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Effect of roasting on the volatile constituents of *Trichosanthes kirilowii* seeds

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ABSTRACT

Roasted *Trichosanthes kirilowii* seeds have much more intense flavor than the raw seeds, and are commonly used as food and in the preparations of many medicinal formulations. Volatile constituents in the raw and roasted *T. kirilowii* seeds were separated by simultaneous distillation and extraction, and analyzed by gas chromatography–mass spectrometry on two capillary gas chromatography columns of different polarities (DB-WAX and HP-1). A total of 40 volatile compounds were identified in the raw seeds, with pentanal, 2-pentanol, styrene, (Z)-2-heptenal, (+)-calarene, and α -muurolene being the predominant compounds; 40 volatile compounds were also identified in the roasted seeds, with 3-methylbutanal, ethanol, 2-butanol, 2,3-butanediol, (E,E)-2,4-nonadienal, and 2-isopropyl-5-methyl-9-methylene-bicyclo[4.4.0]dec-1-ene being the most abundant compounds. A total of 15 compounds, mostly aldehydes, were common in both seeds. Roasting of *T. kirilowii* seeds resulted in a significant decrease in the levels of sesquiterpenes and short-chain aliphatic aldehydes. By contrast, high concentrations of 3-methylbutanal, ethanol, 2-butanol, and alkyl pyrazines were generated, which was responsible for the unique flavor of the roasted seeds. The study results may be useful for optimizing the roasting process and oil processing of *T. kirilowii* seeds.

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1. Introduction

Trichosanthes kirilowii is a dioecious liana of the Cucurbitaceae family. Investigation and utilization of this plant have increased over the past 30 years, mainly because novel

compounds continue to be identified in the plant, including trichosanthin, which has the potential to inhibit human immunodeficiency virus [1–3]. *T. kirilowii* seeds have been commonly used in oriental traditional medicine and in Chinese medicine for the treatment of cough, inflammation,

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diabetes, and obstipation [4]. A number of studies have reported special or novel compounds with specific bioactivity in *T. kirilowii* seeds, such as trichosanthrip, trichosanic acid, isoaurone, and hanultarin [4–6]. A recent study indicated that *T. kirilowii* seeds are an excellent nutritional source of amino acids and essential mineral elements, with arginine and manganese found in abundant quantities [7]. In the Chinese food industry, *T. kirilowii* seeds are used as a *Guazi* snack and to produce edible oils. *Guazi* (Chinese name) is a very popular snack, which is produced by roasting edible plant seeds, such as sunflower, pumpkin, and watermelon seeds. Roasted *T. kirilowii* seed is called *Diao-Guazi* in Chinese. *Diao-Guazi* is gaining attention because of its unique flavor and health benefits. It is more expensive than the other *Guazi* products in the supermarket, such as roasted sunflower and pumpkin seeds. As a result, the planting and harvesting of *T. kirilowii* seeds are steadily increasing in China.

The volatile compounds extracted from edible plant seeds have received considerable interest because of their chemical diversity, functional activities, and unique roasted flavors. For example, the volatile oils from parsley and celery seeds exhibited strong antioxidant activity, which was comparable with that of α -tocopherol [8]. After roasting, *T. kirilowii* seeds have much more intense flavor than the raw seeds. Many Chinese medicinal formulations use roasted rather than raw *T. kirilowii* seeds. Despite the long history of use of *T. kirilowii* seeds in a variety of foodstuffs and medicines, there are no reports in the literature regarding the volatile components present in the seeds. Furthermore, so far, no comparison between the volatile components from raw and conventionally roasted *T. kirilowii* seeds has been made.

This study aims to investigate the volatile components from the raw and roasted seeds of *T. kirilowii* harvested in China, and to determine differences, if any, between them.

2. Materials and methods

2.1. Materials and chemicals

Raw seeds of *T. kirilowii* were harvested from Langli village in Anji County (Zhejiang, China) in November 2011. They were immediately transported to our laboratory (using the cold chain method) and stored at 4°C in the dark.

Anhydrous sodium sulfate and calcium chloride were supplied by Lingfeng (Shanghai, China). Ether and pentane were obtained from Sinopharm (Shanghai, China) and CNW (Düsseldorf, Germany), respectively. Both solvents were distilled before use. Standard methyl nonanoate was purchased from Fluka (Buchs, Switzerland). The *n*-alkanes (C₇–C₂₈) standards were obtained from Aladdin (Shanghai, China).

2.2. Roasting of *T. kirilowii* seeds

The raw seeds (200 g) were roasted in an open electric roaster (equipped with an automatic heat regulator; Siruite Machinery Plant, Kaifeng, China) with constant stirring at 140 ± 5°C for 30 minutes, 160 ± 5°C for 15 minutes, and 180 ± 5°C for

10 minutes, respectively. Each roasting run was conducted in duplicate. After the roasting, the samples were cooled at room temperature and then stored at 4°C in the dark. The optimal roasting condition was found to be 160 ± 5°C for 15 minutes based on aroma impressions assessed by 10 panelists.

2.3. Isolation of volatile components

Both types of seeds were dehulled and the kernels were removed and weighed for the extraction of volatile components. The volatile components were extracted from the seeds using a simultaneous distillation and extraction (SDE) setup equipped with Likens–Nickerson apparatus (TrueLab, Shanghai, China) connected to a vacuum pump. The seeds (50 g) were initially cooled to 4°C, mixed with 20 mL aqueous saturated solution of calcium chloride, and then ground using a commercial blender for 10 seconds. The sample solution was then mixed with double-distilled water (600 mL), and a solution of methyl nonanoate (50 µg) in a 1:1.12 (v/v) pentane:ether mixture (1 mL) was added as an internal standard. The mixture was placed in a 2000-mL round-bottomed flask, whereas the solvent mixture [50 mL of a 1:1.12 (v/v) pentane:ether] was added to a 250-mL round-bottomed flask in the SDE equipment. The sample flask was heated to 52°C for SDE. After 1.5 hours of processing, the collected solvent distillate was dried over anhydrous sodium sulfate and concentrated at 42°C using a Vigreux column to make up a final volume of approximately 1 mL for gas chromatography–mass spectrometry (GC–MS) analysis.

2.4. Determination of volatile compounds by GC–MS

Analysis was performed using a polar capillary DB-WAX column (polyethylene glycol, 30 m × 0.25 mm i.d. × 0.25-µm film thickness; J&W Scientific, Folsom, CA, USA) and a nonpolar HP-1 column (dimethylpolysiloxane; 30 m × 0.25 mm i.d. × 0.25-µm film thickness; J&W Scientific, Folsom, CA, USA) connected to a QP2010 GC–MS system (Shimadzu, Japan). The oven temperature was held at 40°C for 2 minutes, and then increased at a rate of 5°C/minute up to a final temperature of 250°C. The oven was then held at 250°C for 10 minutes. The temperatures of injector and ion source were set at 230°C and 200°C, respectively. The GC–MS was operated at an ionization energy of 70 eV in the electron impact mode over a range of 33–650 amu. Helium was used as the carrier gas at a constant flow rate of 1.6 mL/minute. The extract (0.3 µL) was injected with an autosampler in splitless mode.

Retention indices (RIs) were calculated according to the Kovats method using *n*-alkanes (C₇–C₂₈) as external references. The experimental RIs of the volatile compounds were compared with those from the NIST Chemistry WebBook web site (National Institute of Standards and Technology, USA). To identify the peaks in the mass spectra, we compared our mass spectra results with those from the NIST147 library, and also with authentic reference standards when available. Approximate concentrations of the volatile compounds were calculated according to the internal standard method using methyl nonanoate.

3. Results and discussion

3.1. Volatile components from raw *T. kirilowii* seeds

Forty compounds were isolated and identified from the volatile extract of raw *T. kirilowii* seeds. The components are listed in an increasing RIs order on a DB-WAX (polar) column (Table 1). Aldehydes (44.31%), hydrocarbons (34.41%) including terpenes, and alcohols (13.76%) were identified as the predominant chemical classes. The total amount of other chemical classes consisting of seven compounds, including heterocyclic compounds, esters, acids, and ketones, was only 6.2%. The six most abundant compounds, representing

approximately 63% of the total amount of volatile compounds in the raw seeds, were pentanal (19.84%), (+)-calarene (16.59%), (Z)-2-heptenal (7.72%), styrene (6.58%), 2-pentanol (6.39%), and α -muurolene (5.93%). The high content of short-chain aliphatic aldehydes in the volatile constituents may be due to lipid oxidation, as the seed lipids contain 87.32% of unsaturated fatty acids according to fatty acid compositions analysis in our laboratory (data not shown). Pentanal has a fruity, banana-like, green odor and is used in flavorings. It is the key compound that imparts the specific aroma in ripened avocado fruits. The compounds pentanal, hexanal, and pentanol were related to the presence of lipoxygenase in its seed, which catalyzed the peroxidation of polyunsaturated fatty acids containing the 1,4-pentadiene structure. This has been

Table 1 – Volatile constituents of raw *Trichosanthes kirilowii* seeds.

No.	Compounds	Retention indices		Identification ^a	Percentage of total area (%)
		DB-WAX	HP-1		
1	1-(1-Methylethyl)-cyclopentene	927	n.d.	C	0.69
2	Pentanal	984	<700	A	19.84
3	2-Methyl-butanoic acid ethyl ester	1059	841	A	2.84
4	Hexanal	1086	779	A	4.08
5	Undecane	1099	1099	A	0.39
6	3-Pentanol	1110	<700	A	1.93
7	2-Pentanol	1124	<700	A	6.39
8	(E)-2-Ethyl-2-butenal	1161	811	B	0.55
9	3-Methyl-2-butenal	1199	750	A	0.54
10	3-Methyl-1-butanol	1209	718	A	0.91
11	(E)-2-Hexenal	1219	829	A	0.50
12	2-Pentyl-furan	1236	977	A	0.46
13	1-Pentanol	1254	752	A	2.03
14	Styrene	1260	875	A	6.58
15	(Z)-2-Heptenal	1324	932	A	7.72
16	6-Methyl-5-hepten-2-one	1341	n.d.	C	0.28
17	1-Hexanol	1356	872	A	0.40
18	2,2-Dimethyl-propanoic acid heptyl ester	1390	1260	B	0.33
19	Nonanal	1394	1084	A	0.38
20	(E)-2-Octenal	1430	1028	A	0.30
21	1-Octen-3-ol	1455	966	A	0.33
22	Acetic acid	1458	<700	A	0.41
23	Copaene	1486	1370	B	2.77
24	Benzaldehyde	1521	933	A	0.85
25	β -Cubebene	1535	1419	B	0.42
26	(+)-Calarene	1585	1440	A	16.59
27	(E)-2-Decenal	1643	1238	A	0.45
28	Acetophenone	1648	1034	B	0.75
29	2,4-Nonadienal	1663	1169	B	1.64
30	2-Hydroxybenzaldehyde	1675	1009	A	1.22
31	Germacrene D	1683	1469	A	0.75
32	(E,E)-2,4-Nonadienal	1699	1185	A	4.49
33	α -Muurolene	1719	1487	B	5.93
34	Cadina-1(10),4-diene	1753	1514	B	0.29
35	(E,E)-2,4-Decadienal	1765	1269	A	0.34
36	2,4-Decadienal	1808	1288	A	1.41
37	Benzyl alcohol	1875	1031	A	0.81
38	β -Ionol	1936	1401	B	0.48
39	δ -Cadinol	2193	1623	B	0.48
40	2,3-Dihydrobenzofuran	2391	1224	A	1.13

n.d. = not detected.

^a The reliability of the proposed identification has been indicated according to the following: A, mass spectrum and retention indices on both the polar and nonpolar columns agreed with those of the standards, computer database, and literature; B, mass spectrum and retention indices on both the polar and nonpolar columns agreed with values from the computer database and the literature; C, mass spectrum and retention index on a polar column agreed with the values from the computer database and the literature.

shown in rice seeds and linseeds [9,10]. (Z)-2-Heptenal has a meaty odor and was identified as a key aroma compound in lamb meat [11]. 2-Pentanol has a mild green, fusel oil odor, and has been identified in plant seeds such as beans, soybeans, roasted barley, peanut, and filbert [12]. It is the key aroma compound of Chinese chili pepper at the ripening stage [13].

Interestingly, the raw seeds contained significant quantities of volatile sesquiterpenoids. Among them, (+)-calarene and α -muurolene were the major constituents. The total amount of sesquiterpenes in the raw seeds was 26.75%. (+)-Calarene was found to be one of the major volatile components used as a quality indicator of different ginsengs [14,15]. Limited information suggests that (+)-calarene is a major compound in plant seeds. Although calarene can be

synthesized [16], the synthesized calarene contains both (+)-calarene and (–)-calarene. Natural calarene, however, only consists of (+)-calarene. Related essential oils containing (+)-calarene as the major compound have a sedative activity upon inhalation of their vapors, and are thus, expected to promote the health and healing benefits of aromatherapy [17]. With this in mind, raw *T. kirilowii* seeds or its essential oil may serve as an important source of natural (+)-calarene and may be used in aromatherapy. Research now shows that sleep aromatherapy curbs conditioned fears by altering the neural representation of a feared stimulus [18]. α -Muurolene has a woody-type odor and was found in fenugreek seeds [19]. This imparts the characteristic flavor released by fig syconia [20]. α -Muurolene synthase was identified in fungus *Coprinus cinereus*

Table 2 – Volatile constituents of roasted *Trichosanthes kirilowii* seeds.

No.	Compounds	Retention indices		Identification ^a	Percentage of total area (%)
		DB-WAX	HP-1		
1	3-Methylbutanal	923	<700	A	7.60
2	Ethanol	940	<700 ²	A	10.58
3	Pentanal	984	<700	A	4.28
4	2-Butanol	1030	<700	A	11.67
5	Hexanal	1085	779	A	1.52
6	2-Ethoxy-propane	1092	<700	B	0.44
7	2-Pentanol	1123	<700	A	0.48
8	2-Ethoxy-butane	1153	<700	B	2.07
9	2-Heptanone	1184	873	A	0.41
10	4-Methyl-2-pentanol	1199	739	A	0.50
11	2-Hexanol	1210	779	A	0.44
12	1-Pentanol	1254	752	A	0.37
13	3-Hydroxy-2-butanone	1285	<700	A	4.35
14	2-Heptanol	1306	889	A	1.13
15	2,5-Dimethyl-pyrazine	1320	885	A	1.41
16	(Z)-2-Heptenal	1324	932	A	1.33
17	2-Ethyl-5-methyl-pyrazine	1383	970	A	0.60
18	2-Ethyl-6-methyl-pyrazine	1389	977	A	1.14
19	Nonanal	1394	1083	A	0.43
20	2,3,5-Trimethyl-pyrazine	1399	980	A	1.67
21	3-Ethyl-2,5-dimethyl-pyrazine	1444	1056	A	2.20
22	Acetic acid	1457	<700	A	0.93
23	2-Ethyl-3,5-dimethyl-pyrazine	1460	1060	A	0.60
24	Copaene	1486	1370	B	1.46
25	2,3,5-Trimethyl-6-ethylpyrazine	1491	1135	B	1.02
26	Pyrrrole	1518	743	A	0.36
27	Benzaldehyde	1521	928	A	0.45
28	2-Methyl-5-(2-propenyl)-pyrazine	1537	1073	B	0.52
29	2,3-Butanediol	1541	806	B	5.18
30	2-Isopropyl-5-methyl-9-methylene-bicyclo[4.4.0]dec-1-ene	1584	1419	B	7.35
31	Benzeneacetaldehyde	1643	1005	A	2.09
32	Acetophenone	1648	1034	B	0.69
33	2,4-Nonadienal	1663	1168	A	1.45
34	(E,E)-2,4-Nonadienal	1698	1184	A	5.50
35	α -Amorphene	1719	1487	B	2.82
36	(E,E)-2,4-Decadienal	1765	1269	A	0.49
37	2,4-Decadienal	1808	1287	A	1.54
38	Benzothiazole	1948	1185	B	1.68
39	2-Methoxy-4-vinylphenol	2193	1278	B	0.39
40	2,3-Dihydrobenzofuran	2390	1224	A	0.72

n.d. = not detected.

^a The reliability of the proposed identification has been indicated according to the following: A, mass spectrum and retention indices on both polar and nonpolar columns agreed with those of the standards, computer database, and literature; B, mass spectrum and retention indices on both polar and nonpolar columns agreed with values from the computer database and the literature; C, mass spectrum and retention index on a polar column agreed with the values from the computer database and the literature.

[21]. α -Muurolene and copaene (2.77%) determined in this study are also found as main volatile components in a Chinese herb named *Melia azedarach* and in Greek propolis [22,23].

Styrene has balsamic or gasoline aromatics and is usually considered an artificial volatile organic pollutant in environmental monitoring. However, it occurs as a minor volatile compound commonly found in many foods such as almonds, beef, wheat, and strawberry [24,25]. Recently, styrene was reported as a major volatile compound in pea seed and irradiated linseed [26,27]. Although styrene has been found to be produced by some fungi [28–30], its origin in foods remains unclear.

3.2. Volatile components from roasted *T. kirilowii* seeds

Forty volatile compounds were identified in the volatile extract from the roasted *T. kirilowii* seeds. The components are listed in an increasing RIs order on a DB-WAX (polar) column (Table 2). The predominant chemical classes were alcohols (30.35%) and aldehydes (26.68%). The next highest classes were hydrocarbons (11.63%) and heterocyclic compounds (11.32%). The total amount of minor classes including acids, ethers, and ketones was 8.35%. The six most abundant compounds, representing nearly 50% of the total amount of volatile compounds in the roasted seeds, were 2-butanol (11.67%), ethanol (10.58%), 3-methylbutanal (7.60%), 2-isopropyl-5-methyl-9-methylene-bicyclo[4.4.0]dec-1-ene (7.35%), (E,E)-2,4-nonadienal (5.50%), and 2,3-butanediol (5.18%). Another major aldehyde, (E,E)-2,4-nonadienal, has deep-fried odor and is a key volatile flavor compound contributing to the gravy odor in beef [31].

2-Butanol has sweet odor and is commonly determined as a characteristic volatile compound in some well-known fermented products such as wines, cheeses, and sauces [32–34]. The most abundant three alcohols were ethanol, 2-butanol, and 2,3-butanediol. The other four short-chain linear alcohols, namely, 2-pentanol, 2-hexanol, 1-pentanol, and 2-heptanol, were oxidative decomposition products of lipids. The methyl-branched alcohol, 4-methyl-2-pentanol, was probably derived from the Strecker degradation of amino acids.

3-Methylbutanal has a malty flavor. It is well-known that 3-methylbutanal is formed by a thermally induced Strecker degradation of the amino acids leucine and isoleucine. This is supported by a previous research, which determined the level of leucine and isoleucine as 1.40 and 2.71 g/100 g meal, respectively [7]. Furthermore, 3-methylbutanal is a representative of volatile formation behavior of all Strecker aldehydes, pyrazines, and furans. It was indicated as an important volatile compound contributing to the unique roasted aroma of pumpkin seed [35].

Eleven heterocyclic compounds that include pyrrole, benzothiazole, and eight derivatives of pyrazine were generated by the roasting, which was attributed to the Maillard reaction and pyrolysis. Pyrrole and pyrazine derivatives are widely distributed in processed food items, such as roasted sorghum and almond, and smoke condensate of black tea leaves and bread flour [36–38]. Four of the alkyl pyrazines detected, namely, 2,5-dimethyl-pyrazine, 2-ethyl-5-methyl-pyrazine, 2-ethyl-6-methyl-pyrazine, and 2,3,5-trimethyl-pyrazine, have also been found in roasted soybean oil, and may contribute to the characteristic roasted, nut- and peanut-like burnt aroma [39]. Of these four compounds, 2-ethyl-5-methyl-pyrazine and

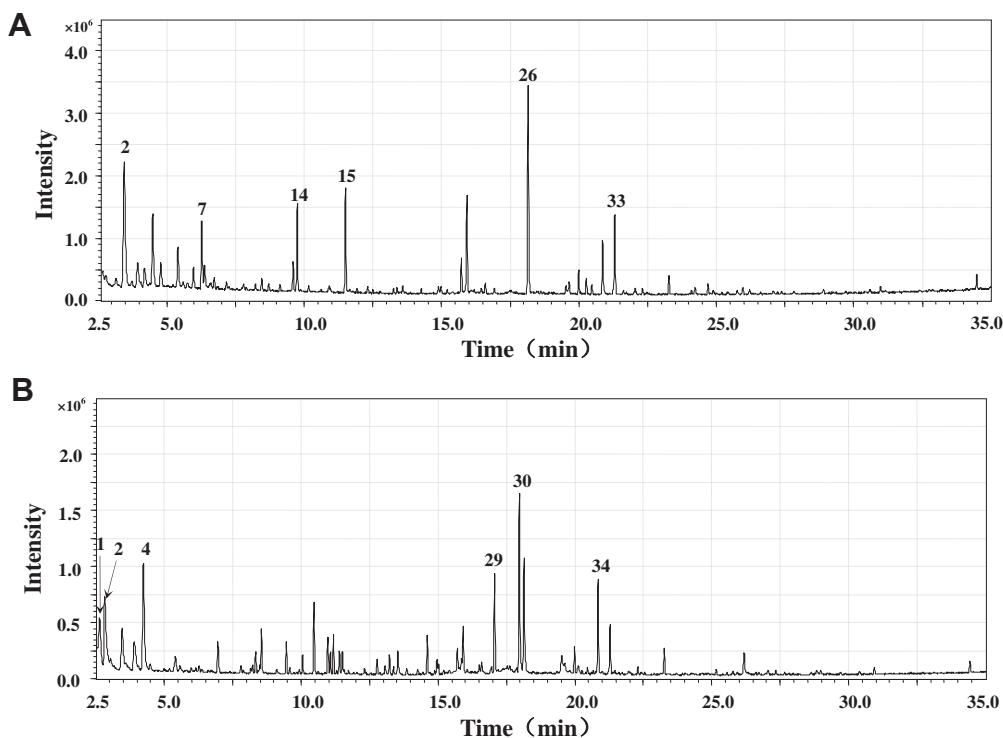


Fig. 1 – Typical gas chromatography–mass spectrometry chromatograms of volatile constituents from the (A) raw and (B) roasted *Trichosanthes kirilowii* seeds. The number of major compounds and the peak identification are shown in Tables 1 and 2.

2-ethyl-6-methyl-pyrazine are synthetically accessible through the reaction between L-ascorbic acid and L-threonine or L-serine [40].

3.3. Comparison between volatile compounds in raw and roasted *T. kirilowii* seeds

The numbers of volatile peaks isolated by GC from both seeds were very similar (Fig. 1A and B). However, the volatile profile including percentage and species as well as the odor of the raw and roasted seeds differed. The main difference in volatile classes and the most abundant compounds in the raw and roasted *T. kirilowii* seeds are listed in Table 3. All chemical classes were relatively different, except ketones. Aldehydes were the most abundant volatile class in the raw seeds, whereas alcohols were the most abundant volatile class in the roasted seeds. Esters were present in minor quantities in the raw seeds, whereas they were not detected in the roasted seeds. Ethers and pyrazines were only found in the roasted seeds. The most distinct changes in the volatile classes were aliphatic aldehydes, sesquiterpenes, aliphatic alcohols, and alkyl pyrazines.

The GC–MS identification indicated that a total of 15 compounds were common to both seeds, with the majority of these compounds being aliphatic aldehydes (Tables 1 and 2). The total percentage of aldehydes in the raw seeds was 1.66 times more than that in the roasted seeds. After roasting, aliphatic

short-chain aldehydes such as pentanal, hexanal, and (Z)-2-heptenal decreased significantly, whereas no significant variations of medium-chain aliphatic aldehydes, such as nonanal, 2,4-nonadienal, 2,4-decadienal, (E,E)-2,4-nonadienal, and (E,E)-2,4-decadienal, were observed. It is reasonable to assume that the roasting process caused rapid volatilization of these most abundant short-chain aldehydes with low boiling points. Notably, the most abundant aldehyde, pentanal, and the second most abundant (Z)-2-heptenal in the raw seeds decreased by 78% and 85% after roasting, respectively.

The roasting also led to a large decrease in 2-pentanol and 1-pentanol levels. Their levels in the raw seeds were about 13 and six times more than those in the roasted seeds, respectively. Nevertheless, alcohols were quantitatively the main chemical class found in the volatile fraction of roasted seeds. The total percentage of alcohols in the roasted seeds was 2.21 times higher than those in the raw seeds. This is because new alcohols were generated in larger amounts, including the most abundant alcohols, ethanol and 2-butanol. Roasting also caused a significant increase in volatile concentrations of heterocyclic compounds. The main contribution was from the generated eight alkyl pyrazines, which contributed a total of 9.16%. Both seeds contained 2,3-dihydro-benzofuran, whereas benzothiazole was produced and 2-pentyl-furan was lost by roasting. Hydrocarbons considerably decreased due to the loss of most sesquiterpenes, except copaene, after roasting. The relative amount of sesquiterpenes in the roasted seeds was only 43.48% of that in the raw seeds. One of the most abundant compounds in raw seeds, that is, (+)-calarene (16.59%) was absent in the roasted samples. Both seeds contained minor amounts of acetophenone with no significant changes. Of all the identified volatile components, only one acid, acetic acid, was detected in both raw and roasted samples.

Overall, the raw seeds contained more lipid-related volatiles whereas the roasted seeds contained more amino acid-related volatiles. The large differences in both chemical classes and relative amounts of odor-active compounds contributed to the great differences in flavor between the raw and roasted *T. kirilowii* seeds. The results may be useful for the production of *Diao-Guazi* snacks and the edible oil produced from *T. kirilowii* seeds.

Table 3 – Quantitative comparison on disappearance, decrease, and generation of volatile classes and most abundant compounds between the raw and roasted *Trichosanthes kirilowii* seeds.

Chemical classes	Relative amount (%)		Decreasing/increasing times ^a
	Raw seeds	Roasted seeds	
Aldehydes	44.31	26.68	–1.66
Predominant three aldehydes ^b	31.60	17.38	–1.82
Alcohols	13.76	30.35	+2.21
Predominant three alcohols ^c	10.35	27.43	+2.65
Hydrocarbons	34.41	11.63	–2.96
Sesquiterpenes	26.75	11.63	–2.30
Heterocyclic compounds	1.59	11.32	+7.12
Pyrazines	n.d.	9.16	n
Esters	3.17	n.d.	d
Acids	0.41	0.93	+2.27
Ketones	1.03	1.10	+1.07
Ethers	n.d.	2.51	n

n.d. = not detected.

^a Times were calculated using the bigger relative amount divided by the smaller relative amount. The symbols +, –, n, and d denote increasing, decreasing, newly generated, and disappeared, respectively.

^b The predominant three aldehydes were pentanal, (Z)-2-heptenal, and (E,E)-2,4-nonadienal for the raw seeds, and 3-methylbutanal, (E,E)-2,4-nonadienal, and pentanal for the roasted seeds.

^c The predominant three alcohols were 2-pentanol, 1-pentanol, and 3-pentanol for the raw seeds, and ethanol, 2-butanol, and 2,3-butanediol for the roasted seeds.

4. Conclusions

A total of 65 volatile compounds were identified in the raw and roasted *T. kirilowii* seeds. The major differences between the raw and roasted seeds were higher percentages of sesquiterpenes and short-chain linear aldehydes in the raw seeds. In addition, large percentages of alkyl pyrazines, 2-butanol, ethanol, and 3-methylbutanal were generated in the roasted seeds. This may explain the great odor differences between the raw and roasted *T. kirilowii* seeds. The results may be useful for optimizing the roasting process and oil processing of *T. kirilowii* seeds.

Conflicts of interest

All contributing authors declare no conflicts of interest.

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