Fatty Acid Composition of California Grown Almonds

S.K. SATHE, N.P. SEERAM, H.H. KSHIRSAGAR, D. HEBER, and K.A. LAPSLEY

ABSTRACT: Eight almond (*Prunus dulcis* L.) cultivars from 12 different California counties, collected during crop years 2004 to 2005 and 2005 to 2006, were extracted with petroleum ether. The extracts were subjected to GC-MS analyses to determine fatty acid composition of soluble lipids. Results indicated palmitic (C16:0), oleic (C18:1), linoleic (C18:2), and α-linolenic (C18:3) acid, respectively, accounted for 5.07% to 6.78%, 57.54% to 73.94%, 19.32% to 35.18%, and 0.04% to 0.10%; of the total lipids. Oleic and linoleic acid were inversely correlated (r = –0.99, P = 0.05) and together accounted for 91.16% to 94.29% of the total soluble lipids. Statistically, fatty acid composition was significantly affected by cultivar and county.

Keywords: almond, California, fatty acid, linoleic acid, lipid, oleic acid

Introduction

Almonds lead global tree nut production. The United States is the largest almond producer and exporter with California accounting for nearly 80% of the global almond production. According to the 2007 Almond Almanac, the 2006 US almond crop valued at $1.9 billion was the largest specialty crop export of the United States. In the United States, California central valley is the main region for almond production with approximately 587000 bearing acres in 2006–2007 dedicated to almond production (ABC 2007). Within this region, 16 counties—Butte, Colusa, Fresno, Glenn, Kern, Kings, Madera, Merced, San Joaquin, Solano, Stanislaus, Sutter, Tehama, Tulare, Yolo, and Yuba account for majority of US almond crop (Figure 1). In 2005–2006, Fresno, Kern, Merced, and Stanislaus each with over 100 million lbs followed by Butte and Madera, each producing between 50 and 99 million lbs, were the leading almond producing counties (ABC 2006). In 2006–2007, Colusa, Kern, and San Joaquin (each with > 100 million lbs), and Fresno, Madera, Merced, and Stanislaus (each with 50 to 99 million lbs) counties were the leading almond producers (ABC 2007).

Earlier, Sathe (1993) analyzed chemical composition of 5 major marketing varieties of US-grown almonds (Carmel, Mission, Neplus, Nonpareil, and Peerless) and reported the seeds to contain 53.59% to 56.05% lipids, 16.42% to 22.17% proteins (N $\times$ 5.18), 4.35% to 5.86% moisture, and 2.69% to 2.93% ash. Two fatty acids, oleic and linoleic, accounted for over 90% of the total lipids indicating the almond lipid profile to be desirable from a human nutrition point of view. Incorporation of almonds (52 g/d) has been shown to result in a significant ($P < 0.05$) increase in monounsaturated fatty acid (MUFA), polyunsaturated fatty acid (PUFA), fiber, vegetable protein, α-tocopherol, Cu, and Mg intakes; 42%, 24%, 12%, 19%, 66%, 15%, and 23%, respectively, (Jaceldo-Siegl and others 2004) over the corresponding control diet. In addition, the study also found that almond supplementation resulted in a 3% decrease in total saturated fatty acids (SFA), 14% decrease in *trans* fatty acids, with a simultaneous increase of 27% in linoleic, and 45% in oleic acid intake. Several recent publications have examined the beneficial effects of nut seed consumption in human health (Feldman 2002; Jiang and others 2005; Mukuddem-Petersen and others 2005; Chen and others 2006; Griel and Kris-Etherton 2006; Jenkins and others 2006; Rajaram and Sabaté 2006; Ros and Mataix 2006; Coates and Howe 2007; Li and others 2007) especially in relation to blood lipid profile and the risk of cardiovascular diseases (CVDs). Almond lipids, in addition to being high in oleic and linoleic acid, are also rich in vitamin E, a known antioxidant (Kodad and others 2006; Chen and others 2006). The α-isomer of vitamin E is a known antioxidant while the γ- isomer seems to be important for protection of cell membranes from free radical damage—an important consideration in cardioprotective effect. To help select almond genotypes that may offer good antioxidant (that is, high α-tocopherol) and cardio-protective effect (high γ-tocopherol) Kodad and others (2006) investigated distribution of α-, γ-, and δ-, tocopherols in Spanish almond varieties and genotypes and found both α- (range 147.2 to 490.3 mg/kg oil) and γ- (6.1 to 26.3 mg/kg oil) isomers to be quite variable. The study therefore suggests selection of almond seeds for high α-, γ-, or both isomers may be possible.

Lipids contribute to the unique flavors and textures of many edible tree nut seeds that often strongly influence consumer acceptance. Location and environmental conditions along with the genetics typically influence chemical composition of many crops. Almond quality has been reported to be dependent on the genotype (Romojaro and others 1988). Schirra and Agabbio (1989) did not find irrigation to influence almond oil composition or the kernel keeping quality. On the other hand, Nanos and others (2002) reported that the oil quality of 2 almond cultivars (Ferragnes and Texas) grown in 2 trial plots in central Greece was intrinsically different with respect to fatty acid composition and sugar composition (sugar type and quantity). The seeds collected from trees growing in the irrigated plot contained higher oleic acid compared to the counterpart sample from nonirrigated plot. Malisiova and others

MS 20080066 Submitted 1/26/2008, Accepted 6/2/2008. *Authors Sathe and Kshirsagar are with Dept. of Nutrition, Food, & Exercise Sciences, College of Human Sciences, Florida State Univ., Tallahassee, FL 32306-1493, U.S.A. Authors Seeram and Heber are with UCLA Center for Human Nutrition, Rm13-138 Warren Hall, 900 Veteran Ave., Los Angeles, CA 90095, U.S.A. Author Seeram is now with Bioactive Botanical Research Lab., Dept. of Biomedical and Pharmaceutical Sciences, College of Pharmacy, Univ. of Rhode Island, Kingston, RI 02881, U.S.A. Author Lapsley is with Almond Board of California, Modesto, CA 95354, U.S.A. Direct inquiries to author Sathe (E-mail: ssathe@mailer.fsu.edu).*

The study was presented at the Inst. of Food Technologists Annual Meeting, Chicago, IL, U.S.A., in July 24 to 28, 2007 (Abstract nr 188–28).

doi: 10.1111/j.1750-3841.2008.00936.x

(2004) found more mature almond seeds (collected in September 2000) to contain more triglycerides (95.9% as opposed to 84.7 of total lipids) and less total polar lipids (3.7% compared with 10.1% of total lipids) as compared to those harvested earlier (June 2000) in the year. Gradziel and others (2000) reported that peach-derived almond cultivars had the highest oil quality as determined by the ratio of oleic to linoleic acid. The study found that almond oil content and oil fatty acid composition was dependent on genotypes, a finding consistent with similar observations reported earlier by Kumar and others (1994) and Abdallah and others (1998). A recent study of 26 almond genotypes grown in Turkey exhibited variable kernel weight (0.5 to 1.34 g, LSD = 0.28 at $P = 0.01$), lipid content (25.29% to 60.77%), and fatty acid composition (Askin and others 2007). These investigators made several interesting observations including: (1) kernel weight significantly ($P < 0.05$) influenced the palmitic ($r = 0.39$), stearic ($r = 0.64$), oleic ($r = 0.61$), and linoleic acid ($r = -0.48$) content; (2) palmitic ($r = -0.44$) and stearic acid ($r = -0.66$) content correlated negatively while oleic acid ($r = 0.44$) content correlated positively with shell thickness; and (3) linoleic and oleic acid contents being negatively correlated ($r = -0.92$). The negative correlation between the linoleic and oleic acid in almond lipids was earlier reported by Abdallah and others (1998) and Kodad and others (2004). Together, these studies suggest that almond lipid content and fatty acid composition is dependent upon not only genotype but also location and climatic conditions prevalent during growing season.

Despite the importance of almond lipids in almond seed quality, only limited research has been conducted on lipid composition of California grown almonds. The current study was designed to assess possible influence of seed variety, location, and production year on fatty acid composition of select California grown almonds.

Materials and Methods

Almond samples (Table 1) were provided by the Almond Board of California (Modesto, Calif., U.S.A.). Seeds collected during crop years 2004–2005 and 2005–2006 were provided by the Almond Board of California packed in semipermeable cellophane bags or Ziploc® double zipper freezer bags (S.C. Johnson & Son, Inc., Racine, Wis., U.S.A.). The seeds were stored in their original packing material at –20 °C until further use. Proximate composition of seed samples was completed within 4 mo from the sample receipt date. The lipids collected were flushed with nitrogen, stored at –20 °C, and analyzed for fatty acid composition within 12 mo of lipid collection.

Seed weight

Seed weight (grams per 100 seeds) for each sample was determined by weighing 3 aliquots ($n = 3$) using an electronic top loading balance (Model PB 5001, Mettler-Toledo, Greifensee, Switzerland) with an accuracy of ± 0.1 g.

Preparation of full fat almond flour

The seeds were ground in an Osterizer blender (Galaxie Model Number 869-18R, Jarden Consumer Solutions, Boca Raton, Fla., U.S.A.) with a speed setting "grind" until uniform flour (approximately 40 mesh) was obtained.

Lipid extraction and determination (AOAC Official Method 948.22 1995)

A known weight (approximately 10 g per thimble) of full fat flour, in triplicate, was extracted with 10 to 15 volumes of petroleum ether (boiling point range 38.2 to 54.3 °C) for 8 h in a Soxhlet apparatus.

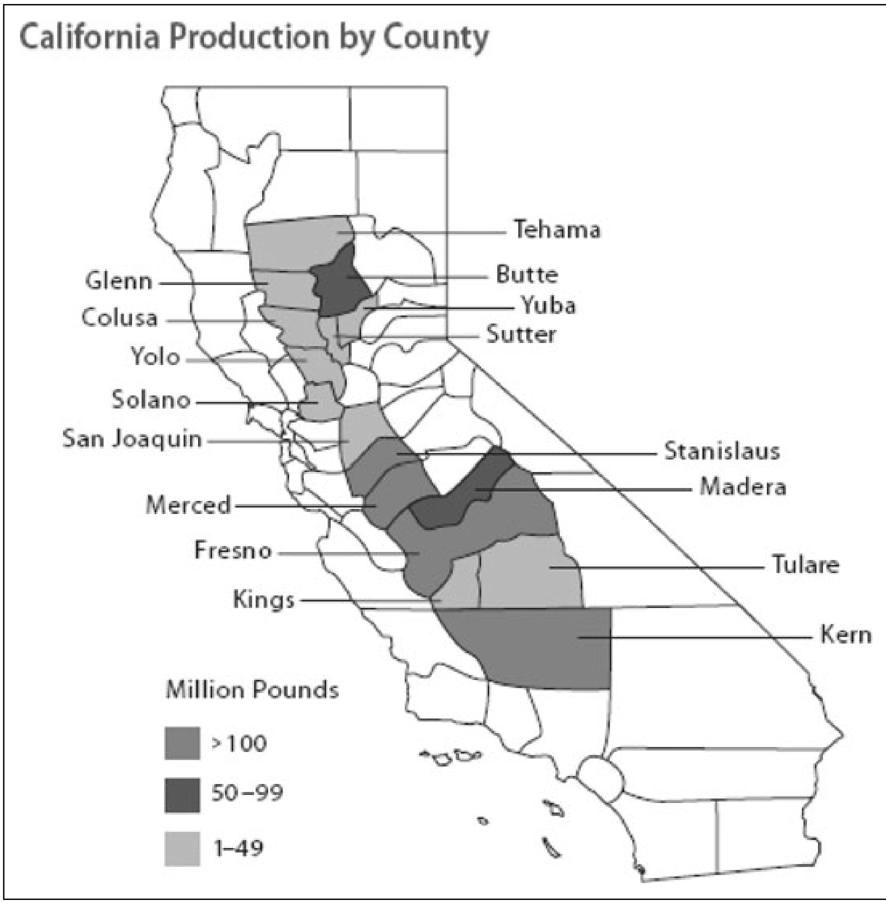

Figure 1 — Almond production in California counties. Source: Almond Almanac (2006).

Table 1 — Fatty acid composition of California commercial almond cultivars.

Cultivar	California county	Crop year	100 seed weight (g)	C14:0	C16:0	C16:1	C18:0	C18:1	C18:2	C18:3	C20:0	Oleic: Linoleic	Oleic + Linoleic
	Butte	2004–2005	110.96 ± 0.56	0.00 ± 0.00	6.03 ± 0.08	0.34 ± 0.01	0.30 ± 0.02	66.69 ± 0.03	26.54 ± 0.05	0.07 ± 0.00	0.04 ± 0.00	2.51 ± 0.00	93.23 ± 0.08
	Fresno	2004–2005	106.72 ± 0.87	0.00 ± 0.00	5.63 ± 0.04	0.32 ± 0.01	0.95 ± 0.03	67.25 ± 0.20	25.71 ± 0.16	0.07 ± 0.00	0.07 ± 0.01	2.62 ± 0.02	92.96 ± 0.04
	Kern	2004–2005	76.87 ± 0.74	0.00 ± 0.00	5.73 ± 0.05	0.38 ± 0.02	0.49 ± 0.03	65.49 ± 0.09	27.79 ± 0.07	0.07 ± 0.00	0.05 ± 0.00	2.36 ± 0.01	93.28 ± 0.02
	Madera	2004–2005	99.56 ± 2.01	0.00 ± 0.00	5.60 ± 0.04	0.31 ± 0.01	0.36 ± 0.02	68.47 ± 0.06	25.15 ± 0.04	0.07 ± 0.00	0.04 ± 0.00	2.72 ± 0.01	93.62 ± 0.02
	Merced	2004–2005	91.26 ± 0.67	0.00 ± 0.00	6.17 ± 0.08	0.53 ± 0.01	0.50 ± 0.21	64.95 ± 0.22	27.75 ± 0.35	0.07 ± 0.00	0.04 ± 0.00	2.34 ± 0.04	92.69 ± 0.13
	San Joaquin	2004–2005	101.72 ± 2.88	0.00 ± 0.00	6.11 ± 0.04	0.52 ± 0.02	0.48 ± 0.02	63.24 ± 0.04	29.53 ± 0.05	0.08 ± 0.00	0.04 ± 0.00	2.14 ± 0.00	92.77 ± 0.03
Butte	Stanislaus	2004–2005	114.29 ± 1.18	0.00 ± 0.00	6.65 ± 0.05	0.57 ± 0.03	0.32 ± 0.02	63.32 ± 0.04	29.05 ± 0.08	0.06 ± 0.00	0.03 ± 0.00	2.18 ± 0.01	92.37 ± 0.06
	Tulare	2004–2005	83.88 ± 2.33	0.00 ± 0.00	5.46 ± 0.04	0.46 ± 0.01	0.40 ± 0.01	71.62 ± 0.03	21.94 ± 0.02	0.08 ± 0.00	0.04 ± 0.00	3.26 ± 0.00	93.56 ± 0.04
	Fresno	2005–2006	108.83 ± 1.92	0.00 ± 0.00	5.48 ± 0.01	0.46 ± 0.02	1.18 ± 0.03	64.97 ± 0.03	27.82 ± 0.06	0.05 ± 0.00	0.05 ± 0.00	2.34 ± 0.01	92.79 ± 0.04
	Yolo	2005–2006	106.17 ± 1.17	0.00 ± 0.00	6.37 ± 0.04	0.38 ± 0.02	1.43 ± 0.03	61.38 ± 0.17	30.31 ± 0.12	0.06 ± 0.00	0.07 ± 0.00	2.03 ± 0.01	91.70 ± 0.08
	Kern	2005–2006	99.17 ± 0.83	0.00 ± 0.00	6.03 ± 0.03	0.38 ± 0.02	1.20 ± 0.03	63.49 ± 0.04	28.78 ± 0.09	0.06 ± 0.00	0.06 ± 0.00	2.21 ± 0.01	92.28 ± 0.05
	Sacramento	2005–2006	116.50 ± 1.26	0.00 ± 0.00	6.06 ± 0.01	0.44 ± 0.02	1.20 ± 0.04	64.66 ± 0.14	27.50 ± 0.14	0.07 ± 0.00	0.06 ± 0.00	2.35 ± 0.02	92.16 ± 0.03
	Yolo	2005–2006	107.00 ± 1.04	0.00 ± 0.00	5.74 ± 0.03	0.44 ± 0.02	1.66 ± 0.02	62.63 ± 0.14	29.40 ± 0.14	0.07 ± 0.00	0.07 ± 0.00	2.13 ± 0.02	92.03 ± 0.02
	Fresno	2005–2006	118.17 ± 1.09	0.00 ± 0.00	5.30 ± 0.02	0.34 ± 0.01	1.06 ± 0.02	65.66 ± 0.19	27.51 ± 0.22	0.07 ± 0.00	0.06 ± 0.00	2.39 ± 0.03	93.18 ± 0.02
	Butte	2004–2005	121.40 ± 3.05	0.00 ± 0.00	5.62 ± 0.06	0.37 ± 0.02	1.06 ± 0.02	59.52 ± 0.20	33.29 ± 0.16	0.07 ± 0.00	0.07 ± 0.00	1.79 ± 0.01	92.81 ± 0.04
	Colusa	2004–2005	110.01 ± 1.50	0.00 ± 0.00	6.10 ± 0.02	0.37 ± 0.01	0.35 ± 0.01	65.08 ± 0.01	27.97 ± 0.01	0.08 ± 0.00	0.05 ± 0.00	2.33 ± 0.00	93.05 ± 0.02
	Fresno	2004–2005	124.40 ± 2.33	0.00 ± 0.00	5.50 ± 0.01	0.34 ± 0.01	0.64 ± 0.02	67.83 ± 0.04	25.56 ± 0.03	0.08 ± 0.00	0.06 ± 0.00	2.65 ± 0.00	93.39 ± 0.02
	Glenn	2004–2005	118.49 ± 2.24	0.00 ± 0.00	5.67 ± 0.03	0.27 ± 0.01	0.52 ± 0.03	67.69 ± 0.12	25.75 ± 0.13	0.07 ± 0.00	0.04 ± 0.00	2.63 ± 0.02	93.44 ± 0.01
	Kern	2004–2005	121.00 ± 1.53	0.00 ± 0.00	5.68 ± 0.20	0.56 ± 0.01	0.34 ± 0.00	73.80 ± 0.10	19.49 ± 0.10	0.08 ± 0.00	0.04 ± 0.00	3.79 ± 0.02	93.30 ± 0.20
	Madera	2004–2005	105.66 ± 2.34	0.00 ± 0.00	5.81 ± 0.01	0.36 ± 0.01	0.45 ± 0.03	64.15 ± 0.10	29.13 ± 0.09	0.08 ± 0.00	0.04 ± 0.00	2.20 ± 0.01	93.27 ± 0.03
	Merced	2004–2005	98.11 ± 1.96	0.00 ± 0.00	5.92 ± 0.02	0.41 ± 0.01	0.81 ± 0.03	63.12 ± 0.07	29.64 ± 0.14	0.06 ± 0.00	0.04 ± 0.00	2.13 ± 0.01	92.76 ± 0.07
	San Joaquin	2004–2005	117.86 ± 2.76	0.00 ± 0.00	5.42 ± 0.03	0.35 ± 0.01	0.70 ± 0.04	68.10 ± 0.09	25.33 ± 0.08	0.07 ± 0.00	0.05 ± 0.00	2.69 ± 0.01	93.43 ± 0.08
Carmel	Stanislaus	2004–2005	78.47 ± 1.81	0.00 ± 0.00	5.64 ± 0.06	0.46 ± 0.02	0.95 ± 0.05	63.02 ± 0.09	29.85 ± 0.12	0.05 ± 0.00	0.05 ± 0.00	2.11 ± 0.01	92.86 ± 0.06
	Tulare	2004–2005	111.95 ± 1.67	0.00 ± 0.00	5.45 ± 0.04	0.35 ± 0.01	0.27 ± 0.02	70.48 ± 0.23	23.32 ± 0.17	0.07 ± 0.00	0.05 ± 0.00	3.02 ± 0.03	93.80 ± 0.07
	San Joaquin	2004–2005	119.17 ± 2.49	0.00 ± 0.00	6.25 ± 0.08	0.34 ± 0.01	0.56 ± 0.03	60.66 ± 0.17	32.06 ± 0.18	0.08 ± 0.00	0.05 ± 0.00	1.89 ± 0.02	92.72 ± 0.05
	Fresno	2005–2006	120.50 ± 1.73	0.00 ± 0.00	6.21 ± 0.03	0.41 ± 0.03	0.94 ± 0.03	63.69 ± 0.06	28.63 ± 0.02	0.07 ± 0.00	0.06 ± 0.00	2.22 ± 0.00	92.32 ± 0.05
	Yolo	2005–2006	121.50 ± 1.44	0.00 ± 0.00	6.15 ± 0.05	0.38 ± 0.03	1.33 ± 0.02	61.13 ± 0.19	30.88 ± 0.15	0.07 ± 0.00	0.07 ± 0.00	1.98 ± 0.02	92.01 ± 0.08
	Sacramento	2005–2006	114.33 ± 2.03	0.00 ± 0.00	5.78 ± 0.02	0.37 ± 0.01	0.69 ± 0.01	62.30 ± 0.10	30.75 ± 0.09	0.06 ± 0.00	0.05 ± 0.01	2.03 ± 0.01	93.05 ± 0.02
	Sacramento	2005–2006	113.50 ± 3.25	0.00 ± 0.00	6.09 ± 0.04	0.45 ± 0.02	0.77 ± 0.02	61.34 ± 0.03	31.23 ± 0.06	0.07 ± 0.00	0.05 ± 0.00	1.96 ± 0.00	92.57 ± 0.08
	Sacramento	2005–2006	118.50 ± 2.57	0.00 ± 0.00	6.35 ± 0.03	0.41 ± 0.01	0.78 ± 0.03	62.36 ± 0.15	29.99 ± 0.12	0.06 ± 0.00	0.06 ± 0.00	2.08 ± 0.01	92.35 ± 0.05
	Fresno	2005–2006	115.83 ± 1.17	0.00 ± 0.00	6.20 ± 0.01	0.41 ± 0.01	0.76 ± 0.03	62.42 ± 0.16	30.09 ± 0.21	0.06 ± 0.01	0.05 ± 0.00	2.07 ± 0.02	92.51 ± 0.06
	Butte	2004–2005	102.79 ± 3.09	0.00 ± 0.00	5.74 ± 0.02	0.25 ± 0.00	0.60 ± 0.03	65.97 ± 0.09	27.31 ± 0.09	0.09 ± 0.00	0.04 ± 0.00	2.42 ± 0.01	93.28 ± 0.05
	Colusa	2004–2005	111.55 ± 0.91	0.00 ± 0.00	5.23 ± 0.03	0.32 ± 0.01	0.82 ± 0.02	68.32 ± 0.13	25.17 ± 0.17	0.08 ± 0.00	0.06 ± 0.00	2.71 ± 0.02	93.49 ± 0.04
	Fresno	2004–2005	132.59 ± 1.03	0.00 ± 0.00	5.96 ± 0.06	0.38 ± 0.02	0.34 ± 0.02	63.33 ± 0.12	29.87 ± 0.21	0.07 ± 0.00	0.04 ± 0.00	2.12 ± 0.02	93.20 ± 0.09
	Glenn	2004–2005	91.42 ± 0.73	0.00 ± 0.00	5.92 ± 0.06	0.40 ± 0.01	0.34 ± 0.02	68.34 ± 0.07	24.90 ± 0.01	0.06 ± 0.00	0.04 ± 0.00	2.74 ± 0.00	93.23 ± 0.05
Mission	Kern	2004–2005	100.35 ± 2.52	0.00 ± 0.00	5.15 ± 0.07	0.35 ± 0.01	0.43 ± 0.02	69.99 ± 0.14	23.96 ± 0.07	0.08 ± 0.00	0.05 ± 0.00	2.92 ± 0.01	93.95 ± 0.08
	Merced	2004–2005	114.20 ± 1.83	0.00 ± 0.00	5.96 ± 0.05	0.53 ± 0.01	0.64 ± 0.03	64.24 ± 0.13	28.52 ± 0.11	0.06 ± 0.00	0.04 ± 0.00	2.25 ± 0.01	92.76 ± 0.02
	San Joaquin	2004–2005	113.68 ± 4.66	0.00 ± 0.00	6.42 ± 0.07	0.45 ± 0.01	0.48 ± 0.01	64.66 ± 0.11	27.86 ± 0.04	0.08 ± 0.00	0.05 ± 0.00	2.32 ± 0.01	92.52 ± 0.07
	Stanislaus	2004–2005	139.73 ± 0.99	0.00 ± 0.00	6.21 ± 0.08	0.50 ± 0.02	0.73 ± 0.02	64.78 ± 0.14	27.67 ± 0.09	0.08 ± 0.00	0.04 ± 0.00	2.34 ± 0.01	92.45 ± 0.05
	Stanislaus	2005–2006	120.67 ± 0.60	0.00 ± 0.00	5.63 ± 0.01	0.25 ± 0.01	1.23 ± 0.04	66.56 ± 0.06	26.20 ± 0.02	0.07 ± 0.00	0.06 ± 0.00	2.54 ± 0.00	92.75 ± 0.06

Continued.

Table 1 – Continued.

Cultivar	California county	Crop year	100 seed weight (g)	C14:0	C16:0	C16:1	C18:0	C18:1	C18:2	C18:3	C20:0	Oleic: Linoleic	Oleic + Linoleic
Monterey	Stanislaus	2005–2006	140.67 ± 1.74	0.00 ± 0.00	6.59 ± 0.01	0.31 ± 0.00	0.97 ± 0.03	66.28 ± 0.12	25.72 ± 0.14	0.08 ± 0.00	0.07 ± 0.01	2.58 ± 0.02	92.00 ± 0.03
	Butte	2004–2005	123.06 ± 2.63	0.00 ± 0.00	5.60 ± 0.05	0.37 ± 0.01	0.42 ± 0.01	70.29 ± 0.02	23.20 ± 0.02	0.08 ± 0.00	0.05 ± 0.00	3.03 ± 0.00	93.49 ± 0.04
	Colusa	2004–2005	144.44 ± 3.99	0.00 ± 0.00	6.01 ± 0.09	0.57 ± 0.01	0.25 ± 0.00	71.60 ± 0.30	21.47 ± 0.31	0.07 ± 0.00	0.03 ± 0.00	3.33 ± 0.06	93.07 ± 0.08
	Fresno	2004–2005	95.83 ± 0.92	0.00 ± 0.00	6.32 ± 0.05	0.33 ± 0.01	0.46 ± 0.02	62.05 ± 0.22	30.73 ± 0.19	0.07 ± 0.00	0.04 ± 0.00	2.02 ± 0.02	92.79 ± 0.06
	Glenn	2004–2005	103.24 ± 1.21	0.00 ± 0.00	6.42 ± 0.02	0.54 ± 0.03	0.46 ± 0.04	65.18 ± 0.07	27.29 ± 0.12	0.07 ± 0.00	0.04 ± 0.00	2.39 ± 0.01	92.47 ± 0.05
	Kern	2004–2005	112.93 ± 1.83	0.00 ± 0.00	5.56 ± 0.04	0.38 ± 0.00	0.72 ± 0.02	69.05 ± 0.07	24.16 ± 0.06	0.07 ± 0.00	0.05 ± 0.00	2.86 ± 0.01	93.21 ± 0.03
	Madera	2004–2005	135.33 ± 1.80	0.00 ± 0.00	5.46 ± 0.05	0.38 ± 0.03	0.89 ± 0.04	65.57 ± 0.16	27.58 ± 0.13	0.07 ± 0.00	0.04 ± 0.00	2.38 ± 0.02	93.16 ± 0.04
	Merced	2004–2005	115.21 ± 0.37	0.00 ± 0.00	6.04 ± 0.05	0.51 ± 0.01	0.98 ± 0.02	64.86 ± 0.08	27.47 ± 0.08	0.09 ± 0.00	0.05 ± 0.00	2.36 ± 0.01	92.33 ± 0.03
	San Joaquin	2004–2005	112.19 ± 0.49	0.00 ± 0.00	5.46 ± 0.15	0.49 ± 0.01	0.38 ± 0.02	71.90 ± 0.24	21.66 ± 0.10	0.08 ± 0.00	0.04 ± 0.00	3.32 ± 0.03	93.55 ± 0.14
Nonpareil	Stanilaus	2004–2005	121.05 ± 1.54	0.00 ± 0.00	6.31 ± 0.08	0.54 ± 0.00	0.70 ± 0.01	68.68 ± 0.04	23.65 ± 0.11	0.07 ± 0.00	0.05 ± 0.00	2.90 ± 0.01	92.33 ± 0.09
	Tulare	2004–2005	100.21 ± 2.34	0.00 ± 0.00	5.93 ± 0.03	0.43 ± 0.02	0.56 ± 0.01	64.16 ± 0.02	28.81 ± 0.03	0.08 ± 0.00	0.04 ± 0.00	2.23 ± 0.00	92.96 ± 0.02
	Stanislaus	2005–2006	132.33 ± 0.33	0.00 ± 0.00	6.29 ± 0.03	0.35 ± 0.01	0.50 ± 0.01	62.82 ± 0.12	29.93 ± 0.12	0.06 ± 0.00	0.05 ± 0.00	2.10 ± 0.01	92.75 ± 0.03
	Stanislaus	2005–2006	136.50 ± 1.61	0.00 ± 0.00	6.64 ± 0.08	0.45 ± 0.01	0.62 ± 0.03	61.89 ± 0.07	30.31 ± 0.05	0.05 ± 0.00	0.04 ± 0.00	2.04 ± 0.00	92.19 ± 0.08
	Yolo	2005–2006	114.83 ± 2.17	0.00 ± 0.00	5.72 ± 0.06	0.42 ± 0.01	1.01 ± 0.01	67.78 ± 0.05	24.94 ± 0.03	0.07 ± 0.00	0.06 ± 0.00	2.72 ± 0.00	92.72 ± 0.08
	Fresno	2005–2006	123.33 ± 1.69	0.00 ± 0.00	5.46 ± 0.04	0.35 ± 0.01	0.73 ± 0.03	68.99 ± 0.21	24.35 ± 0.15	0.07 ± 0.00	0.06 ± 0.00	2.83 ± 0.03	93.34 ± 0.06
	Sacramento	2005–2006	99.83 ± 2.05	0.00 ± 0.00	5.91 ± 0.03	0.42 ± 0.01	0.25 ± 0.01	67.18 ± 0.13	26.14 ± 0.09	0.06 ± 0.00	0.04 ± 0.00	2.57 ± 0.01	93.31 ± 0.05
	Sacramento	2005–2006	93.67 ± 3.09	0.00 ± 0.00	5.59 ± 0.03	0.38 ± 0.00	0.72 ± 0.05	67.12 ± 0.18	26.09 ± 0.21	0.06 ± 0.00	0.05 ± 0.00	2.57 ± 0.03	93.21 ± 0.02
	Sacramento	2005–2006	120.17 ± 2.46	0.00 ± 0.00	5.98 ± 0.01	0.40 ± 0.01	0.47 ± 0.03	68.36 ± 0.06	24.69 ± 0.05	0.06 ± 0.00	0.04 ± 0.00	2.77 ± 0.01	93.05 ± 0.01
	Yolo	2005–2006	123.83 ± 1.69	0.00 ± 0.00	5.67 ± 0.05	0.47 ± 0.01	0.73 ± 0.04	68.30 ± 0.04	24.72 ± 0.04	0.06 ± 0.00	0.05 ± 0.00	2.76 ± 0.01	93.02 ± 0.01
	Butte	2004–2005	112.99 ± 1.27	0.00 ± 0.00	5.40 ± 0.04	0.37 ± 0.01	0.51 ± 0.03	68.94 ± 0.12	24.66 ± 0.12	0.07 ± 0.00	0.05 ± 0.00	2.80 ± 0.02	93.59 ± 0.04
	Fresno	2004–2005	131.98 ± 0.20	0.00 ± 0.00	6.50 ± 0.08	0.44 ± 0.02	0.29 ± 0.03	62.41 ± 0.11	30.26 ± 0.08	0.05 ± 0.00	0.04 ± 0.00	2.06 ± 0.01	92.68 ± 0.04
	Kern	2004–2005	102.94 ± 2.99	0.00 ± 0.00	6.21 ± 0.02	0.42 ± 0.02	0.37 ± 0.02	67.86 ± 0.02	25.03 ± 0.02	0.07 ± 0.00	0.04 ± 0.00	2.71 ± 0.00	92.89 ± 0.00
Padre	Merced	2004–2005	90.77 ± 1.69	0.00 ± 0.00	5.46 ± 0.05	0.31 ± 0.02	0.82 ± 0.05	67.07 ± 0.07	26.22 ± 0.03	0.08 ± 0.00	0.05 ± 0.00	2.56 ± 0.00	93.29 ± 0.08
	San Joaquin	2004–2005	104.61 ± 1.35	0.00 ± 0.00	6.00 ± 0.02	0.34 ± 0.01	0.33 ± 0.01	64.79 ± 0.06	28.45 ± 0.06	0.06 ± 0.00	0.03 ± 0.00	2.28 ± 0.01	93.24 ± 0.01
	Stanislaus	2004–2005	121.50 ± 0.79	0.00 ± 0.00	5.24 ± 0.05	0.37 ± 0.01	0.49 ± 0.03	69.05 ± 0.14	24.75 ± 0.09	0.07 ± 0.00	0.04 ± 0.00	2.79 ± 0.02	93.80 ± 0.06
	Tulare	2004–2005	106.79 ± 1.01	0.00 ± 0.00	5.35 ± 0.02	0.38 ± 0.01	0.55 ± 0.02	69.32 ± 0.03	24.28 ± 0.07	0.07 ± 0.00	0.05 ± 0.00	2.85 ± 0.01	93.59 ± 0.04
	Butte	2004–2005	92.13 ± 2.02	0.00 ± 0.00	6.00 ± 0.01	0.49 ± 0.03	0.77 ± 0.01	61.55 ± 0.05	31.08 ± 0.09	0.08 ± 0.00	0.04 ± 0.00	1.98 ± 0.01	92.63 ± 0.05
	Fresno	2004–2005	106.57 ± 0.71	0.00 ± 0.00	6.16 ± 0.11	0.50 ± 0.03	0.43 ± 0.01	62.03 ± 0.12	30.76 ± 0.13	0.07 ± 0.01	0.04 ± 0.00	2.02 ± 0.01	92.80 ± 0.1
	Kern	2004–2005	82.74 ± 1.01	0.00 ± 0.00	5.76 ± 0.03	0.38 ± 0.02	0.53 ± 0.01	65.36 ± 0.01	27.85 ± 0.03	0.07 ± 0.00	0.04 ± 0.00	2.35 ± 0.00	93.21 ± 0.02
Price	Merced	2004–2005	109.97 ± 2.30	0.00 ± 0.00	5.79 ± 0.03	0.33 ± 0.00	0.64 ± 0.03	63.90 ± 0.06	29.22 ± 0.10	0.08 ± 0.00	0.05 ± 0.00	2.19 ± 0.01	93.12 ± 0.07
	San Joaquin	2004–2005	111.60 ± 1.21	0.00 ± 0.00	5.44 ± 0.00	0.37 ± 0.00	0.42 ± 0.01	69.53 ± 0.06	24.11 ± 0.05	0.08 ± 0.00	0.04 ± 0.00	2.88 ± 0.01	93.64 ± 0.01
	Stanislaus	2004–2005	90.32 ± 0.84	0.00 ± 0.00	5.79 ± 0.02	0.60 ± 0.02	0.56 ± 0.01	64.57 ± 0.04	28.36 ± 0.05	0.08 ± 0.00	0.04 ± 0.00	2.28 ± 0.01	92.92 ± 0.01
	Tulare	2004–2005	98.85 ± 3.46	0.00 ± 0.00	6.23 ± 0.02	0.30 ± 0.01	0.24 ± 0.01	66.80 ± 0.09	26.33 ± 0.09	0.08 ± 0.00	0.04 ± 0.00	2.54 ± 0.01	93.12 ± 0.02
Sonora	Stanislaus	2005–2006	142.50 ± 0.29	0.00 ± 0.00	5.87 ± 0.02	0.36 ± 0.02	0.70 ± 0.03	64.08 ± 0.06	28.86 ± 0.09	0.07 ± 0.00	0.05 ± 0.00	2.22 ± 0.01	92.94 ± 0.03
		LSD	**5.18**	**0.00**	**0.15**	**0.05**	**0.09**	**0.32**	**0.32**	**0.00**	**0.00**	**0.05**	**0.16**

Data are expressed as grams fatty acid per 100 g lipid. LSD = Fisher's least significant difference ($P = 0.05$, $n = 6$). Differences between means in the same column exceeding the LSD value are significant.

At the end of the extraction period, the defatted samples were dried overnight (10 to 12 h) in a fume hood to remove residual traces of petroleum ether and the samples weighed to calculate lipid content.

$$\text{Lipid}(\%) = \frac{[\text{Initial wt. of full fat flour (g)} - \text{final wt. of defatted flour (g)}] \times 100}{\text{Initial wt. of full fat flour (g)}}$$

Fatty acid analysis

Petroleum ether extracts containing lipids were subjected to vacuum distillation at approximately 40 °C using a Rotovap (Bűchi Rotavapor R-3000, Brinkman Instruments Inc., Westbury, N.Y., U.S.A.) to remove ether. Extracted lipids were stored at –80 °C under nitrogen until further analysis. Lipid samples were analyzed in duplicate for saturated and unsaturated fatty acid composition. Methylation method (Lepage and Roy 1986; Bagga and others 1997), briefly described, was used to prepare the samples prior to gas chromatographic (GC) analysis.

A known amount of lipid sample (approximately 5 μL), suspended in a methanol (MeOH)/benzene solution (7 : 3, v/v), was treated with acetyl chloride and incubated at 100 °C for 1 h. After cooling, 6% (w/v) potassium carbonate buffer was added (0.6 M, pH 10.2, 4 mL) and the samples centrifuged at 2000 × *g* for 10 min in an Eppendorf Centrifuge (Brinkmann Model 5810-R, Brinkman Instruments Inc.) at room temperature. A known amount of the supernatant from each sample (approximately 50 μL) was removed and diluted with benzene (1 : 4 v/v) prior to GC analysis. Varian 3400CX gas chromatogram equipped with flame ionization detector (FID) and CP8200 Auto sampler (10 μL syringe) was used. Two microliters (50 : 1 split) of the diluted sample were loaded onto the GC column (Supelco SP-2380, 30m × 0.32 mm ID, 0.25-μm film part nr: 2-4116, 1 mL/min flow rate) using helium as the carrier gas (industrial, combination trap). The column inlet temperature was 260 °C. The heating oven was set at 90 °C for 2 min followed by increasing oven temperature to 150 °C at a rate of 4 °C/min and then to 260 °C at a rate of 10 °C/min. The oven temperature was held for 5 min at 260 °C. The total time for each GC run was 33 min. FID detector set at 300 °C was flushed with hydrogen (industrial) and air (industrial) mixture using helium (industrial) as the makeup gas according to the manufacturer's recommendation. Signal was recorded over 5 to 34 min. GLC-10 Supelco F.A.M.E. Mix. was used as the external standard (ESTD) for fatty acid quantification with integrator parameters set at, initial area reject = 0, threshold = 12, and autoscaling by the largest peak.

Statistics

All samples were analyzed at least in triplicate. Data were analyzed for statistical significance using analysis of variance (ANOVA) (SPSS version 15.0, SPSS, Inc., Chicago, Ill., U.S.A.) and Fisher's least significance difference (LSD, $P = 0.05$). Appropriate correlation (r) coefficients were calculated using linear regression, least squares fit method, Ott (1977).

Results and Discussion

Almond seed samples, seed weight, total lipids

Almond seed samples, their origin, crop year, and 100 seed weight used in the study are summarized in Table 1. Average seed weight exhibited a wide range (76.87 to 144.44 g per 100 seeds, as is basis). Total petroleum ether extractable lipids by the

Table 2 — Correlation coefficients between individual fatty acid amounts (grams fatty acid per 100 g lipid).

Fatty acid		Palmitic C16:0	Palmitoleic C16:1	Stearic C18:0	Oleic C18:1	Linoleic C18:2	Linolenic C18:3	Arachidic C20:0
Palmitic	**C16:0**	**1.00**	–	–	–	–	–	–
Palmitoleic	**C16:1**	0.21	**1.00**	–	–	–	–	–
Stearic	**C18:0**	−0.02	−0.11	**1.00**	–	–	–	–
Oleic	**C18:1**	**−0.60**	0.07	−0.39	**1.00**	–	–	–
Linoleic	**C18:2**	0.54	−0.11	0.33	**−0.99**	**1.00**	–	–
Linolenic	**C18:3**	−0.24	−0.02	−0.18	0.22	−0.20	**1.00**	–
Arachidic	**C20:0**	−0.09	−0.32	**0.82**	−0.20	0.16	−0.03	**1.00**

Significant ($r \geq 0.6$) positive and negative correlations are indicated in bold.

Table 3 — Effect of region and cultivar on almond fatty acid composition.[a]

	Cultivar							
Counties	Overall	Nonpareil	Carmel	Mission	Butte	Padre	Price	*LSD (p < 0.05)*
	C 18:1							
Northern	65.75	68.71	62.33	68.15	63.38	68.94	64.57	*0.377*
Southern	65.71	67.94	62.78	67.42	63.66	68.75	65.40	*0.324*
LSD ($P < 0.05$, $n = 74$)	*0.329*							
	C 18:2							
Northern	27.19	24.42	30.44	25.18	28.90	24.66	64.57	*0.369*
Southern	27.27	25.07	27.31	25.82	28.83	24.87	65.40	*0.316*
LSD ($P < 0.05$, $n = 74$)	*0.322*							
	C 16:0							
Northern	5.80	5.75	5.93	5.42	6.05	5.40	5.79	*0.131*
Southern	5.89	5.99	6.12	5.68	5.97	5.34	5.97	*0.152*
LSD ($P < 0.05$, $n = 74$)	*0.149*							
	C 18:0							
Northern	0.75	0.53	0.79	0.79	1.16	0.51	0.56	*0.075*
Southern	0.61	0.44	0.57	0.67	0.85	0.55	0.51	*0.101*
LSD ($P < 0.05$, $n = 74$)	*0.093*							

[a]Difference between 2 means within a column or a row exceeding the corresponding LSD value is significant ($P = 0.05$). Northern counties = Butte, Colusa, Glenn, Sacramento, and Yolo; southern counties = Fresno, Kern, Madera, Merced, San Joaquin, Stanislaus, and Tulare.

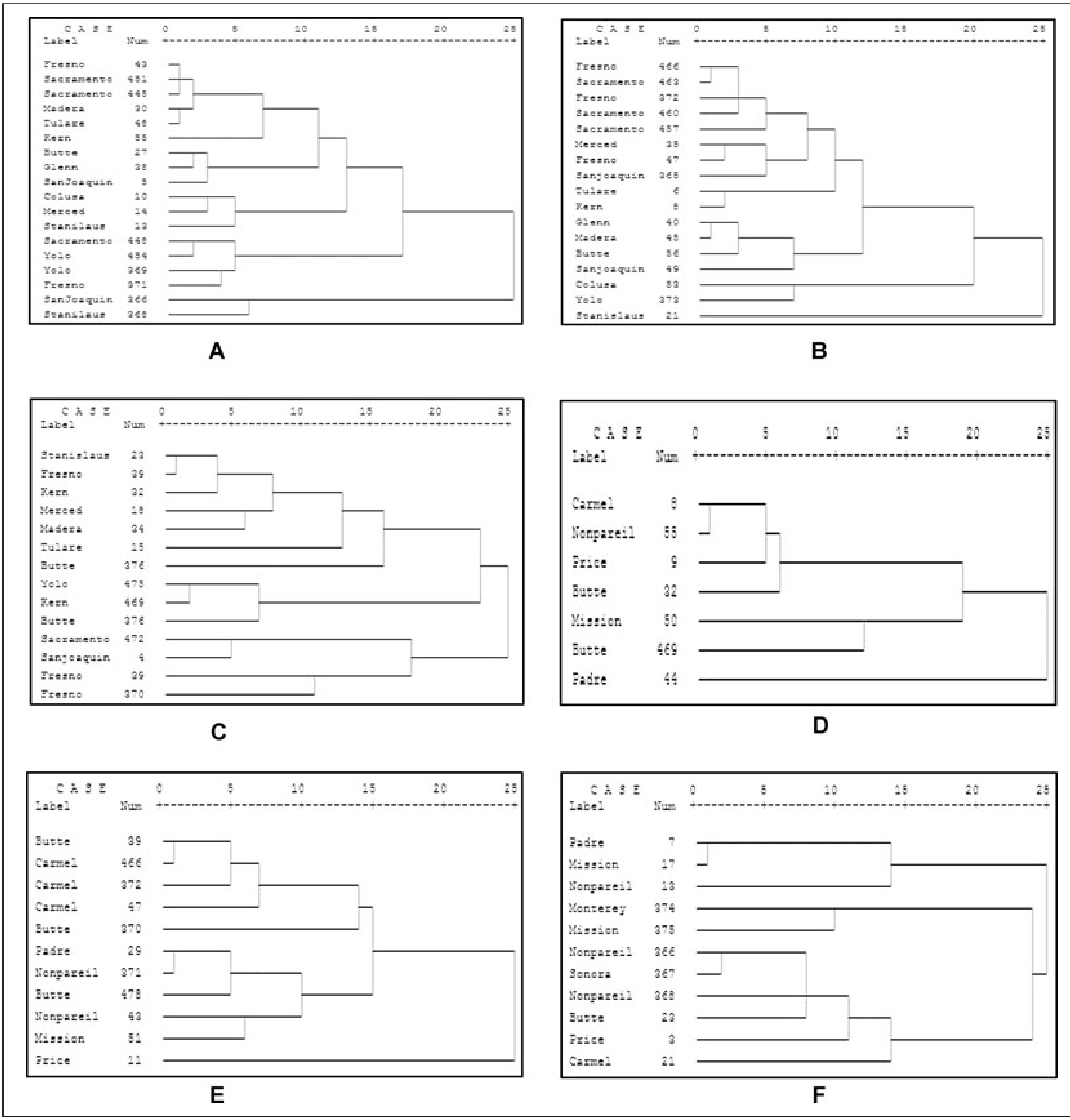

Figure 2—Dendrograms for fatty acid composition of Nonpareil (A), Carmel (B), and Butte (C) grown in different counties and of cultivars from counties with the highest kernel production, Kern (D), Fresno (E), and Stanislaus (F).

Soxhlet method ranged from 49.10% to 66.38% of the edible kernel weight on as is basis (unpublished data). Soler and others (1988) investigated composition of diethyl ether extracted oil from almond variety "Pons" cultivated on the island of Mallorca, Spain from 20 selected trees during the seed development for 3 consecutive crop years (1982, 1983, and 1984). Results indicated oil content was initially approximately 3.5% and reached approximately 61% of kernel weight on a dry weight basis. Several references cited in Soler and others (1988) have also reported oil content (range 50% to 65% on a dry weight basis) in almond seeds while Maguire and others (2004) found 40.8% lipids in almonds bought in local grocery store in Cork, Ireland. Sathe (1993) reported almond oil for 5 US commercial marketing varieties (Carmel, Mission, Neplus, Nonpareil, and Peerless) to be in the range 53.59% to 56.05% (dry weight basis). A recent report (Askin and others 2007) on 26 almond genotypes from eastern Anatolia (Turkey) indicates almond oil content, depending on the genotypes, to vary over a wide range, 25.19% (genotype EL-309) to 60.77% (genotype EL-139). Oil content (hexane extractable) of mature almonds grown and consumed in Bulgaria (Momchilova and Nikolova-Damyanova 2007) has been reported to be 42.3% ± 0.8%. The oil was reportedly composed of triacylglycerols (98.2% ± 1.4%) and small quantities of sterols (0.6% ± 0.2%), diacylglycerols (0.6% ± 0.2%), and polar lipids (0.3% ± 0.1%).

Fatty acid composition

Fatty acid composition of the petroleum ether extractable lipids is summarized in Table 1. Three fatty acids, $C_{16:0}$ (palmitic), $C_{18:1}$ (oleic), and $C_{18:2}$ (linoleic), dominated the lipid composition regardless of the cultivar, county, or the crop year. The range for these 3 fatty acids was 5.15% to 6.65%, 59.52% to 73.80%, and 19.49% to 33.29%, respectively. The average values, expressed as Mean ± SEM, for oleic and linoleic acids were 65.77% ± 0.33% and 27.18% ± 0.32%. Palmitoleic ($C_{16:1}$), range 0.31% to 0.57%; stearic ($C_{18:0}$), range 0.24% to 1.66%; α-linolenic ($C_{18:3}$), range 0.05% to 0.09%; and arachidic ($C_{20:0}$), range 0.03% to 0.07% acids were present in all the tested samples. The corresponding averages for palmitoleic, stearic, and α-linolenic (Mean ± SEM) acids were 0.41% ± 0.04%, 0.64% ± 0.09%, and 0.07% ± 0.01%. The results of fatty acid composition in the current investigation are consistent with the reported literature data (Soler and others 1988; Sathe 1993; Maguire and others 2004; Vekatachalam and Sathe 2006; Askin and others 2007). Both cultivar and harvest year significantly affected fatty acid content. Among the several tree nuts, almonds, and pecans appear to have similar fatty acid distribution (Wakeling and others 2001; Venkatachalam and Sathe 2006). Pecan lipids were shown to be similar to almonds with respect to PUFA : MUFA : SFA (PMS) ratio as well (Wakeling and others 2001). Pecans (Western Schley) grown in Egypt (El-Sharkawy and others 1987) contained more linoleic acid (42 g/100 lipids) compared to 32.88 g/100 g lipids (average of 3 y—1995–1997) for the same cultivar grown in Australia (Wakeling and others 2001) suggesting the possible influence of location on fatty acid composition. Interestingly, Wakeling and others (2001) did not find crop year (1995–1997), or cultivar (Wichita and Western Schley—grown in Australia), to influence pecan fatty acid composition. Ryan and others (2006) reported $C_{18:1}$ and $C_{18:2}$ in pecans purchased in Cork, Ireland to be 40.63% and 50.31%, respectively. Recalculation of the data reported by Ryan and others (2006) for pecan lipid yields a PMS ratio of 5.13 : 4.25 : 0.62 indicating significant variation in relative proportions in nut fatty acids possibly due to origins of the nut seed samples. The PMS ratio in the current investigation was 4.12 : 10.03 : 1, which is higher than 3.02 : 7.31 : 1 reported for almonds by Abbey (1997) (cf Wakeling and others 2001). Region, northern compared with southern counties in which almonds were grown, had a small but statistically significant effect on stearic acid content (Table 3). Of nutritional importance is the dominance of oleic a monounsaturated fatty acid (MUFA), and linoleic, an essential polyunsaturated fatty acid (PUFA), together accounting for over 91% (range 91.69% to 93.95%) of the total extractable lipids. Predominance of oleic acid may partly explain, when stored properly, why almonds have a long shelf life compared to other popular tree nuts such as pecans and walnuts that contain high amounts of PUFAs (notably linoleic and α-linolenic acids). The ratio of oleic to linoleic acid exhibited a wide range and varied from 1.79 to 3.79 (LSD = 0.05, $P = 0.05$). Both cultivar and county significantly affected the oleic to linoleic acid ratio although no systematic correlations between either the county or the cultivar and the ratio of the 2 fatty acids was noted. As indicated in Table 2, oleic and linoleic ($r = -0.99$) and stearic and arachidic ($r = 0.82$) acid contents were strongly correlated whereas correlation between palmitic and oleic ($r = -0.60$) acids was not as strong. Negative correlation between almond oleic and linoleic acid contents has been previously observed (Abdallah and others 1998; Kodad and others 2004; Askin and others 2007). More recently, Askin and others (2007) also found a weak correlation between palmitic and oleic acid ($r = -0.43$).

Although high in total lipids, dominance of oleic and linoleic fatty acids in almond lipids is nutritionally favorable. Consuming whole almonds (that is, with the skins) may also be useful as Ellis and others (2004) have reported that almond cell walls, rich in nonstarchy polysaccharides, decrease lipid absorption in humans on an almond rich diet when compared to the corresponding control.

Dendrogram analyses suggested fatty acid composition was influenced by the cultivar and the county (Figure 2) indicating both to be important in determining fatty acid composition. Statistical analyses of the data summarized in Table 3 confirmed these observations.

Conclusions

On the basis of the results of the current investigation, fatty composition of California grown almonds exhibits significant variation depending on the cultivar, location, and crop year. Oleic and linoleic acid are the 2 most abundant fatty acids in almond lipids.

Acknowledgments

Partial financial support from the Almond Board of California and the College of Human Sciences (Florida State Univ., Tallahassee, Fla., U.S.A.) is gratefully acknowledged. Ms. Erin (Mimi) K. Monaghan is acknowledged for her kind assistance with almond lipid extraction, seed weight determination, and preparation of Table 1. Mengna Su is thanked for her assistance in some of the statistical analyzes.

References

Abbey M. 1997. Health benefits of macadamia nuts and other tree nuts. Horticultural Research and Development Corp.: Sydney, Australia.

Abdallah A, Ahumada MH, Gradziel TM. 1998. Oil content and fatty acid composition of almond kernels from different genotypes and California production regions. J Am Soc Hort Sci 123:1029–33.

[ABC] Almond Board of California. 2006. Almond Almanac. Available from: www.almondboard.com <http://www.almondboard.com/>.

[ABC] Almond Board of California. 2007. Almond Almanac. Available from: www.almondboard.com <http://www.almondboard.com/>.

Askin MA, Balta MF, Tekintas FE, Kazankaya A, Balta F. 2007. Fatty acid composition affected by kernel weight in almond [*Prunus dulcis* (Mill.) D. A. Webb] genetic resources. J Food Comp Anal 30:7–12.

Bagga D, Capone S, Wang H-J, Heber D, Lill M, Chap L, Glaspy JA. 1997. Dietary modulation of omega-3/omega-6 polyunsaturated fatty acid ratios in patients with breast cancer. J Nat Cancer Inst 89(15):1123–31.

Chen C-Y, Lapsley K, Bloomburg J. 2006. Perspective: a nutrition and health perspective on almonds. J Sci Food Agric 86:2245–50.

Coates AM, Howe PRC. 2007. Edible nuts and metabolic health. Curr Opin Lipidol 18:25–30.

Ellis PR, Kendall CWC, Ren Y, Parker C, Pacy HF, Waldron KF, Jenkins DJA. 2004. Role of cell walls in the bioaccessibility of lipids in almond seeds. Am J Clin Nutr 80:604–13.

El-Sharkawy AA, Abdel-El-Malek GS, Kandil SH, Khalil FA. 1987. Chemical composition of oils from new pecan varieties. Agric Res Rev 65:389–96.

Feldman EB. 2002. The scientific evidence for a beneficial health relationship between walnuts and coronary hear disease. J Nutr 132:1062S–101S.

Gradziel T, Mahoney N, Abdallah A. 2000. Aflatoxin production among almond genotypes is not related to either kernel oil composition or *Aspergillus flavus* growth rate. Hort Sci 35:937–9.

Griel AE, Kris-Etherton PM. 2006. Tree nuts and lipid profile: a review of clinical studies. Brit J Nutr 96(Suppl 2):S68–78.

Jaceldo-Siegl K, Sabate J, Rajaram S, Fraser G. 2004. Long-term almond supplementation without advice on food replacement induces favourable nutrient modifications to the habitual diets of free-living individuals. Brit J Nutr 92:533–40.

Jenkins DJA, Kendall CWC, Josse AR, Salvatore S, Brighenti F, Augustin LSA, Ellis PR, Vidgen E, Rao AV. 2006. Almonds decrease postprandial glycemia, insulemia, and oxidative damage in healthy individuals. J Nutr 136:2987–92.

Jiang R, Jacobs DR, Jr, Mayer-Davis E, Szklo M, Heerington D, Jenny NS, Kronmal R, Barr RG. 2005. Nut and seed consumption and inflammatory markers in the multiethnic study of atherosclerosis. Am J Physiol 163:222–31.

Kodad O, Garcia Gómez MS, Socias i Company R. 2004. Fatty acid composition as evaluation of criterion for kernel quality in almond breeding. Acta Hort 663: 301–4.

Kodad O, Socias i Company R, Prats MS, López Ortiz MC. 2006. Variability in tocopherol concentrations in almond oil and its use as a selection criterion in almond breeding. J Hort Sci Biotechnol 81:501–7.

Kumar K, Ahuja KL, Uppal DK. 1994. Kernel quality of almonds (*Prunus amygdalus* Batsch) in terms of oil content, fatty acid composition and phospholipids content. J Food Sci Technol 31:335–337.

Lepage G, Roy CC. 1986. Direct transesterification of all classes of lipids in a one-step reaction. J Lipid Res 27:114–20.

Li L, Tsao R, Yang R, Kramer KG, Hernandez M. 2007. Fatty acid profiles, tocopherol contents, and antioxidant activities of heartnut (*Juglans ailanthifolia* Var. *cordiformis*) and Persian walnut (*Juglans regia* L.). J Agric Food Chem 55:1164–9.
Maguire LS, O'Sullivan SM, Galvin K, O'Connor TP, O'Brien NM. 2004. Fatty acid profile, tocopherol, squalene and phytosteril content of walnuts, almonds, peanuts, hazelnuts and the macadamia nut. Int J Food Sci Nutr 55:171–8.
Malisiova F, Hatziantoniou S, Dimas K, Kletstas, Demetzos C. 2004. Liposomal formulations from phospholipids of Greek almond oil. Properties and biological activity. Z Naturforsch 59c:330–4.
Momchilova S, Nikolova-Damyanova B. 2007. Quantitative TLC and gas chromatography determination of the lipid composition of raw and microwave roasted walnuts, hazelnuts, and almonds. J Liq Chromatogr Rel Prod 30:2267–85.
Mukuddem-Petersen J, Oosthuizen W, Jerling JC. 2005. A systematic review of the effects of nuts on blood lipid profiles in humans. J Nutr 135:2082–9.
Nanos GD, Kazantzis I, Kefalas P, Petrakis C, Stavroulakis GG. 2002. Irrigation and harvest time affect almond kernel quality and composition. Scientia Hort 96:249–56.
Official Methods of Analysis. 1995. 16th ed., Arlington, VA: Assn. of Official Analytical Chemists (AOAC).
Ott L. 1977. An introduction to statistical methods and data analysis. Belmont, CA: Duxbury Press, a division of Wadsworth Publishing Co.
Rajaram S, Sabaté J. 2006. Nuts, body weight and insulin resistance. Brit J Nutr 96(Suppl 2):S79–86.
Romojaro F, Riquelme R, Gimenez JL, Llorente S. 1988. Fat content and oil characteristics of some almond varieties. Fruit Sci Rep 15:53–7.
Ros E, Mataix J. 2006. Fatty acid composition of nuts—implications for cardiovascular health. Brit J Nutr 96(Suppl 2):S29–35.
Ryan E, Galvin K, O'Connor TP, Maguire AR, O'Brien NM. 2006. Fatty acid profile, tocopherol, squalene and phytosterol content of Brazil, pecan, pine, pistachio and cashew nuts. Int J Food Sci Nutr 57:219–28.
Sathe SK. 1993. Solubilization, electrophoretic characterization and *in vitro* digestibility of almond (*Prunus amygdalus*) proteins. J Food Biochem 16:249–64.
Schirra M, Agabbio M. 1989. Influence of irrigation on keeping quality of almond kernels. J Food Sci 54:1642–5.
Soler L, Cañellas J, Saura-Calixto F. 1988. Oil content and fatty acid composition of developing almond seeds. J Agric Food Chem 36:695–7.
Venkatachalam M, Sathe SK. 2006. Chemical composition of selected edible nut seeds. J Agric Food Chem 54:4705–14.
Wakeling LT, Mason RL, D'Arcy BR, Caffin NA. 2001. Composition of pecan cultivars Wichita and Western Schley [*Carya illinoinensis* (Wangenth.) K. Koch] grown in Australia. J Agric Food Chem 49:1277–81.