Original Article

Effect of roasting on the volatile constituents of Trichosanthes kirilowii seeds

Shimin Wu a,b,*, Ting Xu a, Casimir C. Akoh c

a Department of Food Science and Technology, School of Agriculture and Biology, Shanghai Jiao Tong University, Dongchuan Road 800, Shanghai 200240, China
b Bor S. Luh Food Safety Research Center, Shanghai Jiao Tong University, Dongchuan Road 800, Shanghai 200240, China
c Department of Food Science and Technology, Food Science Building, University of Georgia, Athens, GA 30602-2610, USA

A B S T R A C T

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 a-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.

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,
diabetes, and obstitution [4]. A number of studies have reported special or novel compounds with specific bioactivity in T. kirilowii seeds, such as trichosanthirin, 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 website (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

| 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-butanolic 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  | Benzoaldehyde                          | 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  | β-Cadinol                              | 2159 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 quanti-
ties 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 com-
ponents 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].

a-Muurolene has a woody-type odor and was found in fenugreek seeds [19]. This
imparts the characteristic flavor released by fig syconia [20]. a-Muurolene synthase was identified in fungus Coprinus cinereus

| No. | Compounds                          | Retention indices | Identificationa | Percentage of total area (%) |
|-----|------------------------------------|-------------------|-----------------|-----------------------------|
| 1   | 3-Methylbutanal                    | 923 <700          | A               | 7.60                        |
| 2   | Ethanol                            | 940 <700²         | A               | 10.58                       |
| 3   | Pentanal                           | 984 <700          | A               | 4.28                        |
| 4   | 2-Butanone                         | 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-Heptanal                         | 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  | Pyrrole                            | 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  | Benzenecetaldehyde                 | 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.
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. Esters 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.

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.
Acknowledgments

This study was supported by grants from the National Natural Science Foundation of China (Grant No. 31171704) and the National Science and Technology Pillar Program during the Twelfth Five-Year Plan Period from the MOST of China (Grant No. 2011BAD02B03).

References

[1] McGrath MS, Hwang KM, Caldwell SE, et al. GLQ223: an inhibitor of human immunodeficiency virus replication in acutely and chronically infected cells of lymphocyte and mononuclear phagocyte lineage. Proc Natl Acad Sci USA 1989;86:2844–8.

[2] Shu SH, Xie GZ, Guo XL, et al. Purification and characterization of a novel ribosome-inactivating protein from seeds of Trichosanthes kirilowii Maxim. Protein Expr Purif 2009;67:120–5.

[3] Takahashi N, Yoshida Y, Sugitani T, et al. Curcubitacin D isolated from Trichosanthes kirilowii induces apoptosis in human hepatocellular carcinoma cells in vitro. Int Immunopharmacol 2009;9:508–13.

[4] Dat NT, Jin X, Hong YS, et al. An isoaurone and other constituents from Trichosanthes kirilowii seeds inhibit hypoxia-inducible factor-1 and nuclear factor-xB. J Nat Prod 2010;73:1167–9.

[5] Moon SS, Rahman AA, Kim JY, et al. Hanultarin, a cytotoxic sesquiterpene from seeds of Trichosanthes kirilowii. Bioorg Med Chem Lett 2008;18:7264–9.

[6] Yang J, Zhou CQ, Yuan GF, et al. Effects of geographical origin on the conjugated linolenic acid of almonds. J Am Oil Chem Soc 2012;89:401–5.

[7] Zhou JZ, Wu SM, et al. An isoaurone and other constituents from Trichosanthes kirilowii seeds inhibit hypoxia-inducible factor-1 and nuclear factor-xB. J Nat Prod 2010;73:1167–9.

[8] Moon SS, Rahman AA, Kim JY, et al. Hanultarin, a cytotoxic sesquiterpene from seeds of Trichosanthes kirilowii. Bioorg Med Chem Lett 2008;18:7264–9.

[9] Moon SS, Rahman AA, Kim JY, et al. Hanultarin, a cytotoxic sesquiterpene from seeds of Trichosanthes kirilowii. Bioorg Med Chem Lett 2008;18:7264–9.

[10] Moon SS, Rahman AA, Kim JY, et al. Hanultarin, a cytotoxic sesquiterpene from seeds of Trichosanthes kirilowii. Bioorg Med Chem Lett 2008;18:7264–9.

[11] Moon SS, Rahman AA, Kim JY, et al. Hanultarin, a cytotoxic sesquiterpene from seeds of Trichosanthes kirilowii. Bioorg Med Chem Lett 2008;18:7264–9.

[12] Moon SS, Rahman AA, Kim JY, et al. Hanultarin, a cytotoxic sesquiterpene from seeds of Trichosanthes kirilowii. Bioorg Med Chem Lett 2008;18:7264–9.

[13] Liu R, Xiong K, Dai X, et al. The effects of maturity on chilli pepper volatile components determined by SDE, GC–MS and HPLC. Nat Prod Commun 2010;5:985–90.

[14] Cho IH, Lee HJ, Kim YS. Differences in the volatile compositions of ginseng species (Panax sp.). J Agric Food Chem 2012;60:7616–22.

[15] Lee SJ, Moon TW, Lee J. Increases of 2-furanmethanol and maltol in Korean red ginseng during explosive puffing process. J Food Sci 2010;75:C147–51.

[16] Coates RM, James E, Shaw JF. Total synthesis of (+)-calarene. J Am Chem Soc 1970;92:5657–64.

[17] Takemoto H, Ito M, Shiraki T, et al. Sedative effects of vapor inhalation of agarwood oil and spikenard extract and identification of their active components. J Nat Med 2008;62:41–6.

[18] Wixted JT. Sleep aromatherapy curbs conditioned fear. Nat Neurosci 2013;16:1510–2.

[19] Mebazaa R, Mahmoudi A, Fouchet M, et al. Characterisation of volatile compounds in Tunisian fenugreek seeds. Food Chem 2009;115:1326–36.

[20] Borges RM, Bessière JM, Ranganathan Y. Diel variation in fg volatiles across syconium development: making sense of scents. J Chem Ecol 2013;39:630–42.

[21] Agger S, Lopez-Gallego F, Schmidt-Dannert C. Diversity of sesquiterpene synthases in the basidiomycete Coprinus cinereus. Mol Microbiol 2009;72:1181–95.

[22] Meliuoi E, Stratis E, Chinou I. Volatile constituents of propolis from various regions of Greece: antimicrobial activity. Food Chem 2007;105:375–80.

[23] Yang Y, Xiao Y, Liu B, et al. Comparison of headspace solid-phase microextraction with conventional extraction for the analysis of the volatile components in Melia azedarach. Talanta 2011;86:556–61.

[24] Blanch GP, Castillo ML. Changes in strawberry volatile constituents after pre-harvest treatment with natural hormonal compounds. Flavour Fragr J 2012;27:180–7.

[25] Steele DH, Thornburg MJ, Stanley JS, et al. Determination of styrone in selected foods. J Agric Food Chem 1994;42:1661–5.

[26] Azarnia S, Boye JI, Warkentin T, et al. Changes in volatile flavour compounds in field pea cultivars as affected by storage conditions. Int J Food Sci Technol 2011;46:2408–19.

[27] Yalcin H, Ozturk I, Hayta M, et al. Effect of gamma-irradiation on some chemical characteristics and volatile content of linseed. J Med Food 2011;14:1223–8.

[28] Azeem M, Rajarao GK, Nordenhem H, et al. Penicillium expansum volatiles reduce pine weevil attraction to host plants. J Chem Ecol 2013:39:120–8.

[29] Beck JJ, Merrill GB, Palumbo JD, et al. Strain of Fusarium oxysporum isolated from almond hulls produces styrone and 7-methyl-1,3,5-cyclooctatriene as the principal volatile components. J Agric Food Chem 2008;56:11392–8.

[30] Nieminen T, Neubauer P, Sivelä S, et al. Volatile compounds produced by fungi grown in strawberry jam. LWT Food Sci Technol 2008;41:2051–6.

[31] Christlbauer M, Schieberle P. Characterization of the key aroma compounds in beef and pork vegetable gravies a la chef by application of the aroma extract dilution analysis. J Agric Food Chem 2009;57:9114–22.

[32] Delgado FJ, González-Crespo J, Cava R, et al. Formation of the aroma of a raw goat milk cheese during maturation analysed by SPME–GC–MS. Food Chem 2011;129:1156–63.

[33] Díaz C, Conde JE, Méndez JJ, et al. Volatile compounds of bottled wines with denomination of origin from the Canary Islands (Spain). Food Chem 2003;81:447–52.

[34] Wachphon J, Thongthai C, Assavang A, et al. Volatile aroma components of Thai fish sauce in relation to product categorization. Flavour Fragr J 2012;27:262–3.

[35] Bowman T, Barringer S. Analysis of factors affecting volatile compound formation in roasted pumpkin seeds with selected ion flow tube-mass spectrometry (SIFT-MS) and sensory analysis. J Food Sci 2012;71:C51–60.

[36] Lasekan O, Abbas K. Analysis of volatile flavour compounds and acrylamide in roasted Malaysian tropical almond (Terminalia catappa) nuts using supernical fluid extraction. Food Chem Toxicol 2010;48:2212–6.
[37] Lasekan OO, Lasekan WO, Idowu MA. Flavour volatiles of 'malt beverage' from roasted sorghum. Food Chem 1997;58:341–4.

[38] Sung W-C. Volatile constituents detected in smoke condensates from the combination of the smoking ingredients sucrose, black tea leaves, and bread flour. J Food Drug Anal 2013;21:292–300.

[39] Jung MY, Bock JY, Back SO, et al. Pyrazine contents and oxidative stabilities of roasted soybean oils. Food Chem 1997;60:95–102.

[40] Yu AN, Zhang AD. Aroma compounds generated from thermal reaction of L-ascorbic acid with L-cysteine. Food Chem 2010;121:1060–5.