Effect of Roasting Temperatures on the Properties of Bitter Apricot (Armeniaca sibirica L.) Kernel Oil

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Abstract: Volatile compounds and quality changes of bitter apricot (Armeniaca sibirica L.) kernel oil (AKO) with different roasting conditions were determined. Bitter apricot kernels were roasted at 120, 130, 140 and 150°C for 15 min. Unroasted bitter apricot kernel oil was used as the control. Quality indicators included color, acid value and peroxide value, fatty acids, total phenols and oxidative stability. Peroxide values of the tested oils were 0.46-0.82 meq/kg, acid values were 0.60-1.40 mg KOH/g, and total phenol contents were 54.1-71.5 µg GAE/g. Oleic acid was the major fatty acid, followed by linoleic, palmitic, stearic and palmitoleic acids. Roasting increased the oxidative stability of bitter AKO. Volatile compounds were tentatively identified and semi-quantified. Among the 53 volatiles identified, benzaldehyde and benzyl alcohol were the major components. These two aroma compounds increased significantly during roasting and contributed sweet and almond flavors. Pyrazines were also prevalent and significantly increased with roasting. Sensory evaluation showed that roasted, nutty, sweet and oily aromas increased as roasting temperature increased.

Practical applications: Bitter apricot kernels cannot be consumed directly, thus it is potentially beneficial to find uses for them, especially in China where bitter apricot processing is a significant industry. Roasted bitter AKO with a pleasant aroma could be prepared and might find use as an edible oil. The roasting process gave the bitter AKO a pleasant flavor. This study provided preliminary information on production parameters and potential quality control parameters.

Key words: bitter apricot kernel oil, Armeniaca sibirica, benzaldehyde, benzyl alcohol, pyrazines

1 INTRODUCTION

Bitter apricots (Armeniaca sibirica L.) belong to the Rosaceae family. The genus Armeniaca is widely cultivated in the mountainous areas of northern and northeastern China, eastern Siberian, and Mongolia. In China, the total area for bitter apricots was about 1,700,000 ha, and the amount of kernels available is estimated at about 192,000 tonnes in 2011¹. The oil content of apricot kernel ranged from 40 to 56%². The major fatty acids reported in apricot kernels were oleic (58.3-73.4%) and linoleic (18.8-31.7%)³. Apricot kernels contain a variety of nutritional components such as high concentrations of flavonoids and phenolic acid antioxidants⁴. Bitter apricot cultivars have a high concentration of amygdalin (~5.5%), while no amygdalin was detected with sweet apricot cultivars⁵. The β-glucosidase enzyme decomposes amygdalin to glucose, benzaldehyde and hydrocyanic acid. Hydrogen cyanide in small quantities has shown beneficial effects such as promoting respiration and improving digestion, although it will lead to respiratory failure and even death when taken in excess⁶. However, amygdalin is removed during oil production and is used in China. Based on previous report, amygdalin < 5 mg/kg in bitter apricot oil is considered safe and the amygdalin in refined bitter apricot oil ranged from 0.17 to 2.15 mg/kg oil⁷.

Bitter apricot kernel oil is not only used as an edible oil, but also be used as a component of lubricants, cosmetics, and surfactants; and to prevent cardiovascular diseases.

Abbreviations: AKO, apricot kernel oil; PV, peroxide value; AV, acid value; CDA, conjugated dienoic acid; RI, retention index; FAME, fatty acid methyl ester; IS, internal standard; MS, mass spectrum; GAE, gallic acid equivalents; GC-MS, gas chromatography-mass spectrometry; HS-SPME, headspace solid-phase micro-extraction.

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and reduce plasma cholesterol levels\textsuperscript{3}. AKO is popular among consumers because of its high nutritional value\textsuperscript{6}. It was found that AKO can positively affect rat growth and it inhibited cyclophosphamide-associated organ degeneration\textsuperscript{6}. Although the volatile profiles during roasting were investigated for palm kernel, peanut, sesame and pumpkin seed oils\textsuperscript{7-10}, roasted bitter AKO has not been studied.

During roasting, the amount of Maillard reaction occurring is affected by roasting temperatures and times\textsuperscript{11}. Also during heating oxidative reaction may occur that give oils an undesirable flavor and produce free radicals\textsuperscript{12}. Thus, it is important to evaluate the oxidative stability of oil samples. Peroxide values (PV), acid values (AV), total phenols, fatty acid composition and conjugated dienoic acid (CDA) values were previously used as quality indicators with roasted seed oils\textsuperscript{13-15}.

The aim of the present work was to determine the changes in volatile compounds of crude extracts of bitter AKO before removal of amygdalin using headspace solid-phase micro-extraction (HS-SPME) and gas chromatography-mass spectrometry (GC-MS). Indicators like color, AV, PV, fatty acid composition, total phenol content and CDA values were used to evaluate oil quality.

2 EXPERIMENTAL PROCEDURES
2.1 Materials and reagents

The bitter apricots used in this study were bought from Chengde Yaou Nuts and Seeds Co., Pingquan, Hebei Province, China. The apricots were harvested in August, 2016. Bitter apricot kernels were vacuum-sealed in plastic bags and kept in a freezer at 4\textdegree C for a period of 12 wk to minimize oxidation. 1,2,3-Trichloropropane (chromatography grade) was purchased from AccuStandard Inc (New Haven, CT, USA). Other chemicals were analytical grade and purchased from Yixiubogu Biological Tech Co. (Beijing, China). Deionized water was obtained using a Milli-Q water purification system (Canrex Analytical Instrument Co., Ltd., Shanghai, China).

2.2 Roasting conditions and extraction of AKO

Bitter apricot kernels (\~500 g) were roasted for 15 min at different roasting temperatures (120, 130, 140 and 150\textdegree C) using an oven (T3-L383b, Media Kitchen Appliance Manufacturing Co., Ltd., Foshan, Guangdong, China). Bitter apricot kernels were put on pans with tin foil and spread evenly on the pan for even roasting. Roasted bitter apricot kernels were pressed for oil production using a laboratory-scale oil press (YKY-6YL-550, Longyan Machinery Manufacturing Co., Ltd., Longyan, Fujian, China). Oil from unroasted bitter apricot kernels was also obtained (control). Crude bitter AKO was centrifuged (HC-2518R, Zonkla Scientific Instrument Co., Ltd., Hefei, Anhui, China) at 2504 x g for 15 min, the supernatant was recovered and sealed in 100 mL flasks and immediately refrigerated for a maximum of 7 days before further analysis. No further oil purification was used.

2.3 Volatile compounds

2.3.1 Extraction of volatile compounds

The volatile compounds were extracted using HS-SPME coupled with GC-MS. The conditions were adapted from a method reported earlier with minor modifications\textsuperscript{16}. A 65\textmu m diameter polydimethylsiloxane/divinylbenzene fiber was used (Supelco, Bellafonte, PA, USA) for the absorption of volatile compounds. The fiber was conditioned at 250\textdegree C for 30 min prior to the first measurement. The bitter AKO sample (2.00 g) and 10 \textmu L of 1,2,3-trichloropropane (1.000 mg/mL in methanol) was used as an internal standard (IS). The samples were weighed into a 15 mL glass vial and sealed with a Teflon rubber septum and an aluminum cap (Beijing Kebio Biotechnological Co. Ltd., Beijing, China). The sample vial was heated on a hot plate (laboratory stirrer/ hot plate PC-620D, Corning Inc., Corning, NY, USA) at 60\textdegree C. After 20 min equilibration, the fiber was insert into the vial and volatile compounds extracted at 60\textdegree C for 30 min. When the headspace extraction was completed, the fiber was immediately transferred to the injection port of the GC (GCMS QP2010, Shimadzu, Kyoto, Japan), and volatile compounds desorbed at 250\textdegree C for 5 min.

2.3.2 GC-MS

Volatile compounds were separated and identified using a capillary column (Rtx-5MS, 30 m x 0.25 mm i.d., film thickness 0.25 mm) coated with diphenyl dimethyl polysiloxane (Restek, Bellafonte, PA, USA). The injection port temperature was 250\textdegree C in a split mode of 1:10. The column temperature was programed as: 45\textdegree C for 10 min, increasing 3\textdegree C/min up to 100\textdegree C and held for 1 min, then increasing at 5\textdegree C/min up to 150\textdegree C and held for 5 min, 10\textdegree C/min up to a final temperature of 250\textdegree C, and held for 10 min. Purified helium gas (\geq 99.999\%, Beijing AP BAIF Gases Industry Co., Ltd., Beijing, China) was used as the carrier gas with a constant flow rate of 1 mL/min. The MS was operated in the electron impact mode at an ionization energy of 70 eV with a scan range of 35-500 atomic mass units. The temperature of the ion source and the transfer line were set at 230 and 250\textdegree C, respectively.

2.3.3 Identification and quantification

Volatile compounds in bitter AKO samples were tentatively identified by matching their mass spectrum with those in the National Institute of Standards and Technology (NIST)\textsuperscript{11} library and comparing their retention indices as found in the NIST Chemistry WebBook (Gaithersburg, MD, USA). The compounds having a \geq 80\% similarity of their mass spectrum with the NIST library data were considered present. The RI was calculated in relation to the retention times of C\textsubscript{7} - C\textsubscript{24} n-alkanes (Supelco) under the same condi-
Roasting of Bitter Apricot Kernel Oil


1,2,3-Trichloropropane (IS) was not found in pistachio seeds oil and peanuts, which made it appropriate as the internal standard. Accurate quantification of volatiles cannot be done using a single internal standard. Thus, concentrations of volatiles are reported relative to the IS rather than as absolute concentrations.

The relative concentration was:
Relative concentration(mg/kg) = (Concentration of the IS/Peak area of the IS) × Peak area of the particular compound

Peak areas were calculated using the computer program supplied by the manufacturer.

2.4 Sensory
A 10-person trained sensory panel (between 20 and 30 years old, 5 males and 5 females) was used. All of the panellists had sensory evaluation experience in descriptive evaluation of roasted, grassy, sweet and other aromas. The single characteristic flavors including roasted, grassy, sweet, nutty, oily and caramel intensity were scored from 0 (no perception of aroma) to 9 (extremely intensive aroma).

An oil sample (40 g) was weighed and put into a 60 mL vial, then sealed and equilibrated in a water bath at 60°C for 10 min. Before sensory evaluation, each panelist needed to shake the vial before removing the cap. Sensory evaluation was carried out at room temperature. To compare the data for different roasting temperatures, spider plots were drawn.

2.5 Quality indicators
2.5.1 Color
The color was measured at room temperature (±20°C), using a colorimeter (DTQC-10A, Beijing Oriental Precision Technology Co., Beijing, China). Lightness L*, and the chromatic coordinates a* (green-red) and b* (blue-yellow) were measured on the oil surface. The colorimeter was recalibrated using a standard white plate after each measurement. All the analyses were done in triplicate.

2.5.2 Peroxide value and acid value
PV and AV of AKO were determined using AOCS Official Methods Cd 8-53 and Cd 3d-63, respectively.

2.5.3 Total phenols
The determination of total phenols was done using the methods of a previous study, with some modifications. A 0.1 mL sample of oil was mixed with 0.5 mL of Folin-Ciocalteu reagent, 1.5 mL of sodium carbonate solution (10%, w/v) and 1.5 mL of deionized water. The absorbance at 765 nm of the mixture was measured after storage at room temperature for 2 hr (L6, Inesa Analytical Instrument Co., Ltd., Shanghai, China). Gallic acid was used to prepare a standard curve and the results were expressed as μg of gallic acid equivalents (GAE)/g of sample.

2.5.4 Fatty acids composition
Fatty acid methyl esters (FAME) of oil samples were prepared based on ISO standard 5508 using the GC. The Rtx-5MS column was used. The temperatures of the injector and detector were 200 and 230°C, respectively. Initial temperature of the column was 120°C and was held for 1 min, then increased at a rate of 10°C/min from 120 to 200°C and held for 16 min. Finally, the temperature gradient was 20°C/min to 220°C and held for 25 min. Purified nitrogen (≥99.999%, Beijing Ruyuanruquan Technology Co., Ltd., Beijing, China) was used as carrier gas with a flow rate of 1 mL/min. A split injector with a split ratio of 1:30 and an injection volume of 1 μL was used. Peaks of FAME were identified by comparing their retention times with authentic standards from Sigma-Aldrich Co. (St. Louis, MO, USA), and relative area percentages as determined by the computer program with the GC among the peaks obtained was used for estimating the amount of each fatty acid.

2.5.5 Oxidative stability
Oxidative stability was determined by measuring changes in PV and CDA on days 1, 3, 6, 9 and 12. A 50 g sample of bitter AKO was placed into a 100 mL flask and sealed with Parafilm (Bemis Company, Inc., Neenah, WI, USA) that according to the manufacturer permitted gas transmission. The flask was covered with foil and put into 60°C oven for 12 days. CDA values were measured according to AOCS official method Ti1a-64 and calculated using the following equation:
CDA (%) = (0.84×A)/(bc-K), where A was the absorbance of bitter AKO samples at 233 nm, b was the length of cell (1 cm), c was the concentration of the sample (g/L), and K = 0.03, which is a correction factor for the background absorptivity of the fatty acid groups using the value for dienoic acid.

2.6 Statistical analysis
All the data are reported as mean ± standard deviation of triplicate determinations. Results of the volatile compounds were statistically analyzed using analysis of variance and Duncan’s multiple range test using the statistical software SPSS 17.0 (SPSS Inc., Chicago, IL, USA) with a 5% significance level.

3 RESULTS AND DISCUSSION
3.1 Volatile compounds
A total of 53 volatile compounds were identified using the NIST library and RI (retention index) in the bitter AKO samples, including N-heterocyclic compounds, O-heterocyclic compounds and non-heterocyclic compounds. There were 8 pyrazines, 3 pyridine derivatives, 4 pyrrole derivatives, 1 pyran derivative, 4 furan derivatives, 5 aldehydes, 4 ketones, 6 alcohols, 6 alkanes, 1 ester and a few other mis-
cellaneous compounds. The identified volatiles are listed in Table 1 including their RI and the relative concentration changes with different roasting temperatures.

Pyrazines were formed during the Maillard reaction through Strecker degradation, and contributed nutty, roasty, potato-like, popcorn-like and earthy aromas. Free amino acids and monosaccharides are considered to be important flavor precursors for the formation of unique flavors like pyrazines during roasting. A previous study reported that various pyrazine provided the typical aroma and was a crucial factor for roasted pumpkin seed oils. Eight pyrazines were identified in this study, most of them were only detected when the roasting temperature reached 130°C. Pyrazines which were not detected in unroasted bitter AKO samples accounted for 53.7% of the total volatiles when the roasting temperature was 150°C. The higher the roasting temperature, the higher the content of pyrazines with ethylpyrazine, 2,5-diethylpyrazine and cyclohexapyrazine only being detected when the roasting temperature reached 140 and 150°C. The 2-methylpyrazine, 2,5-dimethylpyrazine and 2,6-diethylpyrazine were the most abundant pyrazines and accounted for a great proportion of the total pyrazines. 2,5-Dimethylpyrazine was reported as the best overall pyrazine to predict roasted peanut flavor. Cyclohexapyrazine is a pyrazine derivative and is being reported in thermally-heated edible oil for the first time.

Several other nitrogen-heterocyclic compounds were isolated and identified in bitter AKO samples including pyridine derivatives and pyrrole derivatives. Most of these volatiles were not detected until the roasting temperature was 130°C. This may indicate that the formation of these compounds needs a higher roasting temperature. Pyridine and pyrrole derivatives have been reported as Maillard reaction products of amino acid-sugar model systems and contributed to roasty/smoky aromas. In addition, 2-acetylpyrrole was identified in this study. It is a typical Maillard reaction product and has been reported to enhance the roasty flavor of pumpkin seed oil.

Furan-containing compounds were produced during the thermal degradation of fructose and glucose, and were generally described as having the caramel-like, sweet and nutty aromas of heated carbohydrates. In this study, four furan derivatives were detected: 2,5-dimethyl-2,4-dihydroxy-3(2H)-furan-3-one, furfural, 2,5-dimethyl-4-hydroxy-3(2H)-furanone and furfuryl alcohol. Based on the literature, furfural was one of the predominant compounds among the furan derivatives of a roasted rapeseed variety named "Brandy" and was regarded as a typical product of a thermal reaction, which is generated from 1-deoxyosone in the Maillard reaction. 2,5-Dimethyl-4-hydroxy-3(2H)-furanone was identified at 140°C and increased almost 10 fold at 150°C. This compound was first identified in pine-apple and strawberries, and also has been detected in heat-processed foods like coffee and roasted plantains. 2,5-Dimethyl-4-hydroxy-3(2H)-furanone contributed to the sweet aroma of roasted almonds. Furfuryl alcohol was detected at low concentrations, 0.37 and 1.01 mg/kg oil at 140 and 150°C, respectively. Furfuryl alcohol has been reported in roasted perilla seed oil and roasted sesame seed pastes, and contributed to the sweet, nutty and caramel-like aromas. Although most of the furan derivatives generated with roasting do not account for a large proportion of the total volatiles, they made a contribution to the sweet, nutty and roasted aromas of bitter AKO.

Maltol is a pyran derivative and was detected when roasting temperatures were 140 and 150°C and is responsible for a burnt flavor. Aldehydes included hexanal, benzaldehyde, nonanal, phenylacetaldehyde and 2-phenyl-2-butenal. In general, aldehydes are responsible for green, pungent, metallic, beany or rancid aromas, and are often related to the undesirable flavors in fats and oils. Hexanal and nonanal are lipid oxidation products. Hexanal increased significantly as temperature increased (p<0.05) and was responsible for the green and herbaceous aromas in cashew nuts. Phenylacetaldehyde was found in all roasted samples reaching its highest concentration at 130°C. Phenylacetaldehyde contributes green, floral and honey flavors, and was reported as one of the important flavors in roasted virgin rapeseed oil. Benzaldehyde was identified in all samples. It first increased and then decreased, which was opposite of previous studies. Benzaldehyde is an aromatic aldehyde responsible for a pleasant almond-like aroma and is crucial to almond flavor. It is formed from the enzymatic breakdown of the diglucoside amygdalin as almond kernels are disrupted. It has also been reported as one of the major volatiles from the essential oils of the kernels of unripe Japanese apricots (Prunus mume Sieb. et Zucc) and Longwangmo apricots (Prunus armeniaca L.). Thus, the increase of benzaldehyde during roasting could enhance the typical almond aroma of apricot kernel oil. 2-Phenyl-2-butenal was not detected until the roasting temperature reached 130°C and increased significantly (p<0.05) thereafter. It has also been found in roasted peanut oil.

On the other hand, three ketones were not detected until the roasting temperature reached 140°C. 3-Methyl-2-hydroxy-2-cyclopenten-1-one was only detected at 150°C. It was also found in roasted palm kernels oil with a relatively long roasting time of 20 min at 180°C.

Six alcohols were found and reached a maximum at 120°C. Benzyl alcohol was a major component. Compared to unroasted bitter AKO, the relative concentration of benzyl alcohol increased almost 4 – 5 fold. It was one of the dominant volatiles in almond oil and is often found in the essential oils extracted from plants. Phenethyl alcohol was detected in all samples and showed a non-significant (p
Table 1: Volatile compounds identified in bitter AKO using HS-SPME-GC-MS.

<table>
<thead>
<tr>
<th>Compounds</th>
<th>RI</th>
<th>RI</th>
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<th>Reference for aroma description</th>
<th>Relative concentration (mg/kg bitter apricot kernels)a</th>
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<td></td>
<td>150</td>
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</tr>
</tbody>
</table>

- **N-Alkylcycloalkanes**
  - 2-Methylpropane: 813 MS, RI  
- 2,3-Dimethylbutane: 906 MS, RI
- 2,3,3-Trimethylbutane: 999 MS, RI
- 2,6-Dimethylphenol: 1072 MS, RI
- Ethylphenol: 911 MS, RI
- 2,2-Dimethylpropane: 1066 MS, RI
- Cyclohexanecarboxylic acid: 1106 MS, RI

- **Pyrazines**
  - 2-Methylpyrazine: 813 MS, RI  
- 2,5-Dimethylpyrazine: 906 MS, RI
- 2-Ethyl-5-methylpyrazine: 993 MS, RI

- **Cyclohexanes**
  - 2-Methylpropane: 813 MS, RI  
- 2,3-Dimethylbutane: 906 MS, RI
- 2,3,3-Trimethylbutane: 999 MS, RI

- **Benzaldehyde**
  - Hexanal: 798 MS, RI
- 2-Hexanone: 798 MS, RI

- **Furan derivatives**
  - Furfural: 841 MS, RI
- Furfural: 821 MS, RI

- **2,4-Diketo-2,5-dimethyl-3-oxo-2,5-dihydrofuran**
  - 1136 MS, RI

- **2,5-Dimethyl-4-hydroxy-3(2H)-furanone**
  - 1054 MS, RI

- **3-(Dimethylamino)-4-hydroxy-3-cyclobutene-1,2-dione**
  - 1062 MS

- **4-Hydroxy-3-methylfuran**
  - 1104 MS, RI

- **Methyl cyclopentenolone**
  - 1018 MS, RI

- **Aldehydes**
  - Butanal: 773 MS, RI
- 1-Butanol: 858 MS, RI
- Benzaldehyde: 1930 MS, RI
- 2-Heptanone: 1073 MS, RI
- Phenethyl alcohol: 1103 MS, RI
- 1-Nonanol: 1171 MS, RI

- **Thioaldehydes**
  - 156 MS

- **2,4-Dimethylthiophene**
  - 1013 MS, RI

- **Sulfones**
  - 1311 MS, RI

- **Thiophenes**
  - 113 MS, RI

- **Thiophene-2,3-dithione**
  - 1236 MS, RI

- **Carotenoids**
  - 929 MS, RI

- **Benzyl alcohol**
  - 1150 MS, RI

- **3-Methyl-2-buten-2-one**
  - 1265 MS, RI

- **2-Methyl-3-pentanol**
  - 999 MS, RI

- **4-Ethyl-2,2,6,6-tetramethylpiperidine**
  - 1022 MS, RI

- **2,5-Dimethylcyclohexane**
  - 1063 MS, RI

- **Dodecan**
  - 1199 MS, RI

- **Benzyl acetate**
  - 1158 MS, RI

- **3-Methyl-2-buten-2-one**
  - 1265 MS, RI

- **4-Methyl-2-buten-2-one**
  - 1013 MS, RI

- **1,2-Dimethylbenzene**
  - 1142 MS, RI

- **1-Nonanol**
  - 1171 MS, RI

- **Aromatic**
  - Benzoic acid: 1311 MS, RI

- **Toluene**
  - 753 MS, RI

- **4-Methylphenol**
  - 1013 MS, RI

- **N-ethyl piperidine**
  - 908 MS, RI

- **Alpha-Pinene**
  - 929 MS, RI

<table>
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<th>Reference for aroma description</th>
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a Retention indices were determined by using n-alkanes (C10-C30) on a Rtx-MS column.
bIdentification of the compounds, MS, RI means tentatively identified using mass spectrum and RI with the NIST library, MS means tentatively identified using mass spectrum from the NIST library.

dThe concentration given were equivalent to the internal standard (concentration of the IS 0.88 mg/kg bitter apricot kernel oil)
eND, not detected.
fValues followed by different letters were significantly different at p < 0.05.

>0.05) upward trend as roasting temperature increased. Phenethyl alcohol was described as having honey, spice, rose and lilac aromas. Small amounts of alkanes and alkenes were detected in all samples. Decane and dodecane were not detected until 130°C. Decane was also detected in flax seed and sesame seed oils.

The relative concentration of toluene decreased and disappeared at 130°C and above. Toluene was found in roasted cashews and was responsible for the green, fatty, and lard aromas. It was also found in roasted peanuts and was considered a high impact aroma-active compound. α-Pinene was only found in unroasted bitter AKO. The ester benzyl acetate was found in all samples with the exception of 140°C. It is one of the most important esters in ripe berries. 1,2-Dimethoxy-3-methylybenzene increased then decreased. Creosol, a guaiacol derivative, increased with temperature, but was relatively low throughout. It was one of the most abundant volatile compounds in olives. The volatile phenols in olive oils lead to musty and muddy flavors. Other ethers disappeared at 130°C. However, acids were not detected, possibly because of their high volatility and heat lability. In addition, benzyl cyanide was detected in all samples.

3.2 Sensory evaluation

The average scores for bitter AKO at different temperatures are shown in Fig. 1. The major descriptor for unroasted bitter AKO were grassy and oily. This could be related to the volatile aldehydes and alcohols like nonanal and 1-hexanol. At 120°C, the grassy descriptor decreased while sweet, nutty and roast aromas were noted. The sweet aroma could be explained by the significantly (p < 0.05) increased benzaldehyde, which was related to almond, sugar, burnt and cherry flavors. Other aldehydes, like phenyl-acetaldehyde, which provided floral and honey aromas were also found at 120°C. The relative concentration of benzyl alcohol also increased significantly (p < 0.05) at 120°C and this compound contributed to the cherry and walnut flavors. Roasted and nutty aromas were noted at 130°C and intensified as roasting temperature increased. The perception of roasted aroma was probably associated with the generation of pyrazine compounds. At 130°C they accounted for a large proportion of total volatiles, and these compounds contribute roast and nutty aromas. Pyrrole derivatives like 2-acetylpyrrole were correlated to nut, walnut and bread flavors. Also the furan derivatives like furfural, furfuryl alcohol and 2,5-dimethyl-4-hydroxy-3 (2H)-furanone contributed caramel flavors to bitter AKO. As the roasting temperature increased, oily flavor also increased. This could be explained by the increased aldehydes.

The sensory evaluations were consistent with the result of the volatiles analysis. The roasting temperature of 140°C and 150°C for 15 min gave the best sensory results. However, the obvious caramel aroma at 150°C might be objectionable to some, so roasting at 140°C was considered to be the most suitable for the production of bitter AKO.

3.3 Influence of roasting temperature on quality

3.3.1 Color

After 15 min of thermal heating, the lightness L* of bitter AKO decreased quickly from 140 to 150°C (Table 2). The a* value increased significantly (p < 0.05) with roasting temperature, while the b* value also increased significantly (p < 0.05). These experimental results were in agreement with a study of almonds where the L* and a* values decreased and increased, respectively. The composite color of bitter AKO changed gradually from light yellow to deep brown, which was consistent with that found with cashew oils. This browning has been attributed to the formation of Maillard reaction products and other non-enzymatic reactions.

3.3.2 Acid value and peroxide value

According to the "Hygienic Standard for Edible Vegetable of the People’s Republic of China", edible vegetable oils with an AV of <3 mg/kg are acceptable. The AV of bitter AKO showed an increasing trend as roasting temperature increased (Table 2). The AV increased during thermal processing. PV also increased with temperature but was also well below the value of 2.5 meq/kg for almond oil that was suggested as an acceptability cut-off. At about 5 meq/kg and above a rancid flavor was noted. The PV of hazelnut oil increased slightly as roasting temperature went from 100 to 150°C.

3.3.3 Total phenols

Total phenols fluctuated (Table 2) which was also found with *Pistacia terebinthus* (a snack food from the same family as pistachios) oil. The increase was mainly related to the accumulation of relatively polar compounds. The increase of total phenols could be related to their high resistance to oil oxidation. Many Maillard reaction products...
### 3.3.5 Oxidative stability

which suggested the possible volatilizing of these compounds at higher temperature. Further results showed that roasting temperature had the lowest CDA during storage. Similar results were found with soybean oils and mustard seed oil. These results probably reflect the previously discussed production of anti-oxidant compounds at higher temperatures.

### 3.3.4 Fatty Acids

Nine fatty acids were identified in apricot kernel oil including small amounts of arachidic and eicosanoic acids and some odd numbered fatty acids. Table 3 shows the changes in the major fatty acids. Oils with high levels of oleic and linoleic acid are commercially desirable. The results were similar to those for Longwangmo and *Prunus armeniaca* apricot. AKO prepared using either baked (80°C) or sun-dried kernels, cold pressed and then heat pressed at 40 and 120°C, respectively contained 70.3-71.3% oleic acid and 22.3-23.0% linoleic acid. Roasting had little or no effect on the fatty acid composition similar to cashew oils. On the other hand, minor changes occurred in hazelnuts, rice germs and sesame oils during roasting.

### 3.3.5 Oxidative stability

PV and CDA values were measured during storage of the oils. PV of the unroasted oil increased at 60°C significantly ($p<0.05$) in the first 12 days. However, the PV of the roasted oils after 12 days was less than the control and inversely related to the roasting temperature. Similar results were found for perilla seed oil.

CDA measures the primary oxidation products of polyunsaturated fatty acids ([Fig. 2B](#)). The initial CDA values of all samples were similar. Again the higher roasting temperature had the lowest CDA during storage. Similar results were found with soybean oils and mustard seed oil. These results probably reflect the previously discussed production of anti-oxidant compounds at higher temperatures.

### 4 CONCLUSIONS

The pyrazines as the major aroma volatiles contributed pleasant aromas like roast and nutty to the crude extract of bitter AKO. Benzaldehyde which was detected in all tested samples although higher in roasted bitter AKO contributed almond and sugar aromas. Other aroma volatiles like pyra, furan derivatives, aldehydes and alcohols also probably contributed to the typical aroma of bitter AKO. From the sensory results and the relative concentration changes in volatiles, 140°C was considered as the most suitable roasting temperature for the production of bitter AKO. AV and PV were consistent with the requirements for an edible oil. During the accelerated oxidation experiments, PV and CDA, both increased with the higher roasting temperature showing the slowest changes, i.e., roasting would increase the oxidative stability of bitter AKO suggesting that this might be an economical and efficient way to use apricot kernels.

### Table 2 General properties of bitter AKO with different roasting temperature.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Control</th>
<th>120</th>
<th>130</th>
<th>140</th>
<th>150</th>
</tr>
</thead>
<tbody>
<tr>
<td>L*</td>
<td>38.8 ± 0.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>38.4 ± 0.1&lt;sup&gt;b&lt;/sup&gt;</td>
<td>37.5 ± 0.1&lt;sup&gt;c&lt;/sup&gt;</td>
<td>37.2 ± 0.2&lt;sup&gt;d&lt;/sup&gt;</td>
<td>31.8 ± 0.2&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td>a*</td>
<td>4.2 ± 0.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5.2 ± 0.1&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5.7 ± 0.1&lt;sup&gt;c&lt;/sup&gt;</td>
<td>6.6 ± 0.1&lt;sup&gt;d&lt;/sup&gt;</td>
<td>7.3 ± 0.2&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td>b*</td>
<td>8.8 ± 0.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>10.2 ± 0.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>11.3 ± 0.1&lt;sup&gt;c&lt;/sup&gt;</td>
<td>11.7 ± 0.2&lt;sup&gt;d&lt;/sup&gt;</td>
<td>14.3 ± 0.1&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td>Acid value, AV (mg KOH/g)</td>
<td>0.60 ± 0.03&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.83 ± 0.02&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.93 ± 0.03&lt;sup&gt;c&lt;/sup&gt;</td>
<td>1.1 ± 0.1&lt;sup&gt;d&lt;/sup&gt;</td>
<td>1.4 ± 0.02&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td>Peroxide value, PV (meq/kg)</td>
<td>0.46 ± 0.01&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.49 ± 0.01&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.57 ± 0.02&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.64 ± 0.01&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.81 ± 0.01&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td>Total phenols content (µg GAE/g)</td>
<td>71.5 ± 0.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>54.1 ± 0.4&lt;sup&gt;b&lt;/sup&gt;</td>
<td>68.2 ± 0.3&lt;sup&gt;c&lt;/sup&gt;</td>
<td>55.0 ± 0.4&lt;sup&gt;d&lt;/sup&gt;</td>
<td>60.2 ± 0.5&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Different letters in the same row represented significant differences ($p<0.05$). Control represented unroasted AKO sample.

### Table 3 Changes in major fatty acid content of bitter AKO with different roasting temperatures.

<table>
<thead>
<tr>
<th>Fatty acids (%)</th>
<th>Control</th>
<th>120</th>
<th>130</th>
<th>140</th>
<th>150</th>
</tr>
</thead>
<tbody>
<tr>
<td>Palmitic acid, C16:0</td>
<td>4.45 ± 0.07&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4.44 ± 0.06&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4.41 ± 0.03&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4.45 ± 0.08&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4.41 ± 0.07&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Palmitoleic acid, C16:1</td>
<td>0.69 ± 0.04&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.69 ± 0.04&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.7 ± 0.02&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.69 ± 0.01&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.7 ± 0.04&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Stearic acid, C18:0</td>
<td>0.8 ± 0.02&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.83 ± 0.03&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.81 ± 0.03&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.78 ± 0.08&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.81 ± 0.02&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Oleic acid, C18:1</td>
<td>72.4 ± 0.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>72.1 ± 0.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>72.2 ± 0.12&lt;sup&gt;a&lt;/sup&gt;</td>
<td>72.4 ± 0.16&lt;sup&gt;a&lt;/sup&gt;</td>
<td>72.2 ± 0.27&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Linoleic acid, C18:2</td>
<td>21.8 ± 0.29&lt;sup&gt;a&lt;/sup&gt;</td>
<td>22.1 ± 0.18&lt;sup&gt;a&lt;/sup&gt;</td>
<td>21.9 ± 0.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>22 ± 0.28&lt;sup&gt;a&lt;/sup&gt;</td>
<td>21.8 ± 0.4&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Different letters represented significant differences ($p<0.05$).
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Conflict of Interest Statement

The authors have no conflicts of interest with respect to this manuscript.

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