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Pyrazine contents and oxidative stabilities of roasted soybean oils

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Soybeans were roasted with constant stirring for 15 min at 130°C, 150°C and 170°C, and oils were extracted from the roasted soybeans using an expeller. Color, conjugated diene, conjugated triene, peroxide values, tocopherols and fatty acid compositions in the oils were determined. Pyrazines in the oils were extracted by both simultaneous distillation–extraction and solvent extraction. Isolation and identification of pyrazines were carried out by gas chromatography and gas chromatography/mass spectrometry. Oxidative stabilities of the roasted soybean oils were studied during storage for 60 days at 65°C. As roasting temperature increased, the oil became darker; the red and yellow colors increased. Conjugated diene and conjugated triene increased with increasing roasting temperature. Peroxide values of all the oils were 0 meq kg^{-1} oil. The contents of total tocopherols in the oils decreased markedly with increasing roasting temperatures. The total tocopherol contents in the oils from soybeans roasted at 130°C, 150°C and 170°C were 70.0, 8.3 and 0.0 mg per 100 g oil, respectively. Fatty acid composition varied slightly with roasting temperatures. Nine alkyl pyrazines were identified: pyrazine, 2-methylpyrazine, 2,5-dimethylpyrazine, 2,6-dimethylpyrazine, 2,3-dimethylpyrazine, 2-ethyl-6-methylpyrazine, 2-ethyl-5-methylpyrazine, 2,3,5-trimethylpyrazine and tetramethylpyrazine. Total pyrazine contents greatly increased with increasing roasting temperature, showing 3.07, 9.46 and 19.7 mg total pyrazines per 100 g oils extracted from soybeans roasted at 130°C, 150°C and 170°C, respectively. The oxidative stability tests showed that, as the roasting temperature increased, the oxidative stability of the oil increased greatly. © 1997 Elsevier Science Ltd

INTRODUCTION

Delicate, but definite, flavors are appreciated in the Orient, and a household normally has several types of oils on hand for cooking and flavoring foods. One of the highly regarded oils is dark sesame oil, which is made by roasting sesame seeds under selected conditions before cold pressing. It is normally too expensive and too strong in flavor for cooking, and is used as a condiment in the amount of less than a half a teaspoonful per dish. A new type of oil with the taste of freshly roasted nuts might be highly accepted for salads, main meals and desserts.

Wilkens and Lin (1970) reported the volatile flavor components of deep fat-fried soybeans, which have a pleasant odor, described as being a roasted nut or peanut butter-like aroma. The authors reported seven pyrazines and suggested that these pyrazines were responsible for the nut-like or peanut-like aroma associated with deep-fat fried soybeans. Miyata *et al.* (1977) analysed the headspace volatiles of roasted soybean and identified several carbonyl compounds. Doi *et al.* (1980) identified pyrazines, furans and pyrroles from roasted soybeans by Tenax GC trapping of headspace volatiles and gas chromatographic (GC) analysis. The authors reported that pyrazines, furans and pyrroles increased with increasing roasting temperature. This was, however, strictly a comparison involving GC peak areas, and actual concentration data were not collected.

Lim *et al.* (1995) reported that soybean oil extracted from roasted soybeans had a pleasant roasted nut-like flavor, and that there was no significant difference in the flavor preference between the roasted soybean oil and the sesame oil based on a statistical analysis of sensory evaluations. Since roasted soybean oil reportedly has a pleasant nut-like odor, the development of a new market for roasted soybean oil as a condiment with nut-like

odor has great potential. Information on physical and chemical properties, oxidative stabilities and pyrazine contents is indispensable for the development of roast soybean oil as a condiment. However, no literature on the physical and chemical properties, oxidative stabilities and qualitative and quantitative data on pyrazines in the oils extracted from soybeans roasted at different temperature is available. Even though the qualitative data on pyrazines in roasted or fried soybean products have been previously reported, quality and quantity of pyrazines in roasted soybean oil might not be the same since oil is only a part of components in roasted soybeans.

Thus, the objectives of this research were: (1) to determine the selected physical and chemical properties of the roasted soybean oil, (2) to isolate, identify and quantitate pyrazines in the oils extracted from roasted soybeans, and (3) to determine the oxidative stability of the oils prepared from soybeans roasted at 130°C, 150°C and 170°C.

MATERIALS AND METHODS

Soybeans grown in Korea were purchased from the local market. Pyrazine, 2-methylpyrazine, 2,6-dimethylpyrazine, 2,3-dimethylpyrazine, tetramethylpyrazine, 3-ethyl-3-methylpyrazine, 2,3-diethylpyrazine were purchased from Aldrich (Milwaukee, WI).

Preparation of roasted soybean oils

Soybeans (5 kg) were heated in an oven equipped with a stirrer and a temperature controller. Soybeans were roasted with constant stirring for 15 min at 130°C, 150°C and 170°C. The oils were then extracted using an expeller. The extracted soybean oils were filtered to remove any particles. The oils stood for 2 days at 5°C until two distinct layers (clear top layer and viscous gummy layer) had separated. The clear top layers were collected and used as oil samples. The lower viscous gummy layers were discarded.

Determination of color, conjugated diene, conjugated triene, peroxide value

Colors of the samples were measured using a Hunter colorimeter. For the determination of conjugated diene and triene, samples were diluted with 2,2,4-trimethylpentane. Then the absorptivities of the prepared samples were measured at 233 and 265 nm for the conjugated diene and conjugated triene, respectively. The contents of the conjugated diene and conjugated triene were expressed as absorptivities of the 1% soybean oils in 2,2,4-trimethylpentane at 233 and 265 nm, respectively. Peroxide values were measured according to official method Cd 8-53 of the AOCS (1989).

Fatty acid composition

Oils were methylesterified at 75°C for 25 min with 0.25 M sodium methoxide in methanol. Methyl esters of fatty acids were extracted with petroleum ether. Then 1 μl aliquots of the extracts were injected into a gas chromatograph (GC-14B; Shimadzu, Kyoto, Japan) equipped with a flame ionization detector. The column used was a CBP 20 fused silica capillary column (25 m×0.22 mm I.D., 0.25 μm; Shimadzu). The injector, oven and detector temperatures were 250°C, 180°C and 250°C, respectively.

Tocopherol contents

Oil (0.5 g), 30 ml ethanol, 1 ml of 10% pyrogallol in ethanol, and 3 ml of 60% (w/v) KOH solution were transferred into an Erlenmeyer flask (Kim *et al.*, 1994). The samples were saponified in a boiling water bath for 30 min. The solutions were rapidly cooled in running cold water and then transferred to a separatory funnel. Distilled water (30 ml) and 50 ml diethyl ether were added to the separatory funnel, and the sample was shaken gently. After separation of the two phases, the diethyl ether layer was taken. This extraction step was repeated two more times with 50 ml diethyl ether. The diethyl ether extracts were washed with distilled water and dried over anhydrous Na_2SO_4. Then the extracts were evaporated until dry and the samples were redissolved in 2 ml of n-hexane. Tocopherols were determined with a high-performance liquid chromatograph (Model 254; Waters Associates, Milford, MA) equipped with a variable wavelength UV/Vis detector. The column used was Lichrosorb NH_2 (4.6 mm I.D.×200 mm). The mobile phase was n-hexane/isopropanol (98:2, v/v) at a flow rate of 1.0 ml min^{-1}. Tocopherol components were quantified at 298 nm.

Simultaneous distillation–extraction of pyrazines

A 10 g portion of each oil sample and 500 ml of double-distilled water were transferred into a round bottle of 3 litre capacity. Then, the flavor compounds were extracted with diethyl ether in a simultaneous steam distillation–extractor apparatus for 2 h under atmospheric pressure (Schultz *et al.*, 1977; Kim *et al.*, 1996). The extract was dehydrated under anhydrous magnesium sulphate and filtered. n-Dodecane as an internal standard was added to the extract. Then the extract was concentrated under a stream of nitrogen.

Dichloromethane extraction of pyrazines

The extraction procedure described by Reineccius *et al.* (1972) was used. Each oil sample (10 g) was dissolved in 100 ml diethyl ether. The sample solution was extracted (20 ml×5) with a 1 M HCl solution containing 100 g NaCl $litre^{-1}$. The ether layer was discarded and the

aqueous layers were combined and washed (2×50 ml) with diethyl ether and then adjusted to pH 8.3 by dropwise addition of 5 M KOH solution. The aqueous solution was extracted (20 ml×5) with dichloromethane. The dichloromethane extract was dried over anhydrous $MgSO_4$ and filtered. After addition of internal standard (n-octadecane) to the extract, the extract was concentrated under a stream of nitrogen.

Gas chromatography for isolation, identification and quantitation of pyrazines

The extracts were injected into a gas chromatograph (GC-14B; Shimadzu) equipped with a flame ionization detector for the isolation and quantitation of individual pyrazines. The column used was a DB-Wax fused silica capilary column (30 m×0.25 mm I.D., 0.15 μm; J&W Scientific, Folsom, CA, USA). The temperatures of injection port and detector were 220°C and 230°C, respectively. The oven temperature was held 40°C for 5 min, then programmed at 3°C min^{-1} to 220°C. For the quantitation of pyrazines, extracts obtained by dichloromethane extraction were analysed and the peak areas were compared with those of authentic samples to calculate the content of pyrazines. We found that the detector response was almost solely dependent on the molecular weight of pyrazines. Thus, the contents of some pyrazines, for which we did not have authentic samples, were calculated by comparing the peak areas with those of other pyrazines with similar molecular weight.

For identification, a Varian 3700 gas chromatograph coupled to a mass spectrometer (Varian Mat 212 system) was used. Mass spectra were obtained by electron ionization at 70 eV and a source of temperature of 220°C. The spectra were recorded on a Varian SS MAT 188 system.

Oxidative stability of roasted soybean oils

To study the oxidative stability of soybean oil, 3 g of oil were transferred, in duplicate, to a 30 ml serum bottle. The sample bottles without caps were stored in a forced-draft air oven at 65°C for 60 days. The oxidation of oils was studied by measuring the increases in peroxide contents, conjugated diene and conjugated triene.

Statistical analysis

Statistical analysis was accomplished using SAS methods (Statistical Analysis Systems Institute Inc., 1985). Duncan's multiple range test was used to ascertain the treatment effect on the oxidative stabilities of roasted soybean oils (Jung *et al.*, 1995).

RESULTS AND DISCUSSION

Selected physical and chemical properties

Table 1 shows the Hunter values (color), conjugated dienes and trienes, peroxide value, tocopherol contents and fatty acid compositions in oils extracted from soybeans roasted at 130°C, 150°C and 170°C. Hunter *L*, *a*, *b* values were used for measuring and comparing the colors of oils. *L* measures lightness and varies from 100 for perfect white to zero for black; *a* measures red when plus, grey when zero and green when minus; *b* measures yellow when plus, grey when zero and blue when minus. As roasting temperature increased, the *L* value decreased; i.e. the oil was getting darker with increasing roasting temperature. As the roasting temperature increased, Hunter *a* and *b* values increased; i.e. red and yellow colors increased with increasing roasting temperature. The increase in darkness and redness of oils with increasing roasting temperature seemed to be due to the non-enzymatic browning between reducing sugars and amino groups at the elevated temperatures.

The absorptivities (1% oil in 2,2,4-trimethylpentane) at both 233 and 265 nm increased as the roasting temperature increased. The increased absorptivities at 233 and 265 nm with increasing roasting temperature indicated that roasting induced the formation of conjugated dienes and conjugated trienes. It can not be excluded, however, that the elevated roasting temperature might induce the formation of greater amounts of interfering substances that are extracted along with the oils from

Table 1. Selected physical and chemical properties of roasted soybean oils

	Oils obtained from soybeans roasted at:		
	130°C	150°C	170°C
Hunter color			
L	89.8	89.1	78.8
a	−12.2	−9.0	3.7
b	72.8	74.2	88.1
Conjugated diene[a]	6.76	7.49	8.44
Conjugated triene[b]	0.78	1.15	1.83
Peroxide value (meq kg^{-1} oil)	0	0	0
Tocopherols (mg%)			
α	20.3	8.3	trace
β	trace	trace	trace
γ	44.5	trace	trace
δ	5.2	trace	trace
Fatty acid composition (%)			
Palmitic acid	11.4	11.7	11.5
Stearic acid	2.8	2.7	2.6
Oleic acid	37.9	40.0	39.8
Linoleic acid	42.5	40.7	41.0
Linolenic acid	5.4	4.9	5.1

[a]Conjugated diene content was expressed as absorptivity of 1% oil in 2,2,4-trimethylpentane at 233 nm measured by a UV spectrophotometer.
[b]Conjugated triene content was expressed as absorptivity of 1% oil in 2,2,4-trimethylpentane at 265 nm measured by a UV spectrophotometer.

the roasted soybeans. Peroxide values were the same (0 meq kg^{-1} oil) for all the oils extracted from soybeans roasted at different temperatures. This result indicated that oil oxidation might not occur during roasting because of the relatively short roasting time (15 min), even though the roasting temperatures were high.

Tocopherol contents in oils varied greatly, depending on the roasting temperature. The contents of α-, γ- and δ-tocopherol in oils from soybeans roasted at 130°C were 20.3, 44.5 and 5.2 mg per 100 g oil, respectively. Oils obtained from soybeans roasted at 150°C contained only α-tocopherol and its content was 8.3 mg per 100 g oil. Only a trace amount of tocopherol was detected in the oil extracted from soybeans roasted at 170°C; i.e. as the roasting temperature increased, the tocopherol content decreased greatly. These present results are in accordance with that previously reported for roasted sesame oils (Yen, 1990), namely that the tocopherol contents vary with different roasting temperatures. Yen (1990) studied the effects of roasting temperatures (180–260°C) on the contents of γ-tocopherol (the major tocopherol) in sesame oil. Yen reported that the level of γ-tocopherol in oils was raised by roasting temperatures up to 200°C but fell with higher roasting temperatures, and reported γ-tocopherol contents in sesame oils extracted after roasting at 180°C, 200°C, 220°C, 240°C and 260°C of 375.5, 480.7, 281.1, 244.6 and 138.6 mg kg^{-1} oil, respectively. It is, however, interesting to note that tocopherol reductions with increasing roasting temperature were greater in roasted soybean oil than in roasted sesame oil. The reduction of tocopherols in oils prepared from soybeans roasted at high temperature might be explained by thermal decomposition of tocopherols and chemical reaction (esterification) of tocopherols with carboxyl acid moieties of amino acids, peptides and proteins at increased roasting temperature. Yoshida *et al.* (1992) reported that addition of free fatty acids resulted in a great acceleration of tocopherol reduction in purified vegetable oils during microwave heating. However, hydrocarbons with the same number of carbons but no carboxylic acid moiety did not accelerate the tocopherol reduction in the oils. Thus, the possible explanation for the greater reduction of tocopherols in soybean oil than sesame oil is the greater opportunity for the chemical reactions of tocopherols with the carboxylic acid moieties of peptides and proteins with increasing roasting temperature since soybeans contain higher amounts of proteins for a given amount of oil than sesame seeds. Clear experimental evidence is, however, needed to verify this hypothesis.

The fatty acid composition of roasted soybean oil varied slightly with roasting temperature. The oils prepared from soybeans roasted at 150°C and 170°C contained higher oleic acid but lower linoleic acid contents than the oil prepared from soybeans roasted at 130°C. The relative composition of palmitic acid, stearic acid, oleic acid, linoleic acid and linolenic acid in soybean oil prepared from soybeans roasted at 130°C were 11.4, 2.8, 37.9, 42.5 and 5.4%, respectively. However, the relative composition of palmitic acid, stearic acid, oleic acid, linoleic acid and linolenic acid in soybean oil prepared from soybeans roasted at 150°C were 11.7, 2.7, 40.0, 40.7 and 4.9%, respectively.

Pyrazines in roasted soybean oils

Gas chromatograms of the simultaneous distillation–extraction extract of soybean oils extracted from soybeans roasted at 130°C, 150°C and 170°C are shown in Fig. 1. A gas chromatogram of the dichloromethane extract of soybean oils prepared from soybeans roasted at 170°C is shown in Fig. 2. Table 1 shows the pyrazine contents of the oils extracted from soybeans roasted at different temperatures. The total volatile content increased greatly with increasing roasting temperature (Fig. 1 and Table 1). Both extraction methods (simultaneous distillation–extraction and dichloromethane extraction) provided similar gas chromatograms. Nine alkylpyrazines were isolated and identified from the dichloromethane extracts. These included pyrazine, 2-methylpyrazine, 2,5-dimethylpyrazine, 2,6-dimethylpyrazine, 2,3-dimethylpyrazine, 2-ethyl-6-methylpyrazine, 2-ethyl-5-methylpyrazine, 2,3,5-trimethylpyrazine and 2,3,5,6-tetramethylpyrazine. Among them, methylpyrazine, 2,6-dimethylpyrazine, 2,3-dimethylpyrazine and tetramethylpyrazine were positively identified. However, pyrazine was not detected in the extracts prepared by the simultaneous distillation–extraction method. Johnson *et al.* (1971) suggested that the alkylpyrazines contributed to the roasted-nutty characteristics of typical roasted peanut flavor. Most of the identified alkylpyrazines in the our present research such as pyrazine, methylpyrazine, 2,5-dimethylpyrazine, 2,6-dimethylpyrazine, 2,3-dimethylpyrazine, 2-ethyl-6-methylpyrazine, 2-ethyl-5-methylpyrazine, trimethylpyrazine and tetramethylpyrazine were previously identified also in roasted peanut volatiles (Walradt *et al.*, 1971). By comparing the retention times of authentic samples, it was concluded that there was no 2-ethyl-3-methylpyrazine or 2,3-diethylpyrazine in the oils extracted from roasted soybeans.

Dichloromethane extracts were used for the quantitation of pyrazines in the oils since this method was well established for the quantitation of pyrazines from food samples (Reineccius *et al.*, 1972). In our present results, total identified pyrazine contents were 3.07, 9.46 and 19.78 mg per 100 g oils extracted from soybeans roasted at 130°C, 150°C and 170°C, respectively; i.e. the pyrazine content in oil from soybean roasted at 170°C was 6.41 times greater than in oil extracted from soybeans roasted at 130°C. 2,5-Dimethylpyrazine was the major pyrazine in the oil extracted from soybeans roasted at 130°C, representing as much as 54.7% of the total identified pyrazines. 2-Methylpyrazine greatly increased as the roasting temperature increased. It represented

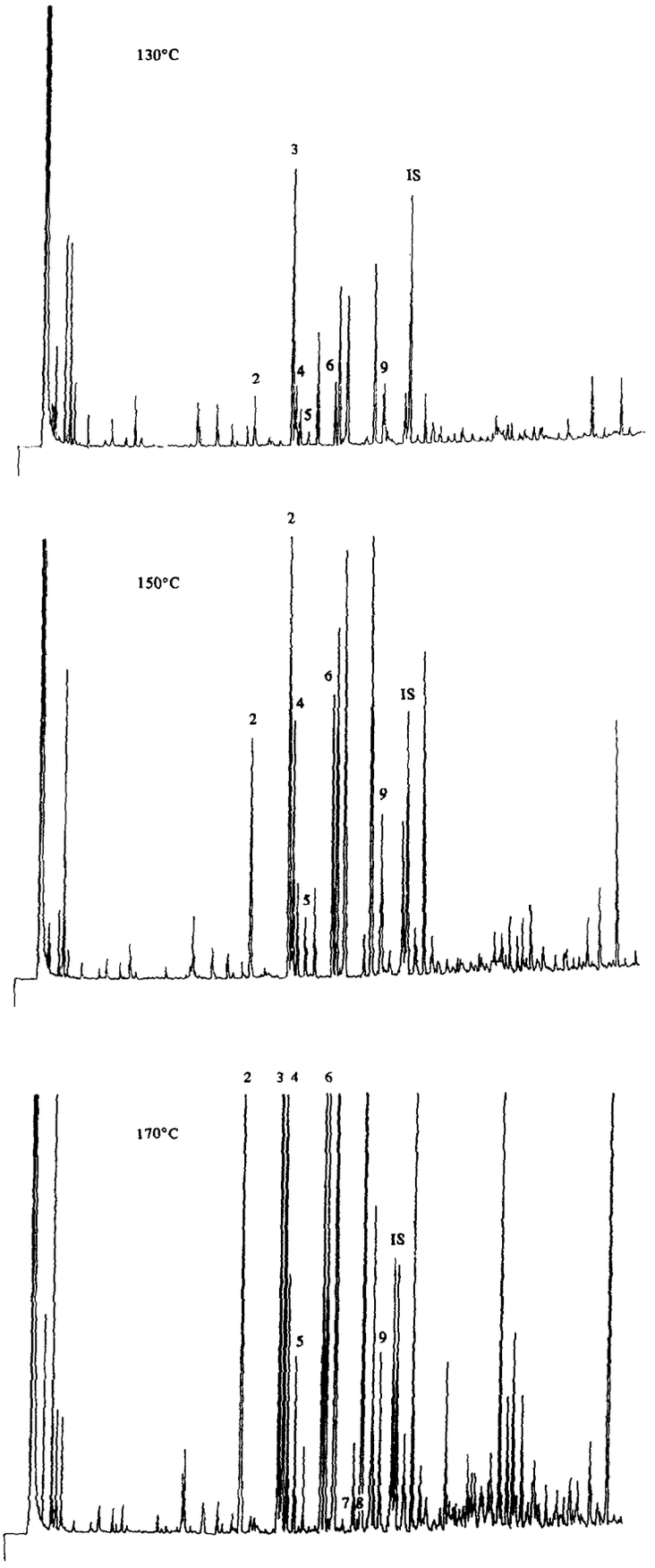

Fig. 1. Gas chromatogram of the simultaneous distillation–extraction extract of soybean oils extracted from soybeans roasted at 130°C, 150°C and 170°C: 2, 2-methylpyrazine; 3, 2,5-diemthylpyrazine; 4, 2,6-dimethylpyrazine; 5, 2,3-dimethylpyrazine; 6, 2-ethyl-6-methylpyrazine; 7, 2-ethyl-5-methylpyrazine; 8, 2,3,5-trimethylpyrazine; 9, 2,3,5,6-tetramethylpyrazine.

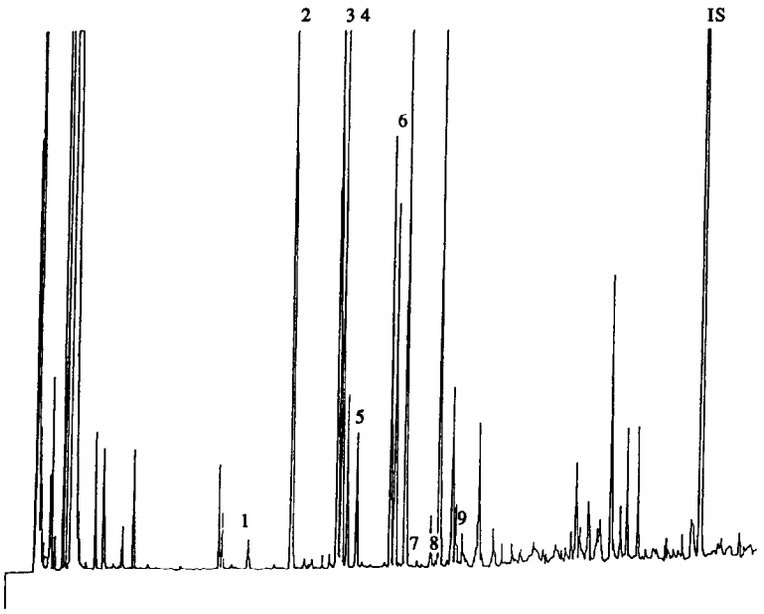

Fig. 2. Gas chromatogram of the dichloromethane extract of soybean oils prepared from soybeans roasted at 170°C: 1, pyrazine; 2, 2-methylpyrazine; 3, 2,5-dimethylpyrazine; 4, 2,6-dimethylpyrazine; 5, 2,3-dimethylpyrazine; 6, 2-ethyl-6-methylpyrazine; 7, 2-ethyl-5-methylpyrazine; 8, 2,3,5-trimethylpyrazine; 9, 2,3,5,6-tetramethylpyrazine.

only 15.0% of the total identified pyrazines in the oil from soybeans roasted at 130°C, but 31.0% in the oil from soybeans roasted at 170°C. In the oil from soybeans roasted at 170°C, 2,5-dimethylpyrazine (6.30 mg per 100 g oil) was the most abundant pyrazine, followed, in decreasing order, by 2-methylpyrazine (6.10 mg per 100 g oil), 2,6-dimethylpyrazine (3.53 mg per 100 g oil) and 2-ethyl-6-methylpyrazine (2.43 mg per 100 g oil). Only trace quantities of 2-ethyl-5-methylpyrazine and trimethylpyrazine were found in the oils. The types of pyrazines identified in the oils from roasted soybeans were similar to the previously reported ones in roasted soybeans (Wilkens & Lin, 1970). These authors investigated the types of flavor compounds formed during deep fat frying of soybeans and they reported seven pyrazines; these were pyrazine, 2-methylpyrazine, 2,5-dimethylpyrazine, 2,3-dimethylpyrazine, 2-ethyl-5-methylpyrazine, trimethylpyrazine, and 2-ethyl-3,6-dimethylpyrazine. They suggested that the occurrence of pyrazines in the product they evaluated was directly related to the heat treatment involved and that the pyrazines were responsible for the nut-like or peanut-like aroma associated with deep fat fried soybeans. Doi *et al.* (1980) identified ten pyrazines in roasted soybeans. Among them, 2,6-dimethylpyrazine, trimethylpyrazine and pyrazine were abundant components in the roasted soybeans. In our present results, trimethylpyrazine and pyrazine were not major pyrazines in the oils obtained from roasted soybeans (Table 2). 2-Methylpyrazine, 2,5-dimethylpyrazine and trimethylpyrazine reportedly exhibit a nutty odor and their reported odor thresholds in water were 60, 1.8 and 9 ppm respectively (Maga & Sizer, 1975; Maga, 1982). Since the odor threshold of 2,5-methylpyrazine was low and its concentration was highest among the pyrazines identified in the oils, we concluded that the 2,5-dimethylpyrazine was the most responsible component for the nut-like odor of the oils from roasted soybeans.

Oxidative stability of soybean oil

The oxidative stability tests clearly showed that, as the roasting time increased, the oxidative stability of roasted soybean oil increased greatly. Figure 3 shows the changes in peroxide values in roasted soybean oils during storage at 65°C. Peroxide values in commercial

Table 2. Pyrazine contents in soybean oils extracted from soybean roasted at 130°C, 150°C and 170°C

	Pyrazine contents (mg per 100 g oil)		
	130°C	150°C	170°C
Pyrazine[a]	trace[d]	0.06	0.31
2-Methylpyrazine[c]	0.46	1.83	6.10
2,5-Dimethylpyrazine[b]	1.68	4.25	6.30
2,6-Dimethylpyrazine[c]	0.49	1.50	3.53
2,3-Dimethylpyrazine[c]	0.15	0.43	0.85
2-Ethyl-6-methylpyrazine[b]	0.29	1.32	2.43
2-Ethyl-5-methylpyrazine[b]	trace	trace	trace
2,3,5-Trimethylpyrazine[b]	trace	trace	trace
2,3,5,6-Tetramethylpyrazine[c]	trace	0.07	0.16
Total pyrazine content	3.07	9.46	19.68

[a]Identified by comparison of GC retention time with that of authentic sample.
[b]Identified by comparison of mass spectra with those in the mass library.
[c]Identified by both mass spectra and GC retention time.
[d]trace: content was too small to be calculated.

RBD soybean oil increased greatly, resulting in 220 meq kg^{-1} oil after 9 days of storage at 65°C. Peroxide values of the oils obtained from roasted soybeans, however, increased slowly, resulting in less than 1.6 meq kg^{-1} oil after 9 days of storage at 65°C. As the roasting temperature increased, the peroxide formation in the oils obtained from roasted soybeans greatly decreased ($P < 0.05$), as shown in Fig. 3. After 43 days of storage, the peroxide values of the oils extracted from soybeans roasted at 130°C, 150°C and 170°C were 457, 121 and 50 meq kg^{-1} oil, respectively. The oil from soybeans roasted at 170°C reached a peroxide value of 158 meq kg^{-1} even after 60 days of storage at 65°C.

Figures 4 and 5 show the changes in conjugated diene and conjugated triene contents in roasted soybean oils during storage at 60°C, respectively. The conjugated diene and conjugated triene were measured by the absorptivities at 233 and 265 nm, respectively. Since the initial absorptivities of the oils obtained from soybeans treated at different temperatures were different, the changes of the conjugated dienes and trienes were determined by the difference in absorptivities between oils stored at 60°C and initial original oils. The absorptivity differences at 233 and 265 nm were used to measure the increase in conjugated dienes and conjugated trienes, respectively. The combined results from Figs 1–3 clearly show that the oil from soybeans roasted at higher temperature had a much greater oxidative stability than oil from soybeans roasted at lower temperature ($P < 0.05$). Our present result was in accordance with previously reported results for sesame oils (Yen & Shyu, 1989), showing that oxidative stability of sesame seed oil increased with increasing roasting temperature. Probably the greater antioxidative stability of soybean oils

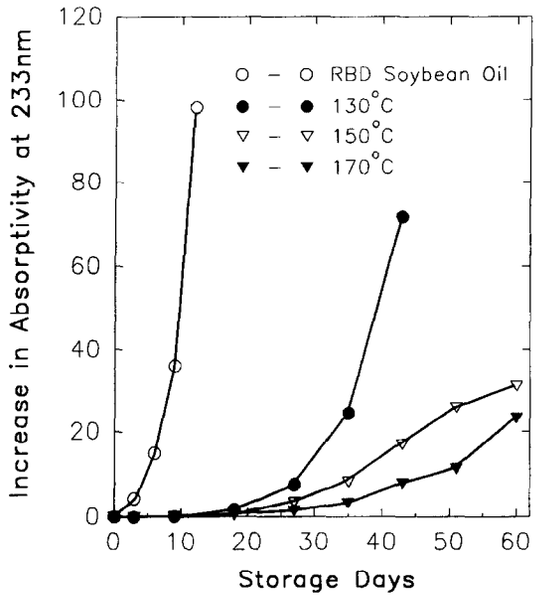

Fig. 4. Changes in conjugated diene contents in roasted soybean oils during storage at 65°C.

prepared from soybeans roasted at higher temperature was due to non-enzymatic reaction products formed during the roasting process. As seen in Table 1, the higher the roasting temperature, the darker the oil; i.e. the higher the roasting temperature, the greater the formation of non-enzymatic reaction products. Maillard reaction products, formed through the interaction of proteins and reducing sugars, reportedly have strong antioxidant activities (Elizalde *et al.*, 1991, 1992; Lee, 1992; Beckel & Waller, 1983; Namiki *et al.*, 1982*a*,*b*).

In summary, color, conjugated diene, conjugated triene, tocopherols and fatty acid composition in the

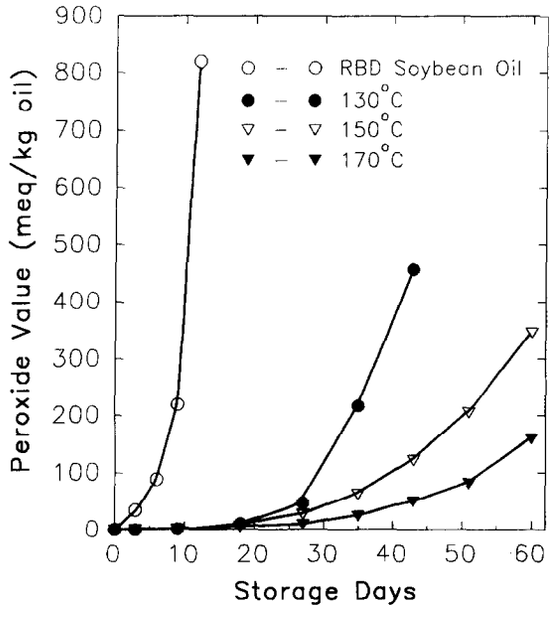

Fig. 3. Changes in peroxide values in roasted soybean oils during storage at 65°C.

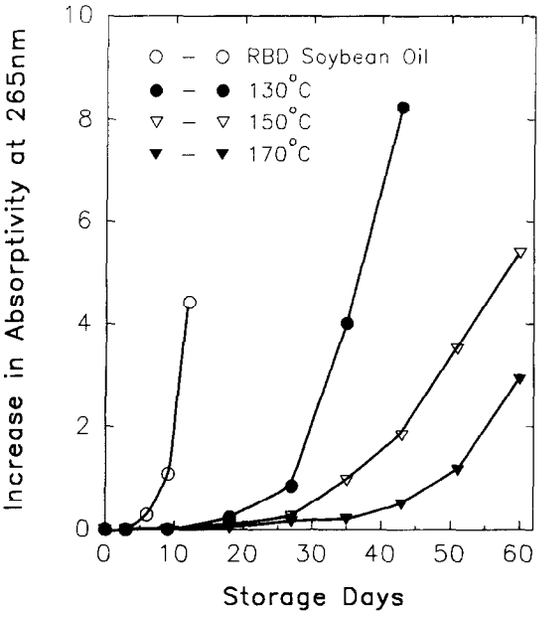

Fig. 5. Changes in conjugated triene contents in roasted soybean oils during storage at 65°C.

roasted soybean oils varied with the roasting temperature. Nine alkyl pyrazines were identified: pyrazine, 2-methylpyrazine, 2,5-dimethylpyrazine, 2,6-dimethylpyrazine, 2,3-dimethylpyrazine, 2-ethyl-6-methylpyrazine, 2-ethyl-5-methylpyrazine, 2,3,5-trimethylpyrazine and 2,3,5,6-tetramethylpyrazine. It was concluded that 2,5-dimethylpyrazine in the roasted soybean oils was the component most responsible for the pleasant nutty odor of the oils. The oxidative stability of oil increased as the roasting temperature increased.

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