudges: A systematic review. *Food Quality and Preference, 78*, Article 103714.

Winkler, J. K., & Warner, K. (2008). The effect of phytosterol concentration on oxidative stability and thermal polymerization of heated oils. *European Journal of Lipid Science and Technology, 110*(5), 455–464.

Yang, K. M., Cheng, M. C., Ye, Z. S., Chu, L. P., & Chen, H. C. (2022). Chemical properties of peanut oil from arachis hypogaea L. 'tainan 14'and its oxidized volatile formation. *Molecules, 27*(20), 6811.

Yang, K. M., & Chiang, P. Y. (2019). Effects of smoking process on the aroma characteristics and sensory qualities of dried longan. *Food chemistry, 287*, 133–138.

Yeh, H. Y., Chuang, C. H., Chen, H. C., Wan, C. J., Chen, T. L., & Lin, L. Y. (2014). Bioactive components analysis of two various gingers (Zingiber officinale Roscoe) and antioxidant effect of ginger extracts. *LWT-Food Science and Technology, 55*(1), 329–334.

Yin, W. T., Ma, X. T., Li, S. J., Liu, H. M., & Shi, R. (2021). Comparison of key aroma-active compounds between roasted and cold-pressed sesame oils. *Food Research International, 150*, Article 110794.

Zagórska, J., Czernicka-Boś, L., Kukula-Koch, W., Iłowiecka, K., & Koch, W. (2023). Impact of thermal processing on the selected biological activities of ginger rhizome—A review. *Molecules, 28*(1), 412.

Zhang, Q., Saleh, A. S., Chen, J., & Shen, Q. (2012). Chemical alterations taken place during deep-fat frying based on certain reaction products: A review. *Chemistry and Physics of Lipids, 165*(6), 662–681.