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Changes in chemical composition of pumpkin seeds during the roasting process for production of pumpkin seed oil (Part 2: volatile compounds)

Barbara Siegmund*, Michael Murkovic

Graz University of Technology, Institute of Food Chemistry and Technology, Petersgasse 12/II, A8010 Graz, Austria

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Abstract

Pumpkin (*Cucurbita pepo* L.) seed oil is a special product of the southern Austrian region. For the production of the oil, prior to the pressing procedure, the seeds are roasted at temperatures up to 130 °C, which leads to the formation of the typical roasty and nutty aroma. In this study, changes of composition of the volatile fraction of the pumpkin seeds in course of the roasting process are investigated. The analyses were performed by gas chromatography–mass spectrometry after headspace solid phase microextraction. The results show very clearly that the roasting process at these high temperatures is necessary to obtain the typical aroma of the pumpkin seed oil. Compounds that are responsible for roasty/nutty aroma notes (alkylated pyrazines, as well as 2-acetylpyrrole) require a roasting temperature of at least 90 °C. Other compounds that show significant changes in concentration are mainly Strecker degradation products, as well as compounds derived from lipid oxidation.

Keywords: Pumpkin seed oil; *Cucurbita pepo L.*; Roasting; Flavour; Solid phase microextraction; Gas chromatography–mass spectrometry

1. Introduction

The oil of pumpkin seeds (*Cucurbita pepo* L.) is a food speciality of the southern Austrian region (Styria), which has been approved by the Commission of the European Union as a 'protected geographic name' (Schöttel, 1996). The characteristics of the pumpkin seed oil are the dark greenish colour as well as its very typical strong nutty and roasty flavour. Due to its chemical composition, especially of the fatty acids (Murkovic & Pfannhauser, 2000), it is recommended that the Styrian pumpkin seed oil be used for cold dishes; traditionally, it is mainly used for salad dressings. In southern Styria, the pumpkin seed oil is mainly produced by traditional methods. Usually the very labour-intensive production of the oil is done in small oil mills that process lots of 50–100 kg of pumpkin seeds. After crushing, the seeds are roasted and subsequently pressed at elevated temperatures.

During the roasting process, temperatures of 100–130 °C are applied and the typical aroma is formed, which is described as nutty, roasty, spicy, 'warm', slightly green and fatty. To our knowledge only two papers have been published on the aroma of pumpkin seed oil. Nikiforov, Knapp, Buchbauer, and Jirowetz (1996) showed that the dominating compounds of this typical aroma are pyrazine, 2-methylpyrazine, 2,6-dimethylpyrazine, 2-ethyl-5-methylpyrazine, 2,3,5-trimethylpyrazine, and 2-ethyl-3,6-dimethylpyrazine, that are generally known to be responsible for roasty and nutty aroma notes (Maga & Sizer, 1973). In addition, Buchbauer, Boucek, and Nikiforov (1998) identified 2-ethyl-3,5-dimethylpyrazine, 2-isobutyl-3-methylpyrazine and 2-methyl-6-furfurylthiopyrazine as contributors to the aroma of pumpkin seed oil. A clear correlation was found between the sensory attributes and the analytical data derived from headspace analyses of the oil samples. Matsui, Guth, and Grosch (1998) investigated the headspace of a pumpkin seed oil produced from a different species of roasted pumpkin seeds (*Telfaira occidentalis*). The authors again showed that pyrazines contribute significantly to the formation of the aroma,

* Corresponding author. Tel.: +43-316-873-6471; fax: +43-316-873-6971.

E-mail address: barbara.siegmund@tugraz.at (B. Siegmund).

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but also several compounds from other chemical classes. No data have been found in the literature concerning the flavour changes in the course of the roasting process of pumpkin seeds, which is surprising as the roasting process is the crucial factor for the aroma formation. In addition, no scientific investigations have been undertaken to elucidate the temperature levels necessary to achieve the typical aroma of the product. Kim, Yoon, and Rhee (2000) published an interesting work about the roasting effect on the formation of volatile compounds in perilla seed oil (*Perilla frutescens*). For many compounds, especially nitrogen-containing compounds, they described a marked increase in concentration when higher temperatures (up to 190 °C) were applied during the roasting process.

In the present study, we follow the changes in the composition of the volatile fraction of pumpkin seeds used for the production of Styrian pumpkin seed oil in the course of the heating and roasting process, in order to establish a scientific background for a process that has been conducted, as such, for decades. Changes in concentration of the volatile compounds were followed by the use of gas chromatography–mass spectrometry (GC–MS), using headspace solid phase microextraction (HS-SPME) (Pawliszyn, 1997; Steffen & Pawliszyn, 1996) as the extraction technique.

2. Materials and methods

2.1. Chemicals and solvents

2-Methylpropanal, 2-butenal (E), 3-methylbutanal, 2-methylbutanal, pentanal, hexanal, 2-hexenal (E), 2-heptenal (E), nonanal, phenylacetaldehyde, 2,3-butandione, 2-butanone, 1-penten-3-ol, 3-methyl-1-butanol, 1-pentanol, 1-hexanol, 2-methyl-furan, 2-pentylfuran, 2-furancarboxaldehyde, 2-furanmethanol, 3-(methylthio)-propanal, 2-methylpyrazine, 2,5-dimethylpyrazine, 2-acetylpyrrole and 2-ethyl-3,6-dimethylpyrazine, as well as 1,2,3-trichloropropane as internal standard, were purchased from Aldrich, Vienna, Austria. Benzaldehyde and 2-methyl-1-butanol were bought from Merck, Vienna, Austria. Phenylethanol and 2-ethylpyrazine were purchased from Fluka, Vienna, Austria. All reference compounds were of a purity of at least 98%. Methanol (purity min. 99,5%) was purchased from Promochem, Wesel, Germany.

2.2. Roasting process and pumpkin seed samples

The roasting process was performed in an oil-mill where pumpkin seed oil is produced for a commercial purpose. Sixty kilograms of the pumpkin seeds were milled in a stone mill and water (8 l) and salt (300 g) were added. After milling and homogenisation of the seeds, the first sample (ca. 30 g) was withdrawn. The 60 kg milled seeds were heated in a pan with a jacket heater set to a temperature of 150 °C and stirred continuously. During the roasting process, every 10 min, a sample was withdrawn from the pumpkin seeds. Every time that a sample was taken from the roasting pan, the temperature of the seeds in the pan was measured using an infra-red thermometer (Quicktemp 826 T4, Testo, Vienna, Austria) that allows hygienic measurement without food contact. At every sampling time, a sample of about 30 g crushed and processed pumpkin seeds was taken. The samples were immediately cooled to 0 °C in an ice-bath. After bringing the samples to the lab, which took about 1 h, the samples were deep-frozen and kept at −70 °C prior to the analysis of volatile compounds.

2.3. Extraction of the volatile compounds

Solid phase microextraction of the headspace (HS-SPME) was used for the examination of all samples. A Carboxen™/Polydimethylsiloxane fibre (fibre length 1 cm, film thickness 0.75 μm) was used (Supelco, Bellefonte, PA, USA). The fibre was conditioned at 280 °C under helium flow for at least 30 min before the first measurement. For the extraction of the volatiles, about 250 mg of a pumpkin seed sample were put into a 40-ml headspace vial. 0.5 g NaCl, 1 ml double-distilled water and 10 μl of a solution of 1,2,3-trichloropropane (58 mg/l in H_2O/CH_3OH) as internal standard were added. The sample was equilibrated at 50 °C for 10 min, while stirring thoroughly with a magnetic stirrer. The SPME fibre was exposed to the sample headspace for 10 min at 50 °C and was then transferred directly into the injection port of the used GC–MS system. The compounds were thermodesorbed from the fibre in the injection liner and cryo-focussed on the head of the analytical column. The SPME fibre was left in the injection port for re-conditioning during the whole GC run before it was exposed to the headspace of the next sample.

2.4. Gas chromatography–mass spectrometry (GC–MS)

For the GC–MS measurements, a Hewlett Packard system (HP G1800A GCD) was used. The capillary column used was an HP 5 (cross-linked 5% phenyl methyl siloxane column, length 30 m, inner diameter 0.25 mm, film thickness 1 μm). The conditions were as follows: column head pressure 0.54 bar, temperature programme from −30 °C (holding time 1 min) at 10 °C min^{-1} to 250 °C (holding time 5 min). Splitless injection mode was used, the split valve being opened after 2 min. A special SPME liner with an inner diameter of 0.75 mm was used to improve the peak width, especially for compounds with high volatility. Injection temperature, and detector temperature, were 280 °C. Electron impact ionisation was used (70 eV) scanning a mass range from 20 to 250 amu.

2.5. Identification and semi-quantification

For the identification of the volatile compounds, the samples were analysed by GC–MS under the experimental conditions mentioned above. The measured mass spectra were compared with those obtained from reference compounds if available, as well as with data found in the literature (the respective references are given in Table 2) and from a commercially available mass spectra database (Wiley 275). Additionally, linear temperature-programmed retention indices (RI) were calculated according to the equation of van den Dool and Kratz (1963; Farkas, Le Quéré, Maarse, & Kovac, 1994) and compared with RI data from our own retention index database (Farkas et al., 1994). The retention indices for the compounds of interest are given in Table 2.

The relative concentrations of the investigated compounds were calculated by relating the areas of the internal standard, 1,2,3-trichloropropane (*m*/*z* 110), to the areas of the characteristic masses of the compounds of interest. The used *m*/*z* ratios for the semi-quantification of the compounds are given in Table 2. Sample sizes were standardised to a sample weight of 250 mg. The relative concentrations are further on noted as equivalents to the internal standard (TCP-equiv.).

3. Results and discussion

For the traditional production of the Styrian pumpkin seed oil, the pumpkin seeds are crushed and mixed with relatively large amounts of sodium chloride. This mixture is transferred into a roasting pan, where the crushed seeds are heated slowly to obtain the typical aroma. During the roasting process, the crushed seeds are stirred continuously to avoid local overheating and formation of undesired burnt flavour notes. After the roasting process, the warm, crushed pumpkin seeds are transferred to the oil press where the dark green pumpkin seed oil is separated from the oil cake. In our experiment, the temperature of the pumpkin seeds was measured in course of the roasting process. The time–temperature curve is given in Fig. 1. The temperature rose continuously and reached a final temperature of about 120 °C.

For the examination of the volatile compounds from the crushed pumpkin seeds, solid phase microextraction of the headspace (HS-SPME), with subsequent determination via GC–MS, was used. For the extraction of the volatile compounds from this matrix, HS-SPME was chosen, as the method is quick, highly reproducible and helps to avoid the use of large amounts of organic solvents in the laboratory. Besides, HS-SPME does not necessarily require heating of the samples, as is the case with several other sample preparation techniques (e.g.

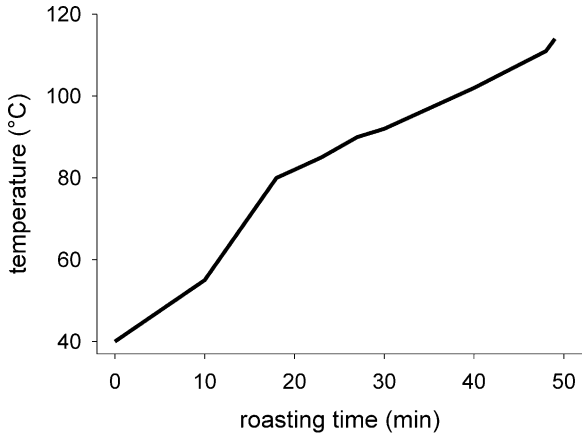

Fig. 1. Temperature of the pumpkin seeds in the roasting pan during roasting of the pumpkin seeds.

simultaneous distillation–extraction according to Likens–Nickerson). As a consequence, artefact formation, caused by thermal treatment in the course of sample preparation, need not be feared. For these reasons, HS-SPME was preferred to other sample preparation techniques. The addition of 1 ml of water was necessary to generate a homogenous slurry of the crushed seeds and to disperse the internal standard homogeneously throughout the sample. Thorough stirring of the slurry in the course of the whole analytical procedure and the addition of NaCl to the sample showed positive influence on the reproducibility and the extraction yield of the headspace compounds. For the whole procedure (including sample preparation, extraction of the volatile compounds from the headspace and GC–MS measurement), high reproducibility, with a maximum standard deviation of ±15%, could be achieved when time and temperature were strictly controlled, both for the equilibration of the system, as well as for the exposure of the SPME fibre to the headspace of the sample. Table 1 gives the mean relative concentrations and the standard deviations for five selected compounds from the sample drawn at the end of the roasting process. This sample was chosen for the evaluation of the methodology as many different compounds, including thermally generated flavour compounds, were identified in this sample. The high reproducibility makes the technique suitable for determining relative concentration changes, in the course of the roasting process of the investigated pumpkin seeds.

1,2,3-Trichloropropane (TCP) was used as internal standard, as this compound was not found in the pumpkin seeds. It is well known that discrimination of compounds with high or low volatility occurs in SPME. Consequently, quantification cannot be carried out seriously by the use of one single internal standard. We used the internal standard, not for quantification, but to correct variations of the capacity of the SPME fibre, as well as of variations of the sensitivity of the GC–MS

Table 1
Mean relative concentrations and selected standard deviations of selected compounds, for the whole analytical procedure (HS-SPME and GC–MS), of matrix-crushed and roasted pumpkin seeds; $n = 4$

Compound	Mean relative concentration (TCP-equiv.)	RSD (%)
Dimethylsulfide	0.2	13.5
2-Methylbutanal	2.0	10.7
Pentanal	3.1	10.6
2-Methylpyrazine	1.0	10.1
2,5 (6)-Dimethylpyrazine	8.1	11.3

system. In addition, it was not the aim of this study to give quantitative data of the volatile compounds, but to follow the relative concentration changes in the course of the thermal treatment of the crushed seeds. Therefore, given concentrations are not noted as absolute concentration values but as equivalents to the internal standard.

A rather high number of compounds could be identified in the headspace of the pumpkin seeds belonging to the chemical classes of aldehydes, ketones, alcohols and furan derivatives, as well as sulfur compounds and N-heterocyclic compounds. Table 2 lists the compounds, grouped into compound classes, including the retention indices of the compounds and the m/z ratios that were used to follow the concentration changes. The relative concentrations, after the different roasting times, in terms of equivalents to the internal standard are also given in Table 2.

Eleven aldehydes were identified in the samples. The concentrations of the compounds, 2-methylpropanal, 3-methylbutanal, 2-methylbutanal and phenylacetaldehyde—obviously derived from Strecker degradation—increased significantly during the roasting process, especially during the last 20 min of the process, where temperatures rose above 100 °C. At the beginning of the roasting process, a slight decrease in concentration was observed for 2-methylpropanal, 3-methylbutanal and 2-methylbutanal, before the concentrations increased significantly. This fact can also be seen from Fig. 2. We suppose that primary heating of the samples led to evaporation of these aldehydes that were already present in the pumpkin seeds before the roasting process. Further heating of the seeds led to acceleration of the Strecker degradation reaction and formation of the compounds in relatively high concentrations. Benzaldehyde, which is supposed to be a degradation product of the amino acid phenylalanine (Adamiec, Rössner, Velisek, Cejpek, & Savel, 2001), showed similar behaviour.

The two sulfur compounds that were identified in the headspace of the pumpkin seeds—dimethylsulfide and 3-(methylthio)-propanal—are also likely derived from Strecker degradation. Previously, Balance (1961) described the production of those compounds as Strecker degradation products derived from methionine, which also seems to be a plausible reaction pathway for the investigated matrix. Dimethylsulfide showed an interesting concentration profile, which seems to be closely correlated with the high volatility of the compound. Relatively high concentrations were found in the first, unheated sample. Primary heating of the seeds led to a first loss of dimethylsulfide. Further heating again forced the formation of dimethylsulfide, whereas, at the final temperature, concentration again decreased significantly. Presumably this behaviour can be attributed to the high temperatures of the samples and the high volatility of dimethylsulfide. Disproportioning of dimethylsulfide at higher temperatures could be a second reason for this concentration profile. The concentration of 3-(methylthio)-propanal—again a typical Strecker degradation product (Martin & Ames, 2001; Münch & Schieberle, 1998)—increased significantly at higher temperatures (Fig. 2). Due to its characteristic aroma, reminiscent of cooked potatoes, and its low odour threshold [0.08–0.2 μg/m^3 in air (van Gemert, 1999)], this compound is supposed to have great influence on the aroma of the final pumpkin seed oil.

Other aldehydes identified in the headspace of the seeds are derived from lipidoxidation. Especially pentanal, hexanal, 2-heptenal (E) and nonanal showed very large increases in concentrations in course of the roasting process (Fig. 3). Based on their sensory attributes,

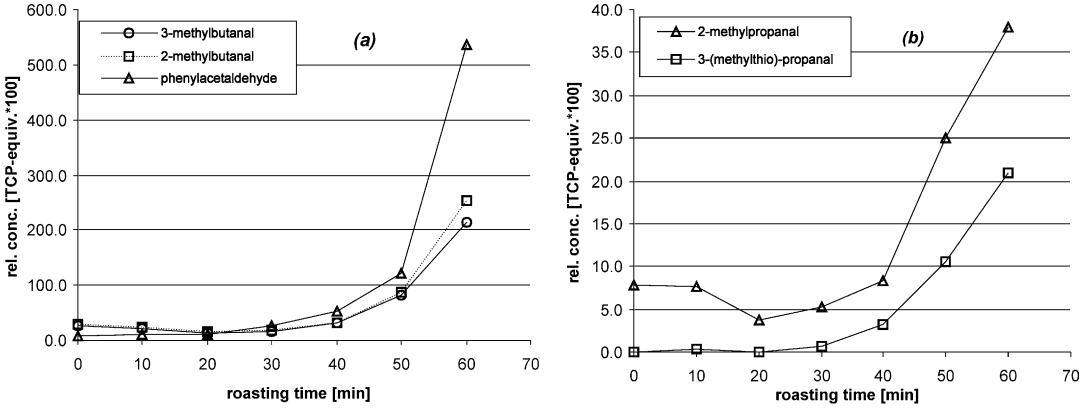

Fig. 2. Formation of Strecker degradation products in the course of the roasting process; TCP concentration 2.32 mg/kg pumpkin seeds.

Table 2
Compounds identified in the headspace of crushed and roasted pumpkin seeds using HS-SPME for sample preparation and GC–MS for the identification and determination of the relative concentrations

Compound	m/z[e]	RI (HP5)	Relative concentration [TCP-equiv.×100][e]						
			Roasting time [min]						
			0	10	20	30	40	50	60
Aldehydes									
2-methylpropanal[a,b]	72	552[f,g]	7.8	7.7	3.7	5.3	8.4	25.0	38
2-butenal (E)[a,b]	70	645	12	116	4.0	2.9	2.2	3.0	4.3
3-methylbutanal[a,b]	58	648	26	20	12	17	33	81	214
2-methylbutanal[a,b]	57	658	28	25	15	19	31	86	253
pentanal[a,b]	44	697	11	14	15	21	24	34	71
hexanal[a,b]	56	800	49	86	103	123	101	122	221
2-hexenal (E)[a,b]	83	850	0.7	2.3	–	–	–	–	–
2-heptenal (E)[a,b]	83	954	–	0.4	0.6	1.6	6.5	12	46
nonanal[a,b]	57	1105	2.4	3.4	4.3	5.8	6.3	12	18
benzaldehyde[a,b]	106	958	26	200	55	78	83	108	237
phenylacetaldehyde[a,b]	91	1043	7.4	12	11	27	53	123	537
Ketones									
2,3-butandione[a,b]	86	586	7.5	3.5	2.8	3.0	12.2	5.6	8.0
2-butanone[b,c]	43	597[f,g]	35	21	15	18	20	37	43
2-pentanone[a,b]	57	685	6.0	3.8	4.9	7.5	5.1	0.4	0.6
2-heptanone[a,b]	58	890	3.9	5.9	5.3	5.2	8.3	29	42
Alcohols									
1-penten-3-ol (E)[a,b]	57	678	49	29	17	11	3.6	1.6	2.3
3-methyl-1-butanol[a,b]	55	730	68	170	62	39	8.3	2.4	3.4
2-methyl-1-butanol[a,b]	57	733	28	56	22	14	2.5	0.6	0.9
1-pentanol[a,b]	42	763	34	35	24	26	18	24	37
1-hexanol[a,b]	56	867	160	154	108	111	40	20	29
phenylmethanol[d]	108	1041	18	65	25	31	31	27	38
phenylethanol[a,b]	122	1113	6.6	41	19	24	24	23	34
Furan derivatives									
2-methylfuran[a,b]	82	600	18	59	8.7	3.2	2.0	1.7	2.4
2-pentylfuran[a,b]	81	991	–	7.2	9.0	13	17	30	76
2-furancarboxaldehyde[a,b]	96	830	3.1	1.7	2.5	3.1	19	25	36
2-furanmethanol[a,b]	98	852	–	–	–	–	–	5.9	8.5
Sulfur compounds									
dimethylsulfide[d]	62	<500	16	2.1	1.3	2.2	6.3	14	6.4
3-(methylthio)-propanal[a,b]	104	905	–	–	–	0.7	3.3	11	21
N-heterocyclic compounds									
2-methylpyrazine[a,b]	94	825	–	–	–	–	3.7	9.5	28
2,5-dimethylpyrazine[a,b]	108	914	5.1	3.9	3.1	5.9	12	38	245
2-ethylpyrazine[a,b]	107	915	0.7	0.6	0.4	0.7	2.2	9.7	14
2-ethyl-5(6)-methyl-pyrazine[c]	121	997[h]	1.6	1.4	1.5	2.2	3.6	8.5	117
2-acetylpyrrole[a,b]	109	1060	1.0	0.9	0.7	1.0	4.4	11	16
2-ethyl-3,6-dimethyl-pyrazine[a,b]	135	1079	0.9	0.8	0.9	1.2	1.7	4.4	39

[a] Retention indices (RI) were compared to those from reference compounds respectively with data from our retention index database.
[b] The compounds were identified by comparison of the measured mass spectra with mass spectra obtained from reference compounds if available as well as by comparison of the mass spectra from a mass spectra library (Wiley 275).
[c] Retention indices are compared with data obtained from literature. The source is given for each compound in the list.
[d] The compounds are tentatively identified. Identification is only based on the comparison of the mass spectra with mass spectra from a mass spectra library (Wiley 275).
[e] Integration of the peak area was performed by using characteristic ions (m/z) for the respective compounds to avoid possible interference by other compounds. As no response ratios between the different ions were taken into account, the concentrations are given in terms of equivalents to the internal standard (TCP-equiv.; concentration of the IS 2.32 mg/kg pumpkin seeds).
[f] Rychlik, Schieberle, and Grosch, 1988.
[g] Acree, and Arn, 2002.
[h] Matsui, Guth, and Grosch, 1998.

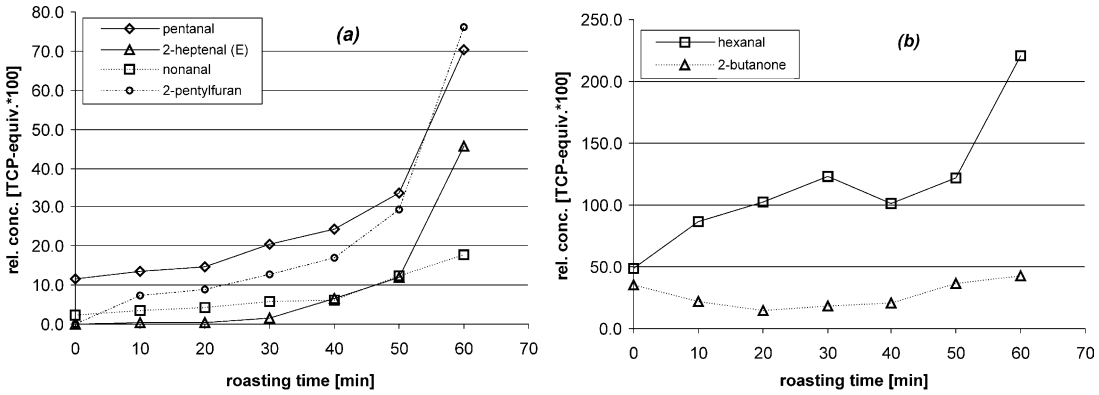

Fig. 3. Formation of lipid oxidation products, as well as 2-butanone, in the course of the roasting process; TCP concentration 2.32 mg/kg pumpkin seeds.

(green, grassy, slightly fruity), those compounds are responsible for the fresh and slightly green notes of the seeds and subsequently of the pumpkin seed oil. The ketones, that were identified at all stages of the roasting process, intensify the slightly fruity attributes.

Seven alcohols were identified in the pumpkin seeds. Phenylmethanol and phenylethanol, as well as pentanol, did not show significant concentration changes, whereas the amounts of 1-penten-3-ol, 3-methylbutanol, 2-methylbutanol and hexanol decreased significantly with higher roasting times and temperatures. As at the same time the concentrations of the corresponding aldehydes increased significantly, oxidation of the alcohols to the corresponding aldehydes is likely to occur under these conditions.

Four furan derivatives could be found in the headspace of the pumpkin seeds. Their occurrence in various nuts and oilseed products has been previously reported (Maga, 1979). For the formation of furan derivatives, two formation pathways are possible: (i) lipid peroxidation and (ii) degradation of carbohydrates. 2-Pentylfuran is derived from lipid peroxidation (Frankel, 1982); the concentration of the compound increased significantly during the roasting process (Fig. 3). In contrast, 2-methylfuran, 2-furanmethanol and 2-furancarboxaldehyde are known to be formed by degradation of carbohydrates (Maga, 1979). The concentration of 2-methylfuran was very high at the beginning of the process and was reduced significantly after 20 min, which could be due to its high volatility and the rather high temperatures in the roasting pan. 2-Furanmethanol and 2-furancarboxaldehyde showed significant increases. Nevertheless, as can be seen from Table 1, the formation of these compounds requires higher temperatures; increased concentrations could be determined for the first time after 40 min of roasting time.

In the headspace of the pumpkin seeds investigated in this study, the following pyrazines were identified: 2-methylpyrazine, 2,5-dimethylpyrazine, 2-ethylpyrazine, 2-ethyl-5(6)-methylpyrazine and 2-ethyl-3,6-dimethylpyrazine. The formation of pyrazines in the course of the Maillard reaction, under conditions similar to those used in the present study, has been previously reported (Maga & Sizer, 1973). Odour thresholds in air and flavour attributes of those compounds are given in Table 3. All of those pyrazines are correlated with sensory attributes, such as roasty, nutty, coffee-like, woody and earthy, and consequently contribute significantly to the typical odour of the pumpkin seed oil. In addition, we identified 2-acetylpyrrole—also known as a typical Maillard reaction product (Ames, Guy, & Kipping, 2001; Reese & Baltes, 1992)—that intensifies the roasty flavour of the oil. Fig. 4 shows the concentration changes of some pyrazines and 2-acetylpyrrole. It can be very clearly seen that the formation of the Maillard reaction products requires a minimum reaction time of 50 min, corresponding to a temperature of at least 100 °C. Reaction temperatures higher than 100 °C led to nearly exponential increase in the formation of the compounds.

Results previously reported in literature concerning the aroma of pumpkin seed oil (Buchbauer et al., 1998;

Table 3
Odour thresholds (van Gemert, 1999) and descriptions of Maillard products identified in the pumpkin seeds

Compound	Odour threshold in air (mg/m^3)	Odour description
2-Methylpyrazine	1.9	Nutty, cocoa, roasty, greenish
2,5-Dimethylpyrazine	0.17	Cocoa, roasted nuts, woody, potato chips
2-Ethylpyrazine	0.25	Peanut-butter, nutty, woody, buttery
2-Ethyl-5-methylpyrazine	0.036	Greenish, nutty, fruity
2-Ethyl-3,6-dimethylpyrazine	0.02–0.00245	Roasted hazelnut, potato chips, woody, burnt almond
2-Acetylpyrrole	Not available	Musty, nutty, licorice, walnut, bread

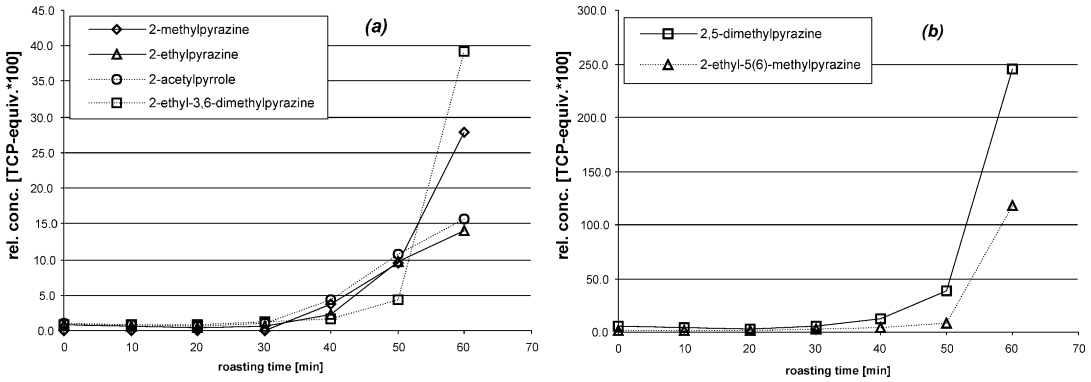

Fig. 4. Formation of pyrazines in the course of the roasting process; TCP concentration 2.32 mg/kg pumpkin seeds.

Matsui et al., 1998; Nikiforov et al., 1996) indicate that the presence of various pyrazines is a determining factor for the typical aroma of this type of product. Including the results of our study, it can be clearly seen that the thermal processing of the seeds, prior to the oil pressing, is necessary for the formation of those compounds, even though treatment of oil seeds at temperatures higher than 100 °C seems to be rather drastic. The results from the roasting of perilla seeds (Kim et al., 2000)—indicating that temperatures higher than 150 °C are necessary to form reasonable amounts, not only of pyrazines, but also of several other flavour compounds—confirm our findings.

4. Conclusion

The results of this study clearly show that the roasting process of the crushed pumpkin seeds is necessary to obtain the characteristic aroma of the final product, the pumpkin seed oil. Several flavour compounds are formed during the roasting process, including compounds from the Strecker degradation, lipid peroxidation, as well as the Maillard reaction. It is also demonstrated that for the formation of the typical roasty and nutty aroma notes, roasting temperatures significantly higher than 100 °C are necessary. Mild conditions, as applied to the production of various cold-pressed vegetable oils, would lead to a product without the desired particular pumpkin seed oil aroma.

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