Available online at www.sciencedirect.com
ScienceDirect
Food Chemistry 102 (2007) 263–269
Food Chemistry
www.elsevier.com/locate/foodchem

Effects of roasting, powdering and storing irradiated soybeans on hydrocarbon detection for identifying post-irradiation of soybeans

Keum Taek Hwang [a,*], Ji Eun Kim [a], Jae Nam Park [a], Jae Seung Yang [b]

[a] Department of Food Science and Human Nutrition and Research Institute of Human Ecology, Chonbuk National University, Jeonju, Jeonbuk 561-756, Republic of Korea

[b] Advanced Radiation Technology Institute, Jeongeup, Jeonbuk 580-185, Republic of Korea

Received 14 November 2005; received in revised form 6 February 2006; accepted 15 May 2006

Abstract

Hydrocarbons, which are produced by irradiation of lipid-containing foods, were analyzed in irradiated soybeans, which were roasted, powdered and stored, to determine whether these treatments affect hydrocarbon detection for identifying post-irradiation of soybeans. Soybeans were irradiated (Irr), irradiated and roasted (Irr–Rst), roasted and irradiated (Rst–Irr), irradiated, roasted and powdered (Irr–Rst–Pwd), and roasted, powdered and irradiated (Rst–Pwd–Irr). They were stored at refrigerated or room temperature for 30 weeks. Oils were extracted using hexane and Na_2SO_4. Hydrocarbon fraction was separated through a Florisil column and analyzed using GC. Hydrocarbons 17:2, 16:3, 17:1 and 16:2 were not detected in non-irradiated soybeans and soybean powder, but they were detected in those irradiated at 0.5 kGy or higher. The levels of the hydrocarbons increased with dose. The hydrocarbon levels in the Irr–Rst, Rst–Irr, and Irr–Rst–Pwd soybeans were little different from those in the Irr soybeans. Hydrocarbon detection in the Rst–Pwd–Irr soybean powder showed a slightly different pattern from those in the other treatments. Hydrocarbon levels in the soybean and soybean powder samples stored at refrigerated temperature for 30 weeks changed little, compared to initial samples. The hydrocarbon detection patterns in the samples stored at room temperature for 30 weeks were similar to the initial and refrigerated samples with slightly lower detection levels in the room-stored samples.

Keywords: Fatty acid composition; Hydrocarbon; Irradiation detection; Soybean powder

1. Introduction

In spite of the tenable benefits and safeness of irradiated foods, consumers are still hesitant over the use of food irradiation. Irradiated foods are required to be properly labeled for international trade; however, there is the possibility of irradiating foods without any notice on the shipment. Therefore, it is necessary to develop an appropriate method to detect irradiation of imported foods in order to apply domestic regulations concerning food irradiation.

Since Nawar's group (Champagne & Nawar, 1969; Dubravcic & Nawar, 1968; Dubravcic & Nawar, 1969) reported that some hydrocarbons are exclusively produced by γ-radiation of lipids and lipid-containing foods, hydrocarbons have been extensively studied as markers to detect irradiation of foods. Two types of hydrocarbons are predominantly produced by irradiation of fatty acids: a hydrocarbon that has one carbon less than the parent fatty acid (C_{n-1}) and a hydrocarbon that has two carbons less and an additional double bond at position 1 (C_{n-2}, 1-ene) (Dubravcic & Nawar, 1968; Spiegelberg, Schulzki, Helle, Bögl, & Schreiber, 1994). The hydrocarbons exclusively detected in irradiated foods have been suggested to be used as markers for identifying post-irradiation of the foods that are fairly high in lipids, such as meats (Champagne & Nawar, 1969; Hwang, 1999a; Spiegelberg et al., 1994), eggs (Hwang, 1999b; Hwang et al., 2001; Schulzki, Spiegelberg, Bögl, & Schreiber, 1995), peanuts (Lesgards et al., 1993;

* Corresponding author. Tel.: +82 63 270 3857; fax: +82 63 270 3854.
E-mail address: keum@chonbuk.ac.kr (K.T. Hwang).

0308-8146/$ - see front matter © 2006 Elsevier Ltd. All rights reserved.
doi:10.1016/j.foodchem.2006.05.015

Park & Hwang, 1999), and sesame seeds (Choi & Hwang, 1997). Severe heating of peanut oils induced the formation of some hydrocarbons; however, the pattern of hydrocarbon production by the heating was totally different from irradiation (Lesgards et al., 1993; Park & Hwang, 1999).

Irradiation of beans, soybeans, soya powder or soybean products is permitted up to 1 kGy for disinfestation or up to 10 kGy for microbial control in Bangladesh, Brazil, Chile, Costa Rica, Ghana, Indonesia, Israel, Mexico, The Netherlands, Pakistan, South Africa, Syria, Thailand and Yugoslavia (International Consultative Group on Food Irradiation, 2004). Hwang, Kim, and Yang (2005) determined hydrocarbons could be also applied for identifying post-irradiation of unprocessed soybeans. Since soybeans are usually roasted, powdered and stored before use, it is necessary to determine whether these treatments affect hydrocarbon detection of irradiated soybeans for proper identification of irradiated soybeans. Hydrocarbons were analyzed in the soybeans treated in various ways such as irradiation, roasting and powdering. Hydrocarbon detection levels in the soybeans and soybean powder were also determined after 30 week storage.

2. Materials and methods

2.1. Soybean sample preparation

Soybeans (glycine max (L.) Merrill) were purchased from a local market in Jeonju, Korea. Soybeans were (i) irradiated (Irr), (ii) irradiated and then roasted (Irr–Rst), (iii) roasted and then irradiated (Rst–Irr), (iv) roasted, powdered, and then irradiated (Rst–Pwd–Irr), and (v) irradiated, and then roasted and powdered (Irr–Rst–Pwd). Every category had non-irradiated sample as its control. Soybeans and soybean powder (roasted and powdered) were irradiated at 0.5, 1, 5, and 10 kGy with a ^{60}Co γ-radiation source at the Korea Atomic Energy Research Institute (Daejeon, Korea). Roasting for the Rst–Irr, Irr–Rst and Irr–Rst–Pwd samples was done by heating soybeans for 10 min on an electric frying pan (temperature setting: 400; Sunbeam Appliance Co., Oak Brood, IL, USA) in the lab. Powdering for the Irr–Rst–Pwd soybean powder samples was done with a blender (DA-280; Daesung Atron Co., Seoul, Korea) in the lab, blending roasted soybeans for 10 min. Soybeans for the Rst–Pwd–Irr soybean powder were roasted and powdered in a local mill (the roasting and powdering conditions were not known.), and then irradiated. Samples were stored at refrigerated (2–5 °C) and room temperatures for 30 weeks.

2.2. Fatty acid composition of oils in soybeans

Oil extraction for fatty acid composition analysis followed the Bligh and Dyer method (Bligh & Dyer, 1957). Methylation of the oils was carried out using the AOCS Official Method Ce 2-66 (1989). The FAMEs were analyzed on a Hewlett–Packard 6890 Series gas chromatography (Hewlett–Packard Co., Wilmington, DE, USA), equipped with a flame-ionization detector (FID). The column was an HP-23 *cis/trans* FAME column (30 m × 0.25 mm × 0.25 μm; Hewlett–Packard Co.). Helium was used as carrier gas. One microlitre of each sample was injected. The initial flow rate of the carrier gas was 1 ml/min for 12 min and then increased at 0.2 ml/min up to 2 ml/min. The injector and detector temperatures were 250 °C and 270 °C, respectively. The injector was set in a split ratio of 100:1. Initial column temperature was 150 °C for 2 min, programmed to increase at 3.5 °C/min up to 170 °C, at which point it was held for 10 min followed by increases of 4 °C/min to 210 °C and then 25 °C/min to 250 °C with a final hold for 5 min.

2.3. Hydrocarbons in soybeans and soybean powder

Soybeans (35–40 g) were ground in a blender with 50 g anhydrous Na_2SO_4. Hexane (200 ml) was added. The contents were homogenized thoroughly using a homogenizer (M133/1281-1; Biospec Products Inc., Bartlesville, OK, USA). The rest of the oil extraction procedure was the same as in a previous report (Hwang, 1999b). Hydrocarbons were fractionated from the oil extracts by Florisil column chromatography and analyzed using GC as in the previously reported method (Hwang, 1999b).

2.4. Statistical analysis

Three to six determinations were carried out. Significant differences ($p < 0.05$) for prominently detected hydrocarbons among treatments were determined by ANOVA, followed by Sheffe's multiple range test, using an SPSS 12.0 package (SPSS Inc., Chicago, IL, USA).

3. Results and discussion

3.1. Fatty acid composition of oils in soybeans

Moisture contents of soybeans and soybean powder were 12.1% (w/w) and 7.6%, respectively. Crude fat con-

Table 1
Fatty acid compositions (%, w/w) of oils extracted from soybeans and soybean powder prior to irradiation

Fatty acid	Soybeans	Soybean powder
Palmitic	9.9 (0.05)[a]	9.8 (0.06)
Stearic	3.6 (0.02)	3.6 (0.02)
Oleic	26.0 (0.1)	26.0 (0.05)
Vaccenic	1.4 (0.00)	1.4 (0.01)
Linoleic	49.6 (0.07)	49.6 (0.11)
Linolenic	8.2 (0.11)	8.3 (0.06)
Arachidic	0.3 (0.02)	0.3 (0.01)
11-Eicosanoic	0.2 (0.00)	0.2 (0.00)
Behenic	0.5 (0.00)	0.5 (0.01)
Lignoceric	0.2 (0.00)	0.2 (0.01)

[a] Mean (standard deviation) of three determinations.

tents were 14.5% (w/w, wb) and 17.5%, respectively. Fatty acid compositions between non-irradiated soybeans and soybean powder had little difference (Table 1). Linoleic acid was the most abundant fatty acid in soybean oils, followed by oleic and palmitic acids. Thus, the major hydrocarbons induced by irradiation were expected to be 6,9-heptadecadiene (17:2) and 1,7,10-hexadecatriene (16:3) from linoleic acid, 8-heptadecene (17:1) and 1,7-hexadecadiene (16:2) from oleic acid, and *n*-pentadecane (15:0) and 1-tetradecene (14:1) from palmitic acid.

3.2. Hydrocarbons detected in irradiated soybeans

Hydrocarbons 17:1, 16:2, 17:2 and 16:3, induced from oleic and linoleic acids, were not detected in the lipids extracted from non-irradiated soybeans, while they were detected in a fairly large amounts in the lipids from the samples irradiated at every level of tested doses (Table 2). Detection levels of the hydrocarbons increased with dose. Hydrocarbons 15:0 and 14:1, possibly radiation-induced from palmitic acid, and *n*-hexadecane (17:0) and 1-hexadecene

Table 2
Initial levels of hydrocarbons detected in non-irradiated and irradiated soybeans and soybean powder (μg/g oil)[a]

Sample	Hydrocarbon	Dose (kGy)				
		0	0.5	1	5	10
Irr	17:2	–[b]	0.20(0.07)	0.70(0.09)	4.96(0.00)	10.53(1.62)
	16:3	–	0.50(0.11)	1.14(0.03)	5.08(0.01)	9.97(1.21)
	17:1	–	0.20(0.05)	0.49(0.07)	2.93(0.14)	5.98(1.23)
	16:2	–	0.29(0.06)	0.61(0.05)	3.39(0.07)	6.00(0.78)
	15:0	0.21(0.01)	0.30(0.07)	0.40(0.09)	1.25(0.06)	2.19(0.22)
	14:1	0.18(0.03)	0.26(0.05)	0.37(0.06)	1.32(0.10)	2.12(0.15)
	17:0	0.40(0.10)	0.34(0.05)	0.36(0.08)	0.67(0.04)	1.02(0.08)
	16:1	0.22(0.05)	0.22(0.03)	0.28(0.03)	0.61(0.02)	0.97(0.12)
Irr–Rst	17:2	–	0.24(0.02)	0.73(0.07)	5.70(0.54)	9.61(0.09)
	16:3	–	0.48(0.05)	0.96(0.00)	5.64(0.60)	9.81(0.77)
	17:1	–	0.18(0.07)	0.50(0.04)	2.99(0.39)	5.25(0.25)
	16:2	–	0.30(0.04)	0.61(0.08)	3.18(0.39)	5.70(0.06)
	15:0	0.26(0.06)	0.32(0.06)	0.43(0.08)	1.27(0.15)	2.23(0.18)
	14:1	0.13(0.02)	0.27(0.07)	0.34(0.05)	1.17(0.06)	2.36(0.27)
	17:0	0.27(0.05)	0.30(0.03)	0.37(0.08)	0.66(0.07)	0.97(0.08)
	16:1	0.13(0.02)	0.18(0.03)	0.21(0.02)	0.55(0.06)	0.81(0.10)
Rst–Irr	17:2	–	0.30(0.05)	0.87(0.13)	5.89(0.36)	12.31(0.22)
	16:3	–	0.59(0.06)	0.97(0.07)	5.56(0.37)	11.41(0.74)
	17:1	–	0.23(0.02)	0.70(0.02)	3.46(0.18)	6.53(0.13)
	16:2	–	0.32(0.03)	0.63(0.09)	3.41(0.15)	6.75(0.21)
	15:0	0.37(0.06)	0.40(0.06)	0.55(0.11)	1.41(0.05)	2.65(0.09)
	14:1	0.20(0.06)	0.31(0.08)	0.41(0.04)	1.38(0.14)	2.50(0.16)
	17:0	0.31(0.05)	0.34(0.05)	0.41(0.05)	0.73(0.05)	1.14(0.03)
	16:1	0.19(0.03)	0.93(0.08)	1.02(0.04)	0.95(0.07)	1.04(0.08)
Irr–Rst–Pwd	17:2	–	0.26(0.04)	0.82(0.02)	5.03(0.01)	10.65(0.10)
	16:3	–	0.50(0.04)	1.18(0.03)	5.10(0.04)	10.03(0.57)
	17:1	–	0.24(0.01)	0.59(0.03)	2.96(0.04)	5.71(0.08)
	16:2	–	0.30(0.03)	0.65(0.07)	3.10(0.01)	6.14(0.06)
	15:0	0.27(0.09)	0.34(0.05)	0.37(0.08)	1.25(0.07)	2.12(0.01)
	14:1	0.10(0.08)	0.23(0.04)	0.40(0.04)	1.22(0.09)	2.20(0.07)
	17:0	0.27(0.06)	0.28(0.06)	0.33(0.07)	0.62(0.08)	1.01(0.05)
	16:1	0.18(0.01)	0.22(0.02)	0.26(0.03)	0.57(0.07)	0.93(0.06)
Rst–Pwd–Irr	17:2	–	0.24(0.07)	0.35(0.06)	2.13(0.07)	5.49(0.00)
	16:3	–	0.53(0.07)	1.01(0.08)	4.91(0.39)	9.87(0.81)
	17:1	–	0.28(0.08)	0.31(0.13)	1.35(0.15)	3.11(0.06)
	16:2	–	0.29(0.05)	0.56(0.01)	2.77(0.19)	5.66(0.47)
	15:0	0.34(0.10)	0.92(0.08)	1.01(0.08)	1.05(0.16)	1.02(0.11)
	14:1	0.32(0.02)	0.36(0.10)	0.47(0.09)	1.38(0.06)	2.27(0.15)
	17:0	0.43(0.11)	0.62(0.02)	0.59(0.05)	0.60(0.07)	0.70(0.04)
	16:1	0.35(0.08)	0.37(0.02)	0.45(0.05)	0.82(0.10)	1.24(0.08)

Irr: irradiated; Irr–Rst: irradiated and roasted: Rst–Irr: roasted and irradiated; Irr–Rst–Pwd: irradiated, roasted and powdered; and Rst–Pwd–Irr: roasted, powdered and irradiated.

[a] Mean (standard deviation) of six determinations.

[b] –, not detected.

(16:1), possibly from stearic acid, were detected in the non-irradiated samples and increased with irradiated dose (Table 2). In the non-irradiated samples it was not clear whether hydrocarbons were originated from the solvents used for extraction or the soybeans themselves. Due to the lower detection levels of the hydrocarbons 15:0, 14:1, 17:0 and 16:1 in irradiated samples along with their detection in non-irradiated samples, the hydrocarbons 15:0, 14:1, 17:0 and 16:1 would not be clear-cut markers for identifying irradiated soybeans.

Linolenic acid (about 8%) was the fourth most abundant fatty acid in soybean oils (Table 1). 3,6,9-Heptadecatriene (17:3) and 1,7,10,13-hexadecatetraene (16:4) would be expected from linolenic acid by irradiation. The peak appearing just before the peak of 17:2 on GC chromatogram might be 17:3 (figure not shown). However, any possible peak corresponding to 16:4 did not appear before the 16:3 peak. Standard hydrocarbons 17:3 and 16:4 are not commercially available, either. Therefore, the hydrocarbons induced from linolenic acid are hardly used for identifying post-irradiation of soybeans.

Definite irradiation confirmation of soybeans should be based on the simultaneous detection of the hydrocarbons discussed above and on the order of hydrocarbon detection

Table 3
Hydrocarbons detected in non-irradiated and irradiated soybeans and soybean powder after storage at refrigerated temperature for 30 weeks (μg/g oil)[a]

Sample	Hydrocarbon	Dose (kGy)				
		0	0.5	1	5	10
Irr	17:2	–[b]	0.24(0.51)	0.51(0.02)	3.85(0.91)	9.70(1.48)
	16:3	–	0.47(0.09)	0.63(0.12)	3.88(0.17)	9.18(1.66)
	17:1	–	0.13(0.03)	0.26(0.13)	2.23(0.04)	6.67(0.65)
	16:2	–	0.26(0.06)	0.46(0.04)	2.47(0.41)	5.22(1.25)
	15:0	0.19(0.04)	0.21(0.03)	0.20(0.04)	0.84(0.21)	2.18(0.01)
	14:1	0.16(0.08)	0.19(0.04)	0.43(0.29)	0.94(0.24)	2.03(0.36)
	17:0	0.28(0.01)	0.20(0.09)	0.28(0.05)	0.44(0.18)	1.04(0.10)
	16:1	0.25(0.06)	0.22(0.03)	0.40(0.13)	0.88(0.13)	0.97(0.06)
Irr–Rst	17:2	–	0.22(0.10)	0.64(0.30)	4.61(2.45)	9.61(0.04)
	16:3	–	0.42(0.21)	0.89(0.47)	4.64(0.60)	8.81(0.17)
	17:1	–	0.16(0.07)	0.46(0.24)	2.92(1.42)	7.58(0.04)
	16:2	–	0.23(0.11)	0.52(0.28)	2.75(1.51)	6.35(0.11)
	15:0	0.12(0.02)	0.15(0.02)	0.39(0.05)	1.34(0.13)	2.64(0.00)
	14:1	0.12(0.07)	0.31(0.09)	0.54(0.16)	1.66(0.23)	2.67(0.04)
	17:0	0.23(0.14)	0.21(0.01)	0.29(0.10)	0.57(0.18)	1.16(0.07)
	16:1	0.10(0.09)	0.09(0.01)	0.22(0.07)	0.45(0.25)	1.07(0.04)
Rst–Irr	17:2	–	0.25(0.17)	0.87(0.13)	3.87(1.85)	10.31(0.86)
	16:3	–	0.57(0.06)	0.98(0.09)	3.68(1.71)	9.41(0.75)
	17:1	–	0.21(0.15)	1.60(1.74)	2.60(1.34)	6.82(0.51)
	16:2	–	0.31(0.08)	0.91(0.27)	2.23(1.01)	7.11(0.42)
	15:0	0.14(0.08)	0.36(0.05)	1.04(0.51)	0.99(0.57)	2.82(0.10)
	14:1	0.10(0.01)	0.26(0.06)	0.38(0.03)	0.92(0.47)	2.71(0.15)
	17:0	0.21(0.14)	0.26(0.19)	0.43(0.40)	0.45(0.18)	1.18(0.00)
	16:1	0.51(0.63)	0.16(0.08)	0.35(0.36)	0.40(0.19)	1.12(0.00)
Irr–Rst–Pwd	17:2	–	0.47(0.23)	0.84(0.36)	5.53(0.46)	10.55(0.18)
	16:3	–	0.69(0.18)	1.18(0.23)	5.00(0.54)	9.25(0.35)
	17:1	–	0.36(0.11)	0.71(0.38)	3.79(0.02)	5.86(0.16)
	16:2	–	0.36(0.12)	0.60(0.05)	2.95(0.25)	5.65(0.18)
	15:0	0.40(0.00)	0.46(0.01)	1.41(0.11)	1.77(0.12)	2.46(0.64)
	14:1	0.65(0.01)	0.39(0.08)	0.65(0.33)	1.21(0.11)	1.81(0.24)
	17:0	0.27(0.06)	0.36(0.02)	0.59(0.40)	0.70(0.08)	1.02(0.24)
	16:1	0.18(0.01)	0.21(0.06)	0.31(0.20)	0.67(0.03)	1.03(0.06)
Rst–Pwd–Irr	17:2	–	0.41(0.08)	0.53(0.01)	2.30(0.09)	4.72(0.29)
	16:3	–	0.58(0.04)	0.95(0.05)	4.77(0.39)	8.81(0.34)
	17:1	–	0.39(0.18)	0.32(0.05)	1.73(0.58)	3.10(0.09)
	16:2	–	0.39(0.04)	0.50(0.02)	2.69(0.00)	5.53(0.32)
	15:0	0.34(0.10)	0.94(0.29)	0.57(0.08)	1.46(0.16)	1.94(0.11)
	14:1	0.30(0.02)	0.48(0.08)	0.65(0.01)	1.17(0.20)	1.65(0.12)
	17:0	0.33(0.11)	0.76(0.34)	0.36(0.07)	0.88(0.32)	1.02(0.00)
	16:1	0.35(0.08)	0.37(0.02)	0.45(0.05)	0.82(0.10)	1.24(0.08)

Irr: irradiated; Irr–Rst: irradiated and roasted: Rst–Irr: roasted and irradiated; Irr–Rst–Pwd: irradiated, roasted and powdered; and Rst–Pwd–Irr: roasted, powdered and irradiated.

[a] Mean (standard deviation) of three determinations.

[b] –, not detected.

levels in the same order of the parent fatty acid levels. The methodology applied in this study can clearly differentiate irradiated from non-irradiated soybeans by detecting at least the four prominent hydrocarbons (17:1, 16:2, 17:2 and 16:3).

3.3. Effects of roasting and powdering on hydrocarbon detection

Roasting of irradiated soybeans (Irr–Rst) and irradiation of roasted soybeans (Rst–Irr) affected little the detection levels of hydrocarbons compared to the treatments without roasting (Irr) (Table 2). Hydrocarbons detected in the soybean powder, which were irradiated and then roasted and powdered (Irr–Rst–Pwd), were also little different from the Irr, Irr–Rst or Rst–Irr, soybeans (Table 2). However, hydrocarbon detection in the Rst–Pwd–Irr soybean powder showed a different pattern from those in the other treatments (Table 2). Especially, the 17:2 level was apparently lower than the 16:3 level in the Rst–Pwd–Irr, comparing that 17:2 and 16:3 levels are similar in the other samples. The reason for the different results in the Rst–Pwd–Irr is not clear since the soybeans for the Rst–Pwd–Irr were roasted and powdered at a local mill without knowing the conditions.

Park and Hwang (1999) and Hwang et al. (2001) reported that heating of peanut oil and egg fat in extreme

Table 4
Hydrocarbons detected in non-irradiated and irradiated soybeans and soybean powder after storage at room temperature for 30 weeks (μg/g oil)[a]

Sample	Hydrocarbon	Dose (kGy)				
		0	0.5	1	5	10
Irr	17:2	–[b]	0.38(0.09)	0.51(0.02)	3.50(0.02)	7.04(0.14)
	16:3	–	0.50(0.00)	0.62(0.01)	3.44(0.02)	6.65(0.12)
	17:1	–	0.36(0.11)	0.40(0.02)	2.60(0.02)	5.30(0.05)
	16:2	–	0.86(0.00)	0.73(0.00)	2.94(0.04)	5.44(0.10)
	15:0	0.22(0.01)	0.34(0.06)	0.32(0.13)	0.90(0.07)	1.67(0.04)
	14:1	0.14(0.00)	0.14(0.00)	0.35(0.00)	0.86(0.05)	1.62(0.02)
	17:0	0.24(0.01)	0.20(0.09)	0.28(0.05)	0.56(0.01)	0.89(0.14)
	16:1	0.15(0.05)	0.16(0.02)	0.35(0.00)	0.37(0.01)	0.63(0.01)
Irr–Rst	17:2	–	0.32(0.08)	0.80(0.01)	3.56(0.02)	8.75(0.18)
	16:3	–	0.47(0.07)	0.96(0.09)	3.29(0.04)	7.33(0.11)
	17:1	–	0.51(0.10)	0.83(0.18)	3.23(0.05)	5.94(0.15)
	16:2	–	0.90(0.22)	0.84(0.03)	2.13(0.00)	4.49(0.12)
	15:0	0.49(0.08)	0.68(0.05)	0.85(0.09)	1.34(0.10)	1.50(0.02)
	14:1	0.31(0.02)	0.21(0.05)	0.26(0.02)	1.16(0.33)	1.63(0.01)
	17:0	0.35(0.01)	0.43(0.01)	0.43(0.01)	0.74(0.00)	1.56(0.01)
	16:1	0.25(0.01)	0.29(0.02)	0.34(0.03)	0.74(0.12)	0.75(0.00)
Rst–Irr	17:2	-	0.26(0.07)	0.73(0.07)	3.7(0.10)	7.35(0.13)
	16:3	–	0.36(0.02)	0.80(0.03)	2.9(0.00)	5.80(0.09)
	17:1	–	0.27(0.05)	0.76(0.05)	3.01(0.02)	6.63(0.22)
	16:2	–	0.60(0.06)	0.71(0.15)	2.4(0.01)	5.03(0.08)
	15:0	0.49(0.02)	0.85(0.19)	1.43(0.00)	1.25(0.12)	2.17(0.40)
	14:1	0.29(0.01)	0.18(0.01)	0.26(0.05)	0.20(0.03)	1.07(0.25)
	17:0	0.21(0.14)	0.26(0.19)	0.43(0.40)	0.45(0.18)	1.18(0.00)
	16:1	0.24(0.00)	0.26(0.03)	0.34(0.03)	0.32(0.01)	0.88(0.01)
Irr–Rst–Pwd	17:2	–	0.40(0.05)	0.58(0.01)	3.79(0.03)	8.63(0.06)
	16:3	–	0.32(0.04)	0.70(0.00)	2.88(0.26)	6.90(0.03)
	17:1	–	0.81(0.03)	0.67(0.01)	3.06(0.04)	5.10(0.02)
	16:2	–	0.51(0.09)	0.76(0.02)	2.36(0.35)	4.19(0.04)
	15:0	1.64(0.04)	1.49(0.02)	1.13(0.02)	1.26(0.16)	2.60(0.16)
	14:1	0.30(0.04)	0.17(0.01)	0.22(0.00)	0.57(0.02)	1.53(0.20)
	17:0	0.45(0.02)	0.61(0.02)	0.86(0.08)	0.98(0.02)	1.18(0.03)
	16:1	0.33(0.00)	0.24(0.01)	0.32(0.00)	0.56(0.14)	1.06(0.01)
Rst–Pwd–Irr	17:2	–	0.46(0.05)	0.80(0.00)	1.29(0.07)	2.86(0.14)
	16:3	–	0.85(0.05)	1.73(0.05)	2.51(0.17)	4.76(0.14)
	17:1	–	0.51(0.12)	0.68(0.03)	1.11(0.12)	2.15(0.12)
	16:2	–	0.65(0.22)	0.97(0.03)	2.27(0.16)	4.25(0.02)
	15:0	0.56(0.05)	0.57(0.01)	1.87(0.17)	1.92(0.13)	2.56(0.12)
	14:1	0.29(0.01)	0.34(0.00)	0.42(0.01)	0.52(0.03)	0.61(0.00)
	17:0	0.70(0.09)	0.84(0.04)	1.66(0.08)	2.16(0.14)	2.75(0.01)
	16:1	0.44(0.19)	0.51(0.03)	0.59(0.01)	0.92(0.26)	1.48(0.55)

Irr: irradiated; Irr–Rst: irradiated and roasted: Rst–Irr: roasted and irradiated; Irr–Rst–Pwd: irradiated, roasted and powdered; and Rst–Pwd–Irr: roasted, powdered and irradiated.

[a] Mean (standard deviation) of three determinations.

[b] –, not detected.

Table 5
Statistical analyses for prominently radiation-induced hydrocarbons among treatments

Hydrocarbon	17:2				16:3				17:1				16:2			
Dose (kGy)	0.5	1	5	10	0.5	1	5	10	0.5	1	5	10	0.5	1	5	10
Irr (I)	a	abc	abc	a	abc	a	a	ab	ab	a	abc	abc	a	abcd	a	abc
Irr (Rf)	a	ad	ab	ab	abc	b	bcd	b	a	a	abe	bcd	a	a	abc	ade
Irr (Rm)	bcd	ad	ad	c	abc	b	be	c	bc	a	abd	a	e	cde	abc	abd
Irr–Rst (I)	a	abc	c	ab	abc	acd	a	b	ab	a	abc	a	a	abcd	ab	abd
Irr–Rst (Rf)	a	abc	abc	ab	ab	abcd	acd	b	a	a	abc	d	a	ab	abc	bcf
Irr–Rst (Rm)	abc	bc	abd	b	abc	acd	be	c	bc	a	bc	abc	e	ef	c	ge
Rst–Ir (I)	abc	c	c	d	bc	acd	a	a	ab	a	bc	bc	a	abcd	a	cf
Rst–Irr (Ref)	a	c	ab	a	bc	acd	bc	b	ab	b	abd	cd	a	fg	bc	f
Rst–Irr (Rm)	ab	abc	ab	ce	ab	bcd	be	cd	ab	a	abc	bcd	cd	cde	abc	dge
Irr–Rst–Pwd (I)	ab	c	bc	a	abc	a	a	ab	ab	a	abc	ab	a	bcd	abc	bc
Irr–Rst–Pwd (Rf)	d	c	c	a	cd	a	ab	b	ab	a	c	abc	a	abcd	abc	abd
Irr–Rst–Pwd (Rm)	cd	ab	ab	be	a	bc	be	c	c	a	abc	a	bc	def	bc	g
Rst–Pwd–Irr (I)	a	d	de	f	abc	ad	ab	b	ab	a	ef	e	a	abc	abc	abd
Rst–Pwd–Irr (Rf)	cd	ad	de	f	bc	ad	acd	b	ab	a	def	e	ab	ab	abc	abd
Rst–Pwd–Irr (Rm)	d	bc	e	g	d	e	e	d	bc	a	f	f	d	g	ab	g

a–g: different letters in each column indicate significant differences at $p < 0.05$ (ANOVA and Sheffe's multiple range test).
Irr: irradiated; Irr–Rst: irradiated and roasted: Rst–Irr: roasted and irradiated; Irr–Rst–Pwd: irradiated, roasted and powdered; and Rst–Pwd–Irr: roasted, powdered and irradiated.
(I) initial hydrocarbon level (Table 2); (Rf) hydrocarbon level after storage at refrigerated temperature for 30 weeks (Table 3); (Rm) hydrocarbon level after storage at room temperature for 30 weeks (Table 4).

conditions produced hydrocarbons 17:1, 17:2, 16:1 and 16:2. Hydrocarbons 17:1, 17:2 and 16:2 were not detected in any non-irradiated soybeans and soybean powder in this study (Table 2), suggesting that roasting conditions for human consumption hardly affect hydrocarbon production.

3.4. Effects of storage on hydrocarbon detection

Hydrocarbon levels in the soybean and soybean powder samples stored at refrigerated temperature for 30 weeks changed little compared to the initial samples (Tables 2 and 3). Hydrocarbons 17:1, 16:2, 17:2 and 16:3 also were not detected in any non-irradiated samples and their levels increased with dose. The hydrocarbon detection patterns in the samples stored at room temperature for 30 weeks were similar to the initial and refrigerated samples with slightly lower detection levels in the room-stored samples (Tables 4 and 5).

4. Conclusions

Hydrocarbons 17:1, 16:2, 17:2 and 16:3 could be clear-cut markers for identifying irradiated soybeans and soybean powder with any treatments such as roasting, powdering and storing. It is also noted that hydrocarbon production levels from oils in soybeans and soybean powder by irradiation were in the order of $(17:2 + 16:3) > (17:1 + 16:2) > (15:0 + 14:1) > (17:0 + 16:1)$, which were the same order of their parent fatty acid levels in the oils of soybean and soybean powder (linoleic acid > oleic acid > palmitic acid > stearic acid). Thus, detection of the prominent hydrocarbons and comparison of their detection levels clearly identify post-irradiation of soybeans and soybean powder.

Acknowledgement

This work was supported by the Regional Research Centers Program of the Korean Ministry of Education and Human Resources Development through the Center for Healthcare Technology Development.

References

AOCS Official Method Ce 2-66. (1989). Preparation of methyl esters of long-chain fatty acid. In *Official and tentative methods of the American Oil Chemists' Society*. Champaign: American Oil Chemists' Society.

Bligh, E. G., & Dyer, W. J. (1957). A rapid method of total lipid extraction and purification. *Canadian Journal of Biochemistry and Physiology, 37*, 911–917.

Champagne, J. R., & Nawar, W. W. (1969). The volatile components of irradiated beef and pork fats. *Journal of Food Science, 34*, 335–339.

Choi, C. R., & Hwang, K. T. (1997). Detection of hydrocarbons in irradiated and roasted sesame seeds. *Journal of the American Oil Chemists' Society, 74*, 469–472.

Dubravcic, M. D., & Nawar, W. W. (1968). Radiolysis of lipids. Mode of cleavage in simple triglycerides. *Journal of the American Oil Chemists' Society, 45*, 656–660.

Dubravcic, M. F., & Nawar, W. W. (1969). Effects of high-energy radiation on the lipids of fish. *Journal of Agricultural and Food Chemistry, 17*, 639–644.

Hwang, K. T. (1999a). Hydrocarbons detected in irradiated pork, bacon and ham. *Food Research International, 32*, 389–394.

Hwang, K. T. (1999b). Hydrocarbons detected in irradiated shell eggs during storage. *Journal of the American Oil Chemists' Society, 76*, 1183–1187.

Hwang, K. T., Kim, J. E., & Yang, J. S. (2005). The identification of post-irradiated soybeans by measuring the concentration of hydrocarbons. *International Journal of Food Science and Technology, 40*, 907–909.

Hwang, K. T., Yoo, J. H., Kim, C. K., Uhm, T. B., Kim, S. B., & Park, H. J. (2001). Hydrocarbons detected in irradiated and heat-treated eggs. *Food Research International, 43*, 321–328.

International Consultative Group on Food Irradiation. (2004). Clearance database. http://www.iaea.org/icgfi/data.htm (updated on May 2004).

Lesgards, G., Raffi, J., Pouliquen, I., Chaouch, A. A., Giamarchi, P., & Prost, M. (1993). Use of radiation-induced alkanes and alkenes to detect irradiated food containing lipids. *Journal of the American Oil Chemists' Society, 70*, 179–185.

Park, J. Y., & Hwang, K. T. (1999). Hydrocarbons as markers for identifying postirradiated peanuts. *Journal of the American Oil Chemists' Society, 76*, 125–129.

Schulzki, G., Spiegelberg, A., Bögl, K. W., & Schreiber, G. A. (1995). Detection of radiation-induced hydrocarbons in baked sponge cake prepared with irradiated liquid egg. *Radiation Physics and Chemistry, 46*, 765–769.

Spiegelberg, A., Schulzki, G., Helle, N., Bögl, K. W., & Schreiber, G. A. (1994). Methods for routine control of irradiated food: optimization of a method for detection of radiation-induced hydrocarbons and its application to various foods. *Radiation Physics and Chemistry, 43*, 433–444.