Profiling of Volatile Compounds with Characteristic Odors in *Bambusa oldhamii* Shoots from Taiwan

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This study focuses on volatile aromatic constituents extracted using solid-phase microextraction (SPME) from underground and aboveground *Bambusa oldhamii* shoots. Analysis was conducted using the extracts after heating at various temperatures and for various durations. Results of gas chromatography-mass spectrometry (GC-MS) revealed six SPME-extracted volatile aromatic compounds in underground *B. oldhamii* shoots and eleven in aboveground *B. oldhamii* shoots. Methyl salicylate with a characteristic mint aroma and methoxy-phenyl oxime that gives a smell of fresh shrimp and crabs are the main volatile compounds found in underground and aboveground shoots of *B. oldhamii*, respectively. Moreover, the two types of shoots tested also contain volatile compounds including fatty acids: *n*-hexadecanoic acid (27.94%) and aliphatic aldehyde: *trans*-2-nonenal (16.31%), respectively. The GC-MS analysis of underground and aboveground *B. oldhamii* shoots steamed at 100 °C for 60 min revealed *n*-hexadecanoic acid as the main fatty acid compound.

Keywords: Bamboo shoot; Bambusa oldhamii; Solid-phase microextraction (SPME); Gas chromatography-mass spectrometry (GC-MS)

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INTRODUCTION

Bamboo shoots, which are root sprouts protected inside bamboo sheaths, are the main by-products of bamboo forest cultivation. Asian cuisines have had a long history of bamboo shoot consumption. Not only are bamboo shoots delicious and crisp in texture, they are also natural and have nutritional benefits of being high in fiber and low in calories (Satya *et al*. 2010). Research conducted on bamboo forests showed a wide variety of bamboo shoots cultivated over a large area, with the four main types being *Dendrocalamus latiflorus*, *Phyllostachys pubescens*, *P. makinoi*, and *Bambusa oldhamii* (Lu 2001). Each type of bamboo shoot has its own distinctive flavor and texture, and local delicacies made from bamboo shoots have been developed in different regions of Taiwan. Thus, the harvest of shoots from *D. latiflorus*, *B. oldhamii*, and *B. edulis* has become central to the management of bamboo forest, indicating high utilitarian value of bamboo forests (Liese 1987). Among diverse bamboo types, *B. oldhamii* shoots are one of the most important summer crops of Taiwan. Besides being consumed as fresh food, *B. oldhamii* shoots can also be processed into dried or canned foods, with canned *B. oldhamii* shoots being the main variety to be exported. Hence, the culinary and economic value of *B. oldhamii* shoots merit attention (Tsai 2002).

In recent years, there has also been research regarding the health benefits of bamboo shoots. For example, *D. latiflorus* shoots are rich in antifungal proteins, such as dendrocinino and dendrocin, which are sources of natural phenolic antioxidants (Park and Jhon 2010). Additionally, the natural oils of bamboo shoots contain phytosterol, which not only helps to lower serum cholesterol but also possesses anti-inflammatory properties (Lu *et al.* 2011). Moreover, to promote the specialty of fermented bamboo shoots, Fu *et al.* (2002) explored further the aroma-active components and unique flavors of *D. latiflorus*. Among six edible bamboo shoot extracts obtained, Tsai (2002) found that the phenolic components in shoots of *D. latiflorus* and *B. oldhamii* have antibacterial properties. The above research findings indicate increasing attention being paid to the characteristics of various bamboo shoots in their applications to health and food products. Furthermore, upon comparison of two types of *P. pubescens* shoots, Chung *et al.* (2012) concluded that spring and winter shoots at room temperature contained different volatile compounds. Zhang *et al.* (2016) revealed that the intensity of bitterness and astringency, tannin content of aboveground *D. latiflorus* shoots were significantly higher than those shaded bamboo shoots. Cui *et al.* (2017) indicated that moso bamboo (*P. edulis*) buried in the soil, its flavor substances and spicy intensity are significantl1y different from those on the soil. The spicy intensity is inversely proportional to the boiling time. It can be confirmed that underground shoots and aboveground shoots have different flavors and compositions.

Extraction of chemically reactive compounds from phytoncides, essential oils, and other organic compounds from plants has been making rapid advances. Highly regarded by industrial professionals, the solid-phase microextraction (SPME) method can easily extract volatile compounds from woody fibers and leaves without the need for organic solvents (Steffen and Pawliszyn 1996; Chen *et al*. 2010). In view of such advantage of this extraction method and its wide applicability, this study utilizes SPME to extract volatile compounds from *B. oldhamii* shoots and analyzed their composition using gas chromatography-mass spectrometry (GC-MS) and gas chromatography coupled with flame-ionization detection (GC-FID). In addition to detecting aroma-active compounds of *B. oldhamii* shoots at ambient temperature, this research also examines the effects of heating temperature and steaming durations on volatile compounds of bamboo shoots. Findings of this study not only would shed further light on the characteristic of bamboo shoots, but also facilitate the promotion of specialty products from bamboo forests both for culinary use and health benefits.

EXPERIMENTAL

Materials

Two kinds of *B. oldhamii* shoots, including shoots buried in soil and those sprouted above soil, were obtained in July 2018 from the Shuili tract of the Experimental Forest (Nantou County, Taiwan), National Taiwan University. In general, the below-ground shoots were at an earlier physiological stage compared to the above-ground shoots. The underground shoots (UB) of *B. oldhamii* were of smaller size with base diameter ranging from 8 cm to 10 cm. The aboveground shoots (AB) of *B. oldhamii* were larger with base diameter ranging from 10 cm to 15 cm. When harvested, the fresh bamboo shoots were washed and then stored in a sealed bag at -80 °C without exposure to light prior to analysis.

Methods

Treatment conditions

To examine the changes in composition and relative contents of volatile aroma constituents under different heating temperatures (40 °C, 60 °C, and 100 °C) and durations (5 min, 30 min, and 60 min), volatile compounds present in *B. oldhamii* shoots were extracted using SPME.

Extraction of volatile compounds by SPME

The manual SPME device and 65-μm polydimethylsiloxane-divinylbenzene (PDMS/DVB) fiber used in this study were purchased from Supelco Co. (Bellefonte, PA, USA). The PDMS/DVB fiber was conditioned as recommended by the manufacturer prior to the extraction. Fresh *B. oldhamii* shoots of 3 g in weight was placed a 20-mL vial closed by a polytetrafluoroethene (PTFE)/silicone septum without any solvent, and then heated for 30 min in water baths of 25, 40, 60, and 100 °C.

The SPME fiber was then inserted into the vial and adsorbed the volatiles of *B. oldhamii* shoots in the headspace of the vial. The adsorption time of each extraction was held for 30 min at different temperatures and then desorbed at the gas chromatography (GC) inlet for 5 min at 230 °C. Similarly, the samples were steamed at 100 °C for various durations before SPME extraction for further analysis.

GC-MS and GC-FID analyses

Volatile compounds present in *B. oldhamii* shoots were analyzed using a Trace GC PoLaris Q mass (ion source temperature 230 °C, 70 eV) instrument (Thermo Electron Corporation, Waltham, MA, USA) equipped with a DB-5ms capillary column (Crossbond 5% phenyl methylpolysiloxane with a length of 30 m, diameter of 0.25 mm, and film thickness of 0.25 μm. The oven temperature was held at 40 °C for 4 min, then programmed to increase from 40 to 230 °C at a rate of 4 °C/min and held for 5 min. Other parameters included injector temperature, 230 °C; carrier gas, helium at a flow rate of 1 mL/min; split ratio, 1:30; and scan range, 50 to 400 amu.

Each extraction took approximately 47 min. Identification of major compounds of *B. oldhamii* shoots was confirmed by comparison against standards, by spiking, and on the basis of their mass spectral fragmentation pattern using the Wiley 7.0 and National Institute of Standards and Technology (NIST) mass spectral search program (version 2.0f) with Xcalibur data system (NIST 2020 MS 2.0, Thermo Fisher Scientific Inc., Waltham, MA, USA). Quantification was performed by percentage peak area calculations using the GC-FID. In addition, the Kovats index, given by the equation below, was also calculated (Eq. 1),

$$\mathrm{KI} = 100\,N + 100\,\frac{\mathrm{Log}\ t'_{\mathrm{R(X)}} - \mathrm{Log}\ t'_{\mathrm{R}(N)}}{\mathrm{Log}\ t'_{\mathrm{R}(N+1)} - \mathrm{Log}\ t'_{\mathrm{R}(N)}} \quad (1)$$

where $t'_{\mathrm{R}(N)}$ and $t'_{\mathrm{R}(N+1)}$ are the adjusted retention time for N and $N + 1$ carbon atoms in *n*-alkanes, $t'_{\mathrm{R(X)}}$ is the adjusted retention time for an unknown compound X, and $t'_{\mathrm{R(X)}}$ should fall between $t'_{\mathrm{R}(N)}$ and $t'_{\mathrm{R}(N+1)}$.

RESULTS AND DISCUSSION

Volatile Compounds of *B. oldhamii* Shoots at Ambient Temperature

Figure 1 displays the volatile aromatic compounds released from UB and AB from *B. oldhamii* and their relative contents at 25 °C. As shown, there were wide differences in the type of compounds extracted and their proportions. The main volatile compounds present in UB of *B. oldhamii* were benzenoids (40.09%), fatty acid (27.94%), and *n*-alkanes (11.21%). In contrast, the compounds found in AB of *B. oldhamii* were nitrogen compounds (30.41%), aliphatic aldehyde (16.31%), furan (13.17%), aliphatic alcohol (12.37%), and benzenoids (11.44%). It is noticeable that aliphatic alcohol, aliphatic aldehyde, and furan were present in AB only. Comparatively, UB had remarkably more benzenoids than their AB counterparts (40.09% *vs.* 11.44%, respectively); while AB had considerably more nitrogen compounds than their UB counterparts (30.41% *vs.* 10.15%, respectively).

After SPME, 6 and 11 volatile compounds were identified from UB and AB of *B. oldhamii*, respectively at 25 °C (Table 1). In other words, UB comprised fewer volatile compounds than AB. As indicated in Table 1, the primary volatile compounds found in UB were methyl salicylate (38.91%), followed by *n*-hexadecanoic acid (27.94%), and methoxy-phenyl oxime (10.15%). In contrast, AB comprised mainly methoxy-phenyl oxime (30.41%), followed by *trans*-2-nonenal (16.31%), and 2-pentyl furan (13.17%). Methoxy-phenyl oxime is the volatile compound found in abundance in both UB and AB of *B. oldhamii*. Zhang *et al.* (2010) investigated the impact of seafood storage methods on their volatile compound contents and found that fresh shrimps and crabs contained substantial amount of methoxy-phenyl oxime, which gives their distinct smell. Though of much smaller relative contents, limonene is another volatile compound found in both UB (1.94%) and AB (3.99%). As shown in Table 2, limonene possesses a distinctive scent (Tu *et al*. 2002; Choi 2006; Gürbüz *et al*. 2006; Costa *et al*. 2008), which Ibrahim *et al*. (2001) found suitable for external use on pets as parasitic insecticide. In addition to its activity against insects and mites, limonene also has mosquito-repellent and antibacterial properties. Thus, limonene is an ingredient often utilized in natural agents against bacteria and insect pests. Despite being a natural enemy of pests, several cases have also shown phytotoxic effect of limonene on plants (Fagodia *et al*. 2017; Ibáñez *et al*. 2020), which also merits attention.

Methyl salicylate, a benzenoid compound, is present only in UB but absent in AB. Wang *et al*. (2008) reported that methyl salicylate has the scent of mint. In their study on food storage of African cultures, Jayasekara *et al*. (2002) found that root bark from *Securidaca longepedunculata* Fers (Polygalaceae), which comprises mainly methyl salicaylate (90%), exhibited insect-repelling property. Moreover, Jao (2000) examined hydrogen cyanide levels of bamboo shoots used as food and reported conversion of some hydrogen compounds within bamboo shoots into cyanogenic glycoside. A commonly found compound in shoots of *D. latiflorus* and *B. oldhamii* is cyanogenic glycoside, which is toxic when consumed by animals at room temperature, revealing a form of defense mechanism adopted by plants. Similarly, the high relative content of methyl salicylate (38.91%) in UB offers protection against bacteria and insects. The UB of *B. oldhamii* contains abundant carbohydrates; hence, to ensure continuous plant growth, its self-defense mechanisms involve not only forming a hard outer sheath, but also converting methyl salicylate into a natural insect repellent. In contrast, three aromatic volatile compounds, namely 2-pentyl furan, 1-octen-3-ol, and benzaldehyde, were found only in AB but were absent in UB. Figure 2 displays the chemical structure of major volatile compounds identified and Table 2 lists their distinctive aromas as reported in related literature.

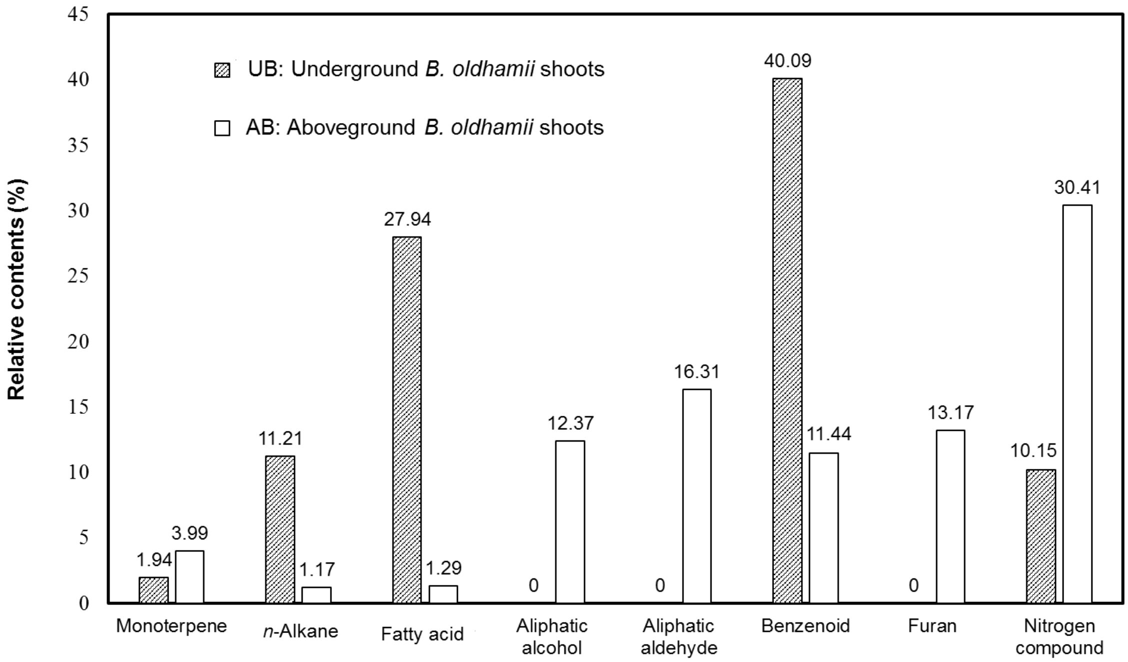

Fig. 1. Classes of volatile aromatic compounds present in *B. oldhamii* shoots at 25 °C

Table 1. Volatile Compounds Released from *B. oldhamii* Shoots at 25 °C

No.	RT (min)	KI[a]	rKI[b]	Compounds	Relative Content (%)		Identification [e]
					UB [c]	AB [d]	
1	9.80	901		Methoxy-phenyl oxime	10.15	30.41	MS
2	12.21	963	960	Benzaldehyde		2.07	MS, KI, ST
3	13.07	983	979	1-Octen-3-ol		2.45	MS, KI, ST
4	13.44	991	988	2-Pentyl furan		13.17	MS, KI, ST
5	15.03	1031	1029	Limonene	1.94	3.99	MS, KI, ST
6	19.87	1155	1153	*cis*-3-Nonen-1-ol		2.11	MS, KI, ST
7	20.13	1162	1161	*trans*-2-Nonenal		16.31	MS, KI, ST
8	20.42	1170	1166	*cis*-2-Nonen-1-ol		7.81	MS, KI, ST
9	21.27	1191	1195	Methyl salicylate	38.91		MS, KI, ST
10	27.13	1358	1355	4-Hydroxybenzaldehyde		9.37	MS, KI, ST
11	42.39	1961	1963	*n*-Hexadecanoic acid	27.94	1.29	MS, KI
12	43.98	2099	2100	*n*-Heneicosane	5.45	1.17	MS, KI, ST
13	45.41	2199	2200	*n*-Docosane	5.76		MS, KI, ST
				Identified compounds (%)	91.33	90.13	

RT: Retention time
[a] Kovats index relative to C_9 to C_{22} *n*-alkanes on the DB-5ms column;
[b] Identification through comparison of mass spectrum, Kovats index on a DB-5ms column in Adams (2007) and co-injection with authentic compounds;
[c] Underground *B. oldhamii* shoots;
[d] Aboveground *B. oldhamii* shoots;
[e] KI, Kovats index; MS, mass spectroscopy; ST, co-injection with authentic standard compounds

Table 2. Characteristic Odors of Volatiles in *B. oldhamii* Shoots at 25 °C

No.	Volatile Compounds	Odor Descriptions	References
1	Methoxy-phenyl oxime	Fresh seafood, fresh prawn or crab	Zhang *et al*. 2010
2	Limonene	Citrus-like, pungent, lemon-like, citric, fresh	Tu *et al*. 2002; Choi 2006; Gürbüz *et al*. 2006; Costa *et al*. 2008; Ibáñez *et al*. 2020
3	Methyl salicylate	Sweet, spicy, minty	Wang *et al*. 2008
4	2-Pentyl furan	Floral, fruit, cucumber, hay, licorice, fatty (very faint), meat broth, savory	Klensporf and Henryk 2008; Yang *et al*. 2008; Thompson *et al*. 2009; Olivares *et al*. 2011
5	1-Octen-3-ol	Mushroom smell	Toshiyuk *et al*. 2010
6	Benzaldehyde	Almond, sweet, candy, fruity, nutty, fragrant	Gocmen *et al*. 2004; Costa *et al*. 2008; Wang *et al*. 2008; Yang *et al*. 2008

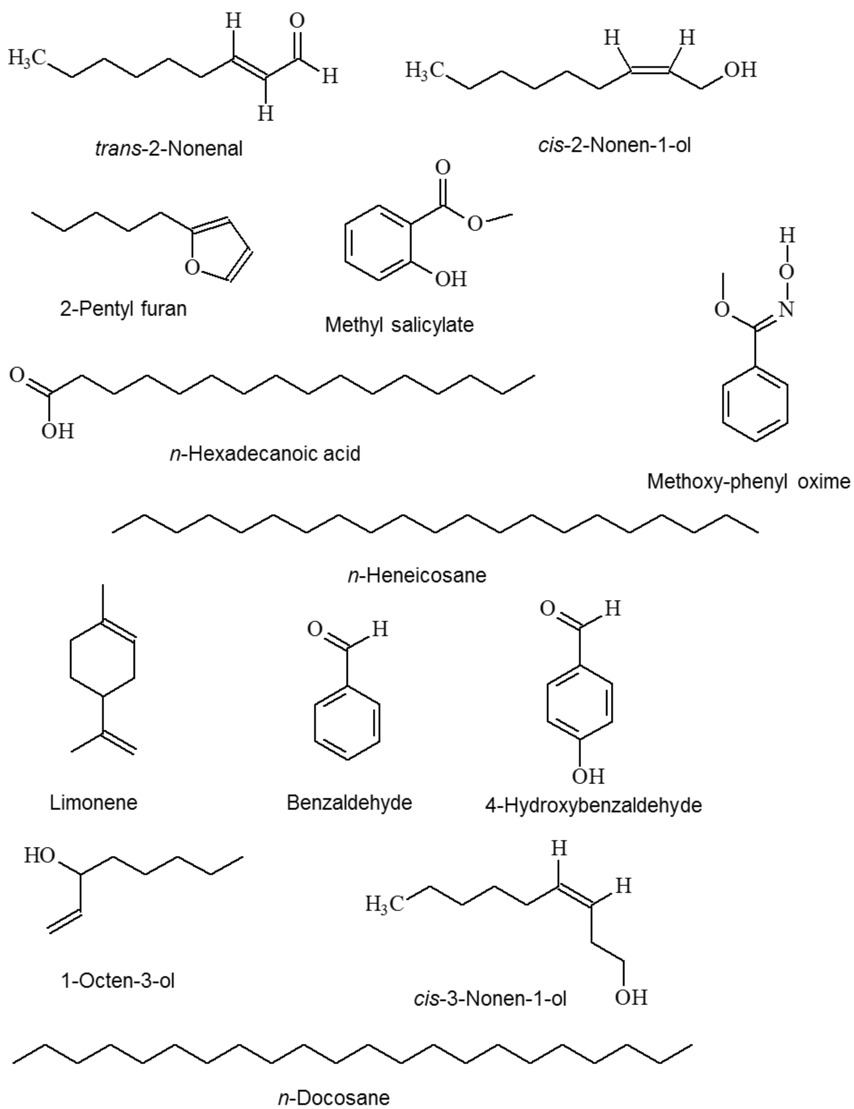

Fig. 2. Chemical structures of major volatile compounds from *B. oldhamii* shoots

Effect of Heating Temperature on Volatile Compounds of *B. oldhamii* Shoots

To investigate the impact of heating temperature on volatile compounds present in UB and AB, approximately 3-g samples were put into 20-mL test bottles. Each sample was heated at 40, 60, and 100 °C for 30 min. Figure 3 shows the volatile aromatic compounds present in the bamboo shoots analyzed using SPME. As shown, at ambient temperature (25 °C), UB comprised predominantly benzenoids (40.09%), followed by fatty acids (27.94%), and *n*-alkanes (11.21%). After heating at 40 °C for 30 min, benzenoids clearly increased in relative content, reaching 66.29%. However, further increase in heating temperature did not lead to higher relative contents of benzenoids. Instead, upon heating at 100 °C, the main volatile compounds present in UB became fatty acids (46.97%), followed by *n*-alkanes (13.60%), and aliphatic aldehyde (7.18%).

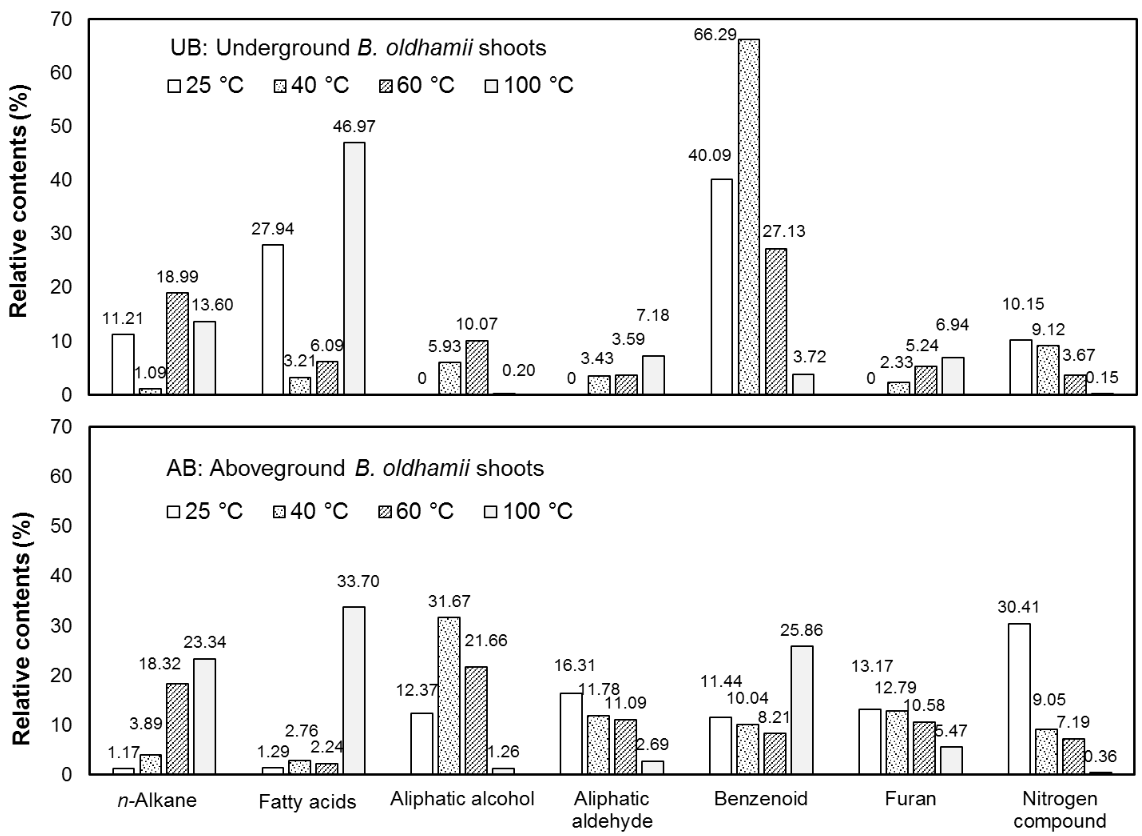

Fig. 3. Relative contents of volatile compounds present in *B. oldhamii* shoots heated at different temperatures for 30 min

In contrast, AB at ambient temperature comprise a higher proportion of nitrogen compounds (30.41%), followed by aliphatic aldehyde (16.31%), and furan (13.17%). However, upon heating at 100 °C, the content of nitrogen compounds dropped markedly to 0.36%. A similar decrease in relative content, though of a smaller extent, was also found in aliphatic aldehyde (2.69%), furan (5.47%), and aliphatic alcohol (1.26%). In contrast, when heated at 100 °C, fatty acids in AB showed a remarkable increase in relative content from 1.29% to 33.70%. Likewise, after heating at 100 °C, the relative content of *n*-alkanes rose from 1.17% at 25 °C to 23.34% while that of benzenoids, from 11.44% to 25.86%.

Hence, the three predominant volatile compounds in AB at ambient temperature and after heating at 100 °C were completely different.

Taken together, changes in relative content of volatile compounds at various heating temperatures evidenced remarkable impact of heating temperature on chemical composition of UB and AB. Heating at any temperature reduced nitrogen compounds in *B. oldhamii* shoots, with a larger reduction observed in AB. Contrasting trends were observed in furan and aliphatic aldehyde; their relative contents in UB increased with heating temperature but decreased in AB. Finally, both UB and AB when heated at 100 °C comprised mainly of fatty acids, followed by benzenoids, and *n*-alkanes.

Table 3 lists the major volatile compounds identified in *B. oldhamii* shoots heated at different temperatures for 30 min. At 25 °C, benzenoids were predominant in UB, with methyl salicylate being the main compound (38.91%). It remained the primary benzenoid compound even at higher heating temperatures of 40 and 60 °C, though its relative content first increased (68.60%), then decreased (25.96%), and eventually it became non-existent at 100 °C. In contrast, when heated at 100 °C, both UB and AB comprised predominantly of fatty acids, with *n*-hexadecanoic acid (46.97% and 33.70%, respectively) being the main compound. As mentioned above, the second predominant compound in UB heated at 100 °C was *n*-alkanes, primarily *n*-heneicosane (10.94%). In contrast, apart from fatty acids, AB heated at 100 °C comprised benzenoids, with 4-hydroxybenzaldehyde (25.45%) as the main compound, followed by *n*-alkanes, again primarily *n*-heneicosane (21.88%).

Table 3. Changes in Relative Contents of Major Compounds of *B. oldhamii* Shoots Heated at Different Temperatures for 30 min

Compounds	25 °C		40 °C		60 °C		100 °C	
	UB	AB	UB	AB	UB	AB	UB	AB
Methoxy-phenyl oxime	10.15	30.41	9.12	9.05	3.67	7.19		0.31
2-Pentyl furan		13.17	2.33	12.79	5.24	9.68	6.94	5.03
trans-2-Nonenal		16.31		11.78		9.12		1.66
cis-2-Nonen-1-ol		7.81	2.36	27.00	5.46	18.36		0.97
Methyl salicylate	38.91		68.60		25.96	0.53		
4-Hydroxybenzaldehyde		9.37		5.77	1.18	5.12	3.07	25.45
n-Hexadecanoic acid	27.94	1.29	3.21	2.76	6.09	2.24	46.97	33.70
n-Heneicosane	5.45	1.17	1.09	3.89	13.74	14.40	10.94	21.88

UB: Underground *B. oldhamii* shoots
AB: Aboveground *B. oldhamii* shoots

Among the compounds listed in Table 3, a notable point was that 4-hydroxybenzaldehyde in AB exhibited the most obvious increase in relative content from 9.37% at ambient temperature to 25.45% after being heated at 100 °C. 4-Hydroxybenzaldehyde, a compound identified in the extract of traditional Chinese medicine ingredient *Gastrodia elata*, suppresses monoamine oxidase (MAO), which was found to help ameliorate depression (Chen 2008). Moreover, Ha *et al*. (2000) identified 4-hydroxybenzaldehyde in the ether fraction of *G. elata* methanol extract. The antiepileptic and anticonvulsive activity of *G. elata* B1 can be partially attributed to the antioxidation property of 4-hydroxybenzaldehyde and its neuromodulation effect. Hence, besides being high in dietary fiber, cooking bamboo shoots to high temperature can also bring additional health benefits.

Effect of Heating Duration on Volatile Compounds of *B. oldhamii* Shoots

Figure 4 displays the volatile aromatic compounds present in bamboo shoots steamed at 100 °C for 5, 30, and 60 min. Contrasting trends are seen with respect to changes in relative contents of compounds analyzed using SPME. As shown, contents of fatty acids in UB increased with heating duration, rising remarkably from 4.49% at 5 min to 46.97% at 30 min, and reaching 68.68% at 60 min. Longer heating duration yielded the predominant compound present in UB. The same linear relationship was also observed for fatty acids in AB, increasing markedly from 7.34% at 5 min to 33.70% at 30 min, and reaching 45.49% at 60 min. Similarly, upon being heated for longer durations, its relative content increased in the main volatile compounds from AB.

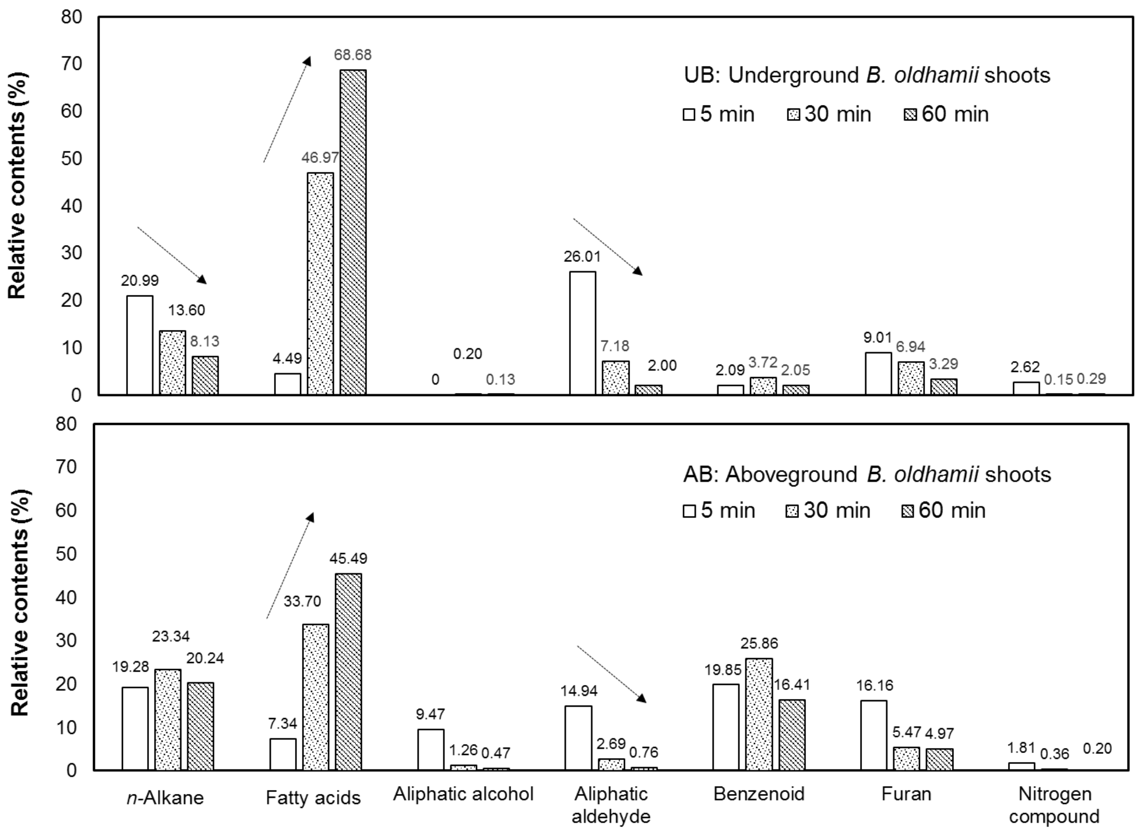

Fig. 4. Relative contents of volatile compounds present in *B. oldhamii* bamboo shoots heated at 100 °C for different durations

In contrast, aliphatic aldehyde, *n*-alkanes, and furan contents in UB showed an inverse relationship between relative content and heating duration. Thus, the longer the shoots are heated, the relative contents of these volatile compounds were decreased. As shown, after heating at 5 min, aliphatic aldehyde (26.01%) was the predominant compound, followed by *n*-alkanes (20.99%) and furan (9.01%). Further heating reduced their relative contents to 7.18%, 13.60%, and 6.94%, respectively, at 30 min. After 30-min heating, the fatty acids (46.97%) content replaced *n*-alkanes as the main component, followed by aliphatic aldehyde. After 60-min heating, the relative content of aliphatic aldehyde and *n*-alkanes dropped considerably from their initial high levels to only 2.00% and 8.13%, respectively. The same inverse relationship was observed only for aliphatic aldehyde and furan, but not for *n*-alkanes in AB. The relative contents of aliphatic aldehyde and furan dropped respectively from 14.94% and 16.16% after 5-min heating to 2.69% and 5.47% after 30-min heating, respectively.

Moreover, notable variation in relative contents of benzenoids present in UB and AB was observed. The UB comprised only 2.09%, 3.72%, and 2.05% of benzenoids after being heated for 5 min, 30 min, and 60 min, respectively; while AB contained 19.85%, 25.86%, and 16.41%, respectively. Despite the wide differences in relative contents, they showed the same trend of changes with heating periods; that is, first increased, then decreased.

Only traces of nitrogen compounds and aliphatic alcohol were present in UB and AB when heated at 100 °C and their relative contents reduced even further after 60-min heating. Taken together, the analysis results revealed variations in trend of changes and relative contents in UB and AB heated for different durations. After 5-min heating at 100 °C, the predominant compound was aliphatic aldehyde in UB and benzenoids in AB. Upon further heating, more fatty acids were formed and it became the main compounds in both types of shoots.

Table 4 lists the major volatile compounds identified in *B. oldhamii* shoots heated at 100 °C for various time intervals.

Table 4. Changes in Relative Contents of Major Compounds of *B. oldhamii* Bamboo Shoots Heated at 100 °C for Different Durations

Compounds	5 min		30 min		60 min	
	UB	AB	UB	AB	UB	AB
n-Hexanal	7.44	0.93	1.60	0.31	0.53	0.11
Methoxy-phenyl oxime	2.62	1.81		0.31	0.21	0.17
2-Pentyl furan	9.01	14.82	6.94	5.03	3.29	3.78
trans-2-Nonenal		12.52		1.66		0.48
cis-2-Nonen-1-ol		6.94		0.97		0.36
(*2E*,*4E*)-Decadienal	16.95	1.01	5.07	0.47	1.28	0.09
4-Hydroxybenzaldehyde		18.33	3.07	25.45	1.62	16.17
n-Hexadecanoic acid	4.49	7.34	46.97	33.70	68.68	45.49
n-Heneicosane	12.76	19.28	10.94	21.88	6.47	18.67
n-Docosane	8.23		1.76	1.46	1.24	1.57

UB: Underground *B. oldhamii* shoots
AB: Aboveground *B. oldhamii* shoots

As shown, the number of volatile compounds present in the shoots varied with heating period. In general, more volatile compounds were found with longer heating duration. In UB, 7 compounds were identified after heating for 5 min and 30 min, but 8 compounds after 60-min heating. Important observation is that the 7 compounds identified after 5- and 30-min heating periods were not the same. Methoxy-phenyl oxime was observed after 5-min heating, which disappeared after 30-min heating but reappeared after

60-min though in traces. In AB, more compounds were identified, 9, 10, and 10 different compounds after heating for 5 min, 30 min, and 60 min, respectively. In other words, AB comprised more volatile compounds than UB. Specifically, *trans*-2-nonenal and *cis*-2-nonen-1-ol were found only in AB but not in UB.

Consistent with the results displayed in Fig. 4, *n*-hexadecanoic acid was the predominant fatty acid compound, and its relative content in both UB and AB increased with increasing heating periods. In contrast, (2*E*,4*E*)-decadienal was the main aliphatic aldehyde compound, with relative contents in both UB and AB decreasing with heating duration. For benzenoids, 4-hydroxybenzaldehyde was the main compound in AB, whose relative content first increased after heating for 30 min, but decreased with further heating for 60 min. These outcomes align with the investigation of Chung *et al*. (2012) that examine the impacts on the volatile compounds in moso bamboo shoots from both spring and winter after steaming.

CONCLUSIONS

This research focused on using solid-phase microextraction (SPME) to extract volatile compounds from UB and AB of *B. oldhamii* and then using gas chromatography-mass spectrometry (GC-MS) to analyze the extracts at ambient temperature and heating for various time periods.

1. At ambient temperature, both underground types of bamboo shoots mainly hold volatile compounds with distinctive scents: 38.91% of methyl salicylate that has the sweet minty fragrance and minty and 30.41% of a nitrogen compound known as methoxy-phenyl oxime, which holds a scent akin to fresh shrimp and crabs.
2. Both underground bamboo shoots (UB) and aboveground bamboo shoots (AB) when heated at 100 °C for 60 min comprised mainly of fatty acids (*n*-hexadecanoic acid), followed by *n*-alkanes (*n*-heneicosane).
3. When UB and AB of *B. oldhamii* were heated at 100 °C for 30 min, they mainly produced the fatty acid compound of *n*-hexadecanoic acid at 46.97% and 33.70%, respectively.

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