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Short communication

Natural variability in the nutrient composition of California-grown almonds

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ABSTRACT

The natural variability in nutrient composition among and within commercially important California almond varieties was investigated in a multi-year study. Seven major almond varieties (Butte, Carmel, Fritz, Mission, Monterey, Nonpareil and Sonora) were collected over three separate harvests and from various orchards in the north, central and south growing regions in California. Comprehensive nutritional analysis (20 macronutrients and micronutrients, 3 phytosterols) of 39 almond samples was carried out by accredited commercial laboratories. The macronutrient and micronutrient profiles obtained were notably similar for all the almond varieties in this study. The three-year mean contents of protein, total lipid, fatty acids (saturated, monounsaturated and polyunsaturated) and dietary fiber for these major varieties varied by no more than 1.2-fold. For individual nutrients, statistically significant variety, year and/or growing region effects were observed, which contributed to the natural variability in nutrient composition of the California almonds among and within varieties. Harvest year had a highly significant effect ($P < 0.01$) on the contents of total lipid, monounsaturated fatty acids and dietary fiber. Growing region had a significant effect ($P < 0.05$) on the content of ash and all minerals tested.

1. Introduction

Almonds (*Prunus dulcis* (Miller) D.A. Webb; synonyms *Prunus amygdalus* Batsch and *Prunus communis* L.) and other tree nuts have a healthy nutrient profile, providing a nutrient-dense source of protein, monounsaturated fatty acids, dietary fiber, vitamin E, riboflavin and essential minerals in addition to phytosterols and

the world have largely focused on individual nutrients (primarily lipids or fatty acids) in almond genotypes (varieties or cultivars and breeding selections) as well as limited studies on genetic and environmental factors influencing composition (Yada et al., 2011).

Variability in oil content and fatty acid composition, as well as tocopherol (vitamin E) content, has been shown to depend mainly on the almond genotype, but also may be affected by environmental factors that vary with orchard site and harvest year (Abdallah et al., 1998; Kodad et al., 2006, 2011b; Kodad and Socias i Company, 2008; López-Ortiz et al., 2008; Sathe et al., 2008). Composition variability in almond skins (seed coats) was investigated by Bolling et al. (2010), who found that the skins of major California almond cultivars had unique polyphenol profiles, and the polyphenol content (flavonoids and phenolic acids) varied 2.7-fold in samples collected over three harvest years.

Almonds are cultivated in many temperate and sub-tropical countries. The state of California in the United States is the major almond-producing region in the world, and presently accounts for about 80% of global almond production (shelled basis) (Almond Board of California, 2012). The commercial almond orchards are located in the north, central and south counties of the state's Central Valley. These orchards all receive supplemental irrigation and fertilization; however, soils, climates and cultivation practices can vary considerably. Pollination of the commercial almond orchards is carried out by managed honey bee populations. The honey bees must transfer pollen between almond trees of different varieties that are pollen compatible. For this reason, almond orchards have trees of at least two compatible varieties. In a typical orchard, rows of the main variety (e.g. Nonpareil) alternate with rows of one or more pollenizer varieties. Variety selection is based on many factors including field performance in specific growing regions, yields, disease resistance and marketability.

Over 30 almond varieties are grown commercially in California, and about ten major varieties account for most of the production (ABC, 2012). Nonpareil has consistently been the most important variety for both production and marketing due to its superior tree and nut characteristics. The majority of commercial almond

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varieties grown in California today are the descendants of two unrelated varieties – Nonpareil and Mission.

Differences among the commercial varieties in terms of physical characteristics, such as kernel shape, size, surface color and ease of blanching (for skin removal), are well established. The unique characteristics are fundamental to the marketing and usage of each almond variety. In contrast, differences in the nutrient composition profiles among these almond varieties have not been identified. Some variability in the contents of individual nutrients can be expected since almonds are natural products. Nutrient composition variability reflects genetic, environmental and analytical factors (Pennington, 2008). No previously published research has evaluated the influence of variety, harvest year and growing region on comprehensive nutrient profiles of major almond varieties. An understanding of the composition variability of California-grown almond varieties would be useful in product development and when compiling food composition data, and also for researchers evaluating storage or processing treatments and investigating the health benefits of almond consumption.

This study was part of a larger investigation to better understand the natural variability of the major almond varieties currently grown in California. In a previous paper the variability in the sensory characteristics of whole raw almonds, both among and within these major varieties, was established (Civille et al., 2010). The objective of the present study was to compare the nutrient profiles of the major almond varieties, and determine the variability in macronutrient and micronutrient composition among and within these varieties obtained from different growing regions in California over three normal harvest years.

2. Materials and methods

2.1. Almond samples

Major almond varieties – Butte, Carmel, Fritz, Mission, Monterey, Nonpareil and Sonora – were chosen as the focus for this study. These have been among the top ten almond-producing varieties in California for many years and presently account for about 80% of the total commercial almond acreage (ABC, 2012).

Raw almonds harvested in 2005–2007 in the three growing regions (north, central and south) of California were purchased from various growers and handlers. Butte, Carmel and Nonpareil almonds were obtained from all three regions; for each variety, the almonds were sourced from the same orchard in each region for three years (Butte, Carmel, Nonpareil: $n = 9$). Fritz, Mission, Monterey and Sonora almonds were obtained only from the central region; for each variety, almonds were sourced from the same orchard in that region for three years (Fritz, Mission, Monterey, Sonora: $n = 3$). A total of 39 sample lots of almonds were included in the study: 13 lots of almonds were collected per harvest year, with 7 lots obtained from the central region and 3 each from the north and south regions per year.

All orchards were operated by independent commercial growers, each using their own orchard management practices as established for the characteristics of the site (climate, soil, etc.). Almonds from each harvest were initially stored by growers and handlers under their warehouse conditions (typically ambient). The raw (shelled) almonds were obtained in lots of ~23 or 91 kg (50 or 200 lb) and each lot represented an individual variety; lots were stored under ambient conditions prior to sampling. One 450-g sample of almonds was randomly removed from each lot and samples were submitted to commercial testing laboratories for complete nutrient analysis.

2.2. Analytical testing

Independent testing laboratories in the U.S. were contracted by the Almond Board of California to provide comprehensive nutrient analysis for all almond samples. These laboratories (Covance Laboratories Inc., Madison, WI; Medallion Labs, Minneapolis, MN) are accredited according to ISO/IEC 17025 standards of the International Organization for Standardization/International Electrotechnical Commission (ISO/IEC) for the majority of nutrient analyses carried out. In general, the laboratories used official methods of the Association of Official Analytical Chemists (AOAC), the American Association of Cereal Chemists International (AACC) and the American Oil Chemists' Society (AOCS), in accordance with the requirements of the almond samples. The analytical methods used at the time of the study are listed in Table 1.

Table 1
Methods used for nutrient analysis of almond samples.[a]

Component	Method reference
Ash	AOAC[b] 923.03. Ash of flour. [Gravimetry]
Dietary fiber, total	AOAC 991.43. Total, soluble, and insoluble dietary fiber in foods. [Gravimetry, enzymatic digestion]
Fat (total lipid, SFA, MUFA, PUFA)	AOAC 960.39. Fat (crude) or ether extract in meat. [Soxhlet extraction]
	AOAC 996.06. Fat (total, saturated, and unsaturated) in foods. [Gas chromatography]
	AOCS[c] Ce 1-62. Fatty acid composition by packed column gas chromatography.
Minerals (Ca, Cu, Fe, Mg, Mn, P, K, Zn)	AOAC 985.01. Metals and other elements in plants and pet foods. [ICP emission spectrometry]
Moisture	AOAC 925.09. Solids (total) and moisture in flour. [Gravimetry, vacuum oven]
Niacin	AOAC 960.46. Vitamin assays. [Microbiological assay]
	AOAC 944.13. Niacin and niacinamide (nicotinic acid and nicotinamide) in vitamin preparations. [Microbiological assay]
Phytosterols	AOAC 994.10. Cholesterol in foods. [Gas chromatography]
	AOAC 2007.03. Campesterol, stigmasterol, and beta-sitosterol in saw palmetto raw materials and dietary supplements. [Gas chromatography]
Protein	AOAC 968.06. Protein (crude) in animal feed. [Dumas method]
Riboflavin	AOAC 970.65 Riboflavin (vitamin B2) in foods and vitamin preparations. [Fluorometry]
	AOAC 981.15. Riboflavin in foods and vitamin preparations. [Fluorometry]
Sucrose	AOAC 982.14 Glucose, fructose, sucrose, and maltose in presweetened cereals. [High-performance liquid chromatography]
α-Tocopherol	AACC[d] Method 86-06.01 Analysis of vitamins A and E by high-performance liquid chromatography.
	Total tocopherols (internally developed high-performance liquid chromatography method; Cort et al., 1983)

[a] Methods in use by accredited commercial laboratories in 2005–2008; details on individual methods used by each laboratory are available from the authors.
[b] AOAC, Association of Official Analytical Chemists; http://www.aoac.org.
[c] AOCS, American Oil Chemists' Society; http://www.aocs.org.
[d] AACC, American Association of Cereal Chemists International; http://www.aaccnet.org.

The present study reports the composition data obtained for analysis of moisture, ash, total protein (nitrogen conversion factor = 5.18), total fat, fatty acids (saturated: SFA; monounsaturated: MUFA; and polyunsaturated: PUFA), sucrose, total dietary fiber, vitamins (α-tocopherol, riboflavin and niacin), minerals (calcium, copper, iron, magnesium, manganese, phosphorus, potassium and zinc) and major phytosterols (β-sitosterol, campesterol and stigmasterol).

2.3. Statistical analysis

ANOVAs by the General Linear Model procedure and post-hoc multiple comparisons by Tukey's test were performed with Minitab software (Minitab Inc., State College, PA). Differences between mean values were considered significant at $P < 0.05$.

3. Results and discussion

In this study, composition data for almonds are reported on a fresh weight basis; therefore some observed differences in the nutrient contents may be due to differences in moisture content of the samples. Moisture levels are influenced by nut maturity as well as conditions at harvest and during storage (Kader and Thompson, 2002). Raw almonds do not typically receive supplementary drying by mechanical means after harvest in normal production years. The moisture content of all samples in the present study fell within a range of 3.2–6.3%; the overall mean (±SD) was 4.2 ± 0.8 ($n = 39$). The almonds analyzed in this study are representative of the product available in California after harvest and during ambient storage (<65% relative humidity) in the months after harvest. Almonds are a low-moisture food and moisture contents between 3 and 6% are within the normal range of variability.

The nutrient composition data of the seven major almond varieties are presented in Table 2; mean nutrient values (±standard deviation) represent each variety's samples obtained over three harvest years. Only the three main varieties (Butte, Carmel and Nonpareil) were obtained from all regions in the three harvest years. Table 3 presents the composition data of these varieties pooled by harvest year or growing region.

3.1. Almond variety effect

The seven almond varieties investigated in this study had similar overall nutrient profiles (Table 2). Nevertheless, significant differences in the contents of some individual nutrients were found, as indicated by the P values shown for each nutrient in relation to variety. Small but statistically significant differences were observed in the three-year mean contents of protein, sucrose, vitamins, some minerals (P, K, Zn), β-sitosterol and stigmasterol. Small but significant differences in SFA and PUFA contents were also observed among some varieties, but all varieties had a similar mean content of total lipids. The PUFA content in all almond samples was comprised of over 99.9% linoleic acid (18:2 n-6), negligible amounts (<0.03%) of α-linolenic acid (18:3 n-3) and no γ-linolenic acid (18:3 n-6) (data not shown). Almonds are not a source of linolenic acid or any omega-3 fatty acids (Robbins et al., 2012).

Protein contents ranged from 18.5 to 24.0 g/100 g almonds among all samples. Within this range, Fritz and Sonora almonds had significantly higher mean protein contents than Butte, Carmel and Nonpareil. The α-tocopherol contents ranged from 18.2 to 32.9 mg/100 g almonds among all samples. A difference of 9 mg α-tocopherol per 100 g almonds was observed between the varieties with the highest (Sonora) and lowest (Monterey) content means, although the variability among Monterey samples was large, as evidenced by coefficient of variation (CV) values >16%.

For many of the nutrients that exhibited a significant variety effect, such as sucrose, riboflavin and niacin, the variability in the content of those nutrients was also considerable within some varieties; CV values were typically >10% and up to 44%. Variability for β-sitosterol and stigmasterol contents was very large for some almond varieties (CV up to 80%). Phytosterol values in this study are likely an underestimate of the total quantities found in the samples. The standard commercial laboratory method of

Table 2
Variability in nutrient composition of seven major California almond varieties obtained over 3 harvest years.

Nutrient	Unit	Varietal nutrient contents (/100 g kernels, fresh weight)[A]							Range[B] (/100 g)	ANOVA P value
		Butte	Carmel	Fritz	Mission	Monterey	Nonpareil	Sonora		
Water	g	4.7 ± 0.9	4.1 ± 0.6	4.6 ± 1.1	4.6 ± 0.6	3.9 ± 0.6	3.9 ± 0.6	4.1 ± 0.7	3.2–6.3	0.051
Protein	g	20.5 ± 0.8 b	20.2 ± 0.6 b	22.5 ± 0.4 a	20.9 ± 0.7 ab	21.3 ± 2.4 ab	20.2 ± 0.9 b	22.4 ± 0.3 a	18.5–24.0	<0.001
Total lipid (fat)	g	50.0 ± 2.5	50.1 ± 2.8	48.4 ± 3.2	49.6 ± 2.1	49.4 ± 2.6	49.6 ± 1.9	50.2 ± 2.0	44.7–54.1	0.902
SFA	g	4.1 ± 0.3 a	3.9 ± 0.1 a	3.4 ± 0.2 b	3.7 ± 0.0 ab	3.7 ± 0.1 ab	3.8 ± 0.1 a	3.9 ± 0.2 a	3.2–4.7	<0.001
MUFA	g	29.4 ± 2.2	29.7 ± 2.4	30.5 ± 2.5	31.6 ± 1.8	32.3 ± 2.6	31.3 ± 2.5	31.4 ± 1.1	24.9–36.1	0.053
PUFA	g	13.9 ± 1.2 a	13.8 ± 0.7 a	12.0 ± 0.6 ab	11.6 ± 0.4 bc	11.2 ± 0.6 bc	11.7 ± 1.3 bc	12.4 ± 1.4 ab	9.4–15.1	<0.001
Dietary fiber (total)	g	12.2 ± 1.7	12.5 ± 1.8	11.0 ± 2.7	13.5 ± 2.4	11.8 ± 2.3	12.9 ± 1.2	11.8 ± 2.7	7.9–16.0	0.292
Sucrose	g	3.1 ± 0.5 b	3.4 ± 0.4 ab	3.0 ± 0.0 ab	2.9 ± 0.2 b	3.7 ± 1.3 ab	4.1 ± 0.6 a	3.1 ± 0.2 ab	2.5–5.1	0.006
Ash	g	2.8 ± 0.2	2.9 ± 0.2	2.9 ± 0.1	3.0 ± 0.1	3.0 ± 0.1	2.9 ± 0.3	3.1 ± 0.3	2.3–3.4	0.166
Calcium (Ca)	mg	288 ± 55	279 ± 49	290 ± 16	330 ± 30	252 ± 32	261 ± 53	234 ± 30	198–373	0.219
Iron (Fe)	mg	3.27 ± 0.47	3.27 ± 0.25	3.63 ± 0.73	3.34 ± 0.41	3.58 ± 0.27	3.47 ± 0.50	3.84 ± 0.41	2.58–4.47	0.375
Magnesium (Mg)	mg	263 ± 24	262 ± 17	260 ± 15	272 ± 17	278 ± 3	275 ± 23	256 ± 4	224–303	0.578
Phosphorus (P)	mg	463 ± 52	462 ± 21	466 ± 60	512 ± 23	524 ± 29	455 ± 36	526 ± 26	364–548	0.029
Potassium (K)	mg	664 ± 21 b	679 ± 44 ab	664 ± 105 ab	724 ± 17 ab	766 ± 102 ab	762 ± 85 a	773 ± 52 ab	543–902	0.003
Zinc (Zn)	mg	2.98 ± 0.41 b	2.77 ± 0.33 b	2.82 ± 0.55 b	2.76 ± 0.22 b	2.79 ± 0.54 b	3.23 ± 0.34 ab	3.80 ± 0.20 a	2.02–4.03	0.002
Copper (Cu)	mg	0.92 ± 0.38	1.09 ± 0.13	0.85 ± 0.10	0.72 ± 0.15	0.94 ± 0.39	1.05 ± 0.24	0.90 ± 0.11	0.46–1.57	0.390
Manganese (Mn)	mg	2.00 ± 0.47	2.14 ± 0.36	2.08 ± 0.68	2.20 ± 0.06	2.12 ± 0.36	2.21 ± 0.38	3.04 ± 1.03	1.31–3.98	0.093
α-Tocopherol	mg	27.6 ± 2.7 ab	29.9 ± 1.5 a	26.3 ± 0.8 abc	28.3 ± 0.5 ab	21.9 ± 3.7 c	26.0 ± 1.9 bc	31.0 ± 1.3 a	18.2–32.9	<0.001
Riboflavin	mg	1.68 ± 0.52 a	1.17 ± 0.35 b	1.01 ± 0.33 b	1.11 ± 0.48 b	1.00 ± 0.37 b	1.32 ± 0.49 b	1.25 ± 0.25 ab	0.58–2.27	<0.001
Niacin	mg	2.71 ± 0.70 b	2.90 ± 0.54 ab	2.52 ± 0.43 ab	3.72 ± 0.34 ab	3.35 ± 1.49 ab	3.49 ± 0.71 a	2.73 ± 1.06 ab	1.40–5.02	0.008
β-Sitosterol	mg	128 ± 18 b	157 ± 28 a	149 ± 20 ab	137 ± 25 ab	130 ± 20 b	134 ± 18 b	144 ± 18 ab	103–206	<0.001
Stigmasterol	mg	3.9 ± 0.7 b	2.5 ± 0.5 b	1.9 ± 0.4 b	2.3 ± 1.0 b	4.3 ± 3.4 ab	6.3 ± 2.4 a	2.7 ± 1.0 b	1.3–9.8	<0.001
Campesterol	mg	5.1 ± 0.8	5.0 ± 0.6	5.3 ± 0.5	4.7 ± 0.4	4.9 ± 0.4	6.0 ± 2.2	5.0 ± 0.4	4.1–11.8	0.570

[A] Value for each nutrient is the mean ± SD; $n = 9$ (Butte, Carmel, and Nonpareil varieties) and $n = 3$ (Fritz, Mission, Monterey, and Sonora varieties). Within each row, means with different lowercase letters are significantly different as tested by Tukey's ($P < 0.05$).
[B] For each nutrient, range represents minimum to maximum values obtained from all samples in study, $n = 39$.

Table 3
Variability in nutrient composition (/100 g kernels, fresh weight)[A] of almonds (Butte, Carmel and Nonpareil varieties) obtained in different harvest years (all growing regions) or from different growing regions (over 3 harvest years).

Nutrient	Unit	Harvest year			ANOVA *P* value	California growing region			ANOVA *P* value
		2005	2006	2007		Central	North	South	
Water	g	4.7 ± 0.7 a	4.2 ± 0.9 ab	3.7 ± 0.4 b	0.005	4.6 ± 1.0 a	3.9 ± 0.4 b	4.1 ± 0.7 a	0.034
Protein	g	20.5 ± 0.6	19.8 ± 0.7	20.6 ± 0.7	0.042	20.4 ± 0.6	20.1 ± 0.5	20.3 ± 1.1	0.692
Total lipid (fat)	g	47.9 ± 2.9 b	51.2 ± 1.2 a	50.6 ± 1.0 a	0.006	49.3 ± 2.4	50.5 ± 2.8	50.0 ± 1.7	0.419
SFA	g	4.0 ± 0.3	3.9 ± 0.1	3.9 ± 0.1	0.384	3.9 ± 0.2	3.9 ± 0.3	3.9 ± 0.1	0.829
MUFA	g	28.4 ± 2.2 b	32.2 ± 2.2 a	29.8 ± 1.2 b	<0.001	28.8 ± 2.3 b	30.9 ± 2.8 a	30.8 ± 1.6 a	0.011
PUFA	g	13.5 ± 1.4 a	12.4 ± 1.6 b	13.6 ± 1.4 a	0.020	13.9 ± 1.2 a	12.9 ± 1.9 ab	12.6 ± 1.1 b	0.018
Dietary fiber (total)	g	11.1 ± 1.3 c	12.4 ± 1.0 b	14.0 ± 0.5 a	<0.001	12.0 ± 1.6	12.6 ± 1.8	13.0 ± 1.1	0.072
Sucrose	g	3.5 ± 0.6	3.6 ± 0.6	3.5 ± 0.8	0.918	3.5 ± 0.8	3.4 ± 0.4	3.6 ± 0.8	0.797
Ash	g	3.0 ± 0.2 a	2.8 ± 0.2 ab	2.7 ± 0.3 b	0.005	3.1 ± 0.2 a	2.7 ± 0.2 b	2.8 ± 0.1 b	<0.001
Calcium (Ca)	mg	261 ± 41	279 ± 60	289 ± 54	0.198	288 ± 34 a	224 ± 23 b	318 ± 42 a	<0.001
Iron (Fe)	mg	3.16 ± 0.30	3.43 ± 0.34	3.43 ± 0.55	0.231	3.16 ± 0.34 b	3.63 ± 0.39 a	3.23 ± 0.37 ab	0.025
Magnesium (Mg)	mg	264 ± 24	267 ± 27	270 ± 13	0.474	267 ± 13 b	288 ± 12 a	245 ± 11 c	<0.001
Phosphorus (P)	mg	464 ± 28	452 ± 47	464 ± 37	0.596	498 ± 16 a	446 ± 19 b	436 ± 38 b	<0.001
Potassium (K)	mg	692 ± 66 ab	680 ± 64 b	733 ± 77 a	0.037	744 ± 95 a	665 ± 25 b	695 ± 53 b	0.002
Zinc (Zn)	mg	2.78 ± 0.36 b	3.04 ± 0.44 ab	3.15 ± 0.31 a	0.035	2.79 ± 0.38 b	2.98 ± 0.34 ab	3.20 ± 0.39 a	0.025
Copper (Cu)	mg	1.03 ± 0.31	1.04 ± 0.26	0.99 ± 0.25	0.822	0.77 ± 0.25 b	1.19 ± 0.16 a	1.10 ± 0.20 a	0.001
Manganese (Mn)	mg	2.10 ± 0.46	2.16 ± 0.38	2.08 ± 0.40	0.895	2.32 ± 0.26 a	2.22 ± 0.43 ab	1.80 ± 0.32 b	0.015
α-Tocopherol	mg	27.7 ± 2.3	27.0 ± 2.7	28.8 ± 2.8	0.165	28.7 ± 2.4	28.0 ± 2.6	26.8 ± 2.6	0.107
Riboflavin	mg	0.86 ± 0.24 b	1.54 ± 0.31 a	1.77 ± 0.34 a	<0.001	1.51 ± 0.49	1.36 ± 0.54	1.29 ± 0.48	0.086
Niacin	mg	3.08 ± 0.70 a	2.43 ± 0.51 b	3.59 ± 0.40 a	<0.001	2.98 ± 0.84	3.05 ± 0.76	3.07 ± 0.62	0.896
β-Sitosterol	mg	115 ± 8 b	149 ± 15 a	155 ± 25 a	<0.001	146 ± 30	138 ± 19	134 ± 26	0.098
Stigmasterol	mg	3.0 ± 0.8 b	5.1 ± 2.2 a	4.6 ± 2.5 a	0.003	3.9 ± 2.0	4.6 ± 2.5	4.2 ± 2.0	0.469
Campesterol	mg	5.4 ± 0.5	4.9 ± 0.8	5.8 ± 2.3	0.390	5.6 ± 0.6	5.5 ± 2.4	4.9 ± 0.5	0.567

[A] Value for each nutrient is the mean ± SD; $n = 9$. Within each row, means with different lowercase letters are significantly different as tested by Tukey's ($P < 0.05$).

saponification (i.e. alkaline hydrolysis) used for analysis of the major phytosterols recovers the free and esterified sterols, but not the glycosidic sterols that can comprise up to 23% of total sterols in almonds (Phillips et al., 2005).

Previous studies of nutrient composition variability among commercial or widely cultivated almond varieties have reported a significant variety (or genotype) effect for one or more nutrients. Researchers in Spain and California found that some commercial almond varieties (or genotypes) had significant differences in total lipid content and/or fatty acid composition (e.g. Abdallah et al., 1998; Kodad et al., 2011a; Kodad and Socias i Company, 2008; Sathe et al., 2008). Other studies comparing commercial varieties have observed significant differences in the content of specific nutrients such as protein (Drogoudi et al., 2012; Ruggeri et al., 1998; Sathe, 1993), dietary fiber (Ruggeri et al., 1998), sugars (e.g. Amrein et al., 2005; Nanos et al., 2002; Romojaro et al., 1988), various minerals (Drogoudi et al., 2012; Prats-Moya et al., 1997) and tocopherols (Kodad et al., 2006, 2011b; López-Ortiz et al., 2008).

3.2. Harvest year effect

The effect of harvest year on moisture, total lipid, MUFA, dietary fiber and ash contents was highly significant ($P < 0.01$) in the almond samples (Table 3). Among the micronutrients, significant differences were observed in the contents of some minerals (K, Zn), riboflavin, niacin, β-sitosterol and stigmasterol in some harvest years.

For total lipid content, only the effect of harvest year was significant in this study. Almond samples from the 2005 harvest year had a significantly lower content of total lipid (47.9 g/100 g) than the 2006 and 2007 samples (51.2 and 50.6 g/100 g, respectively). For dietary fiber content, the significant harvest year effect may have blocked the observation of differences among varieties; variability within the varieties was considerable, with CV > 10% for all varieties except Nonpareil. The harvest year effect on ash content was statistically significant, although ash contents were within a narrow range of 2.3–3.4 g/100 g for all samples.

Some studies have applied statistical analysis to almond kernel composition data from two or more harvest years. Kodad et al. (2006) reported a significant year effect on tocopherol content for almond varieties from a single experimental orchard in Spain). In a later study of 17 almond varieties grown in both Spain and Morocco, Kodad et al. (2011b) demonstrated a significant year effect for α-tocopherol content, as well as other tocopherol homologues and total tocopherol, independent of the two growing sites evaluated. No significant year effect on macronutrient content was reported by Sánchez-Bel et al. (2008) for a single almond variety (Guara) in a cultivation study over two years. The effect of harvest year on almond kernel oil content has not been conclusively demonstrated: Abdallah et al. (1998) and Sathe et al. (2008) reported a significant year effect on kernel oil content for various California almond varieties, but no significant year effect was found by Kodad and Socias i Company (2008) and Kodad et al. (2011a) in extensive two-year studies, although the interaction of genotype × year was significant. Barbera et al. (1994) reported a significant year effect for the content of fat and sugars (but not for protein or ash) in two almond varieties (Ferragnes and Tuono) over three harvest years, but nutrient analysis methods were not provided.

3.3. Growing region effect

Almond samples obtained from orchards located in the central, north, or south growing regions of California differed significantly in the content of ash and all minerals tested (Table 3). This significant growing region or location effect is not unexpected given the common understanding that the mineral content of plant tissues is affected by environmental and agronomic factors including soil composition, irrigation and water sources and fertilizer components. Researchers have demonstrated that these minerals accumulate in developing kernels during almond fruit growth and ripening (Schirra et al., 1994).

In general, the region effect had a higher level of significance on mineral contents than the other effects. Variety and year effects on individual mineral contents were significant for a few minerals only, most notably potassium and zinc (for both variety and year).

The region effect on individual mineral contents was significant for all minerals tested. However, no region had almond samples with consistently high or low mean contents of a majority of minerals. The CV was >10% for most mineral content means, indicating considerable variability within regions. A review of the literature indicates that few published studies have assessed such a wide profile of minerals in almond samples, but in other production regions a significant variety effect was demonstrated for the content of individual minerals (Yada et al., 2011).

Similar protein, total lipid, dietary fiber, sucrose, vitamin and phytosterol contents were found in samples obtained from the different regions. Although a significant growing region effect was observed for the contents of MUFA and PUFA, the harvest year effect had a higher level of significance for MUFA (Table 3) and the variety effect had a higher level of significance for PUFA for all varieties (Table 2) as well as for the three pooled varieties (data not shown).

Kodad et al. (2011b) reported a significant location effect for α-tocopherol concentration in almond kernel oil, although the different almond varieties tested did not show a consistent response in both harvest years; thus, the location effect was dependent on the response of each variety to undetermined environmental factors. In a study with four varieties of California-grown almonds, Abdallah et al. (1998) found that oil content and fatty acid composition varied significantly with growing region, and attributed this finding to the variation in production factors (e.g. soil, irrigation method and temperature) among the regions.

3.4. Nutrient profiles of major almond varieties

Almonds were introduced to the U.S. in the 1800s, likely by planting specific cultivars imported from southern France. Two varieties unrelated to each other – Nonpareil and Mission (also known as Texas) – originated from seedlings selected from those imported sources (Kester, 1994; Kester et al., 1991). The Nonpareil variety currently represents over 35% of total almond production in California (ABC, 2012). Genetic characterization of commercial almond varieties indicates that the majority of today's commercial almond varieties in California are interrelated and are dominated by descendents of Nonpareil and/or Mission (Bartolozzi et al., 1998; Hauagge et al., 1987; Lansari et al., 1994).

A comparison of the macronutrient and micronutrient data (Table 2) reveals the similarity in overall nutrient profiles among the seven almond varieties sampled. This similarity is not unexpected given the interrelatedness of most of the commercial almond varieties. Interestingly, even the two unrelated varieties, Mission and Nonpareil, had very similar nutrient profiles; the only significant difference between nutrient means was the sucrose content, which was higher in Nonpareil.

For some individual nutrients, statistically significant variety, year and/or growing region effects were observed, which contributed to the natural variability in nutrient composition of the almonds among and within varieties. A typical serving size of nuts is 28 g (1 oz) and the almond composition data are presented per 100 g. The nutritional impact of the observed natural variability in almond composition must be considered in the context of the dietary intake of the nuts.

The ranges of mean protein, total lipid, fatty acids and dietary fiber values represent no more than a 1.2-fold difference between varieties having the highest and lowest contents of each macronutrient; sucrose content represents a 1.4-fold difference. The ranges of mean mineral and vitamin contents represent 1.1-fold–1.5-fold differences between varieties, with the exception of a 1.7-fold difference for riboflavin.

This study presents nutrient profile data for seven different almond varieties grown in California. In contrast, the nutrient composition data for "almonds" as cited in the U.S. Department of Agriculture (USDA) National Nutrient Database for Standard Reference (USDA-ARS, 2012) are composite and market-representative values for almonds in the U.S. food supply. The composite data for whole almonds in the current release of the USDA database were largely compiled over the last 15 years from variety-specific nutrient data sets (obtained for nine major California almond varieties) submitted by the Almond Board of California (ABC) to USDA along with industry production statistics (Yada et al., 2011). ABC regularly submits almond nutrient data to USDA and this is the type of data requested. One nutrient data set submitted previously to USDA included the results obtained in this study for all samples from the 2005 and 2006 harvests, so these varietal composition data have been incorporated. The varietal composition data for the samples from the 2007 harvest were recently submitted to USDA for evaluation and may be incorporated in the 2013 update of the nutrient database.

4. Conclusion

The California almond industry grows about 80% of the world's almonds and is regularly asked to identify differences in nutrient composition among common commercial varieties, but to date there have been no published data on varietal nutrient profiles. The data presented here provide comprehensive nutrient profiles for seven major almond varieties grown in California and marketed around the world. The multi-year and multi-region sampling carried out allows for a better understanding of the natural variability in almond composition within and among varieties. Although variety, year and/or growing region had a significant influence on the content of some individual nutrients, the macronutrient and micronutrient profiles obtained over three years for each variety were notably similar.

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