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Variability of Oil Content and of Major Fatty Acid Composition in Almond (*Prunus amygdalus* Batsch) and Its Relationship with Kernel Quality

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Oil content and fatty acid composition were determined for two years in the kernel oil of eight cultivars and 47 advanced self-compatible almond genotypes developed in an almond breeding program. Considerable variation between genotypes was found for all parameters. Oil content ranged from 48% to 67% of the total kernel dry weight but was consistent over the two years. Fatty acid composition was also very variable, with significant differences between genotypes, even in genotypes of the same progeny. Oleic acid, ranging from 63% to 78%, and linoleic acid, ranging from 12% to 27%, were the major fatty acids, showing higher values in some selections than in their parents. The large variability observed for all fatty acids and the presence of selections with higher oil and fatty acid contents than the commercial cultivars represents a very promising base to obtain new almond cultivars with oil of higher quality, satisfying the industrial and consumer sectors.

KEYWORDS: Almond; breeding program; fatty acid composition; oil content; *Prunus amygdalus* Batsch; quality improvement; variability

INTRODUCTION

Almond is a major tree nut cultivated in areas of Mediterranean climate. The kernel is the edible part of the nut and is considered an important food crop, with a high nutritional value. It may be consumed raw or cooked, blanched or unblanched, combined and/or mixed with other nuts. It can also be transformed to be incorporated into other products or to produce marzipan and nougat (*1*).

Almond kernel quality has so far been defined exclusively by physical parameters: size, shape, double kernels, etc. However, the different uses of almond kernels may require kernels with a specific composition, depending on each commodity. The high nutritive value of almond kernels arises mainly from their high lipid content, which constitutes an important caloric source but does not contribute to cholesterol formation in humans, due to their high level of unsaturated fatty acids, mainly monounsaturated fatty acids (MUFA), because MUFAs are inversely correlated with serum cholesterol levels (*2*). Although reports on almond oil content and composition have included only a small number of commercial cultivars (*3–5*), these reports indicate that almond oil, in addition to being very rich in MUFAs, shows a high proportion of oleic acid (*3, 5*).

Kernel tendency to rancidification during storage and transport is a quality loss and is related to oxidation of the kernel fatty acids (*6*). Thus, oil stability and fatty acid composition, essentially the ratio of oleic to linoleic (O/L) acids (*7*), are considered an important criterion to evaluate kernel quality. Also, it has been reported that almond oil content and composition depend primarily on the genotype effect but also on the environmental conditions (*3*).

Until recently, almond breeding has been focused on selecting self-compatible and late-blooming cultivars with fruits of a high physical quality (*8*). Consequently, very little information on chemical evaluation of the almond kernel has been found, although in other species, such as in peach (*9*) and apricot (*10*), breeding programs have incorporated chemical component analysis of the fruits to characterize and evaluate promising new selections. As a consequence, studies carried out to determine the chemical components of the almond oil kernel and their variability are scarce. Incorporation of such analyses in the evaluation of the new plant material would be of great interest in determining the possible commercial and industrial use of the product, since the specific use of the almond kernel depends primarily on its chemical composition (*8*).

In recent years, food and health aspects are receiving special attention from the general public. The determination of food authenticity and origin is a crucial issue in food quality control and safety (*11*). The objective of the report herein was to determine the oil content and composition for a set of almond cultivars and selections, as well as the possibility of establishing the chemical characters helpful for almond cultivar characterization and as a selection criterion in almond quality evaluation.

MATERIALS AND METHODS

Plant Material. Eight cultivars, one selection and 46 self-compatible advanced selections coming from five crosses between two traditional Spanish cultivars ('Marcona' and 'Desmayo Largueta'), a French release

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Table 1. Origin of Cultivars and Selections Studied

genotype	origin
Marcona	local (NE Spain)
Moncayo	'Tardive de la Verdière' × 'Tuono'
A-10-6	'Tuono' × 'Ferragnès'
Bertina	local (NE Spain)
Desmayo Largueta	local (NE Spain)
Felisia	'Titan' × 'Tuono'
Ferragnès	'Aï' × 'Cristomorto'
Guara	chance selection
Soleta	'Blanquerna' × 'Belle d'Aurons'
G-1-1, G-1-23, G-1-27, G-1-38, G-1-41, G-1-58, G-1-61, G-1-64, G-1-67, G-2-1, G-2-2, G-2-7, G-2-11, G-2-22, G-2-23, G-2-25, G-2-26, G-2-27, G-3-3, G-3-4, G-3-5, G-3-8, G-3-12,G-3-24, G-3-28, G-3-65, G-4-3, G-4-10, G-5-18, G-5-25, G-6-14, G-6-24, G-6-39, I-3-10, I-3-11 and I-3-27	'Felisia' × 'Bertina'
H-1-108 and H-1-81	'Moncayo' × 'Desmayo Largueta'
H-2-111, H-2-22, H-3-37 and H-3-39	A-10-6 × 'Marcona'
I-3-65, I-3-67 and G-5-2	'Felisia' × 'Moncayo'
I-1-95 and I-2-12	'Guara' × 'Ferragnès'

('Ferragnès'), a Spanish local selection ('Bertina'), three releases from the CITA breeding program ('Felisia', 'Guara', and 'Moncayo'), and a selection from the same program (A-10-6) (**Table 1**) were studied. These selections were grafted onto the peach × almond rootstock 'Garnem' and grown in blocks of three trees in an alluvial loamy soil. Nuts from open pollination were harvested in 2002 and 2003 at mature stage, when fruit mesocarp was fully dried and split along the fruit suture and peduncle abscission was complete (*12*).

Procedures. For chemical analysis, two replicates of 20 fruits of each genotype were randomly collected. After cracking, seed coats were removed by pouring in warm water. Kernels were dried at room temperature for 2 days and ground in an electrical grinder. Oil was extracted from 4−5 g of ground almond kernels in a commercial fat extractor (Selecta, Barcelona, Spain) for 2 h with petroleum ether as solvent and the heating source kept at 135 °C, because previous checks showed that extraction is practically completed after 2 h, with no differences after 4 h. Consequently, 2 h was considered a sufficient time. The fat content was determined as the difference in weight of the dried kernel sample before and after extraction. The oil sample was utilized to prepare the methyl esters of the corresponding fatty acids (FAME) according to the EU official method (EEC Regulation 2568/91). These methyl esters were separated by use of a flame ionization detector (FID) gas chromatograph equipped with a SP2330 column (30 m × 0.25 mm i.d., 0.2 m film thickness) (Supelco, Bellefonte, PA). The carrier gas was helium at a flow rate of 2 mL min^{-1}. The temperature of the inlet and detector was maintained at 220 and 275 °C, respectively. The initial column temperature was 150 °C. The oven temperature was then increased from 100 to 150 °C at 2.5 °C/min ramp rate, from 150 to 200 °C at 3 °C/min ramp rate, and from 200 to 240 °Cat 13 °C/min ramp rate. The temperature was maintained at 240 °C for 5 min. Injection volume was 1.0 μL. The identification of the FAMEs was achieved by comparison with relative retention times in a reference sample that contained standard methyl esters (Sigma−Aldrich, Madrid, Spain).

Statistical Analysis. All statistical analyses were performed with the SAS program (Cary, NC). The analysis of variance with the PROC GLM procedure was applied to distinguish the effect of the genotype and the year. The mean separation was done with the Duncan test at a probability of 0.05. The coefficients of correlation between the studied variables were obtained as well as between the years of the study, to establish the consistency of the data over the years. Pearson's correlation coefficients were calculated with the PROC CORR procedure.

RESULTS AND DISCUSSION

Results for both years are shown in **Table 2**. In 2002, values of oil content ranged from 50.7% to 67.5%, with a mean value for all genotypes of 57.9%. In 2003, the mean value was 58.15%, with a range from 48.3% to 65%. The variability of oil content in almond kernels confirms the results reported for other almond cultivars (*3, 5, 13, 14*). When only the European commercial cultivars are considered, variability ranged from 54% for 'Guara' to 64.5% for 'Cambra', higher than the range of 35−53% reported for the Californian cultivars (*3*) and the range of 35−61% reported for the Australian cultivars (*5*). A study of 19 cultivars of different origins already showed that the cultivars from America (California and Texas) are less fatty than the European ones (*13*).

Analysis of variance showed that the genotype effect and the interaction genotype × year were significant, whereas the year effect was not significant (**Table 3**), showing that the genetic factor is the most important component for oil content determination in almond. In a similar study, involving four cultivars

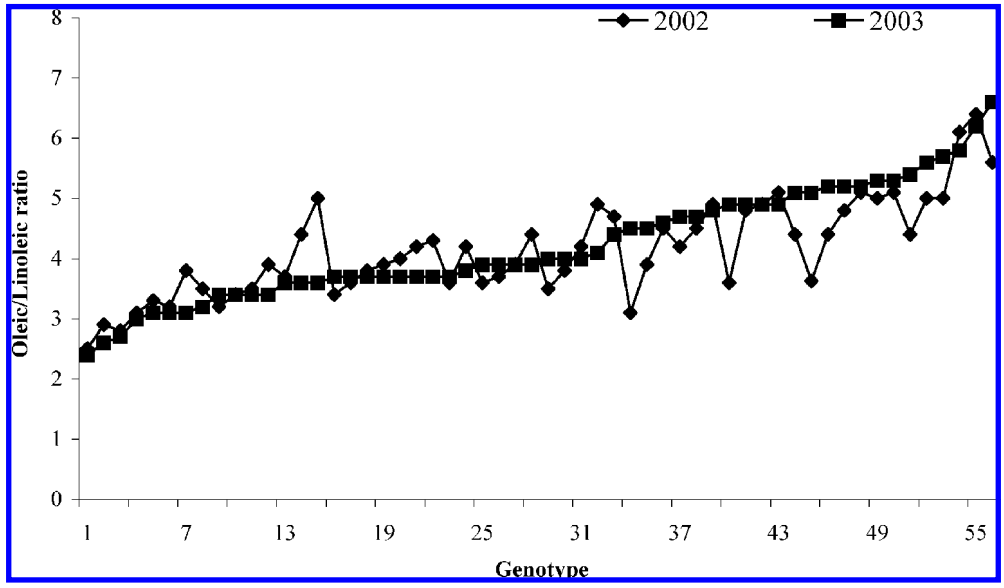

Figure 1. Ratio of oleic to linoleic acid concentrations for the almond genotypes studied in 2002 and 2003.

Table 2. Oil and Fatty Acid Composition of Each Genotype[a]

	oil content		palmitic		palmitoleic		stearic		oleic		linoleic		O/L	
genotype	2002	2003	2002	2003	2002	2003	2002	2003	2002	2003	2002	2003	2002	2003
A-10-6	55.2	56.5	6.3	5.3[b]	0.6	0.5	2.3	2.2	70.3	76.9[b]	19.4	15.4[b]	3.6	4.9[b]
Cambra	63.8	64.5	6.0	5.7	0.7	0.7	1.6	1.9	77.8	76.5	12.7	13.2	6.1	5.8
Soleta	63.8	62.4	6.0	6.3	0.7	0.6	1.2	2.3[b]	74.8	70.7[b]	15.7	17.4	4.9	4.1
Felisia	56.3	55.5	6.5	5.4[b]	0.7	0.6	2.3	1.6[b]	68.1	75.5[b]	22.1	16.7[b]	3.1	4.5[b]
Ferragnès	57.7	62.9[b]	6.6	5.4	0.5	0.4	1.8	2.1	70.4	76.7[b]	20.3	15.1[b]	3.4	5.1[b]
Guara	54.3	55.8	6.7	7.1	0.4	0.4	2.8	1.8	63.1	63.4	25.7	27.1	2.5	2.4
Bertina	56.7	56.2	6.3	5[b]	0.5	0.3[b]	2.5	2.1	69.2	69.9	21.1	22.3	3.2	3.1
Monacyo	57.1	57.5[b]	5.9	5.1	0.5	0.4	2.1	2	74.8	75.5	16.3	16.7	4.6	4.5
Marcona	59.8	58.4	6.3	5.9	0.5	0.6	1.8	2.1	71.4	72.1	19.7	19.1	3.6	3.7
D. Largueta	59.1	55.6	6.1	6.9	0.4	0.4	1.8	1.8	72.4	68.9[b]	18.8	22.3[b]	3.8	3.1
G-1-1	61.4	60.8	5.6	6.0	0.5	0.5	2.4	2.5	75.3	75.3	15.7	15.4	4.8	4.9
G-1-23	62.3	60.9[b]	5.5	5.0	0.5	0.3[b]	2.3	2.1	73.9	75.7	16.6	16.6	4.5	4.6
G-1-27	58.7	58.7	5.9	6.1	0.4	0.4	2.0	2.0	71.1	70.9	19.4	19.3	3.7	3.6
G-1-38	56.9	52.8[b]	5.9	6.7	0.6	0.7	2.0	1.6	72.8	69.9	19.0	20.6	3.9	3.4
G-1-41	67.5	59.4[b]	5.7	5.2	0.5	0.4	2.0	1.7	74.4	77.4[b]	16.8	14.8[b]	4.4	5.2[b]
G-1-58	57.2	56.0	6.1	6.3	0.6	0.6	1.7	1.6	75.5	75.5	15.5	15.8	4.9	4.8
G-1-61	61.3	59.5[b]	6.5	5.9	0.5	0.5	2.3	1.5[b]	74.7	73.6	16.9	18.9	4.4	3.9
G-1-64	58.9	59.2	6.2	6.3	0.4	0.3	2.1	2.0	74.0	71.0[b]	17.1	19.5[b]	4.4	3.6[b]
G-1-67	54.2	57.5[b]	6.4	6.1	0.6	0.5	1.6	1.7	69.8	71.5	20.6	19.6	3.4	3.7
G-2-1	60.9	56.4[b]	6.4	5.7[b]	0.5	0.4	1.9	1.8	67.5	66.9	24.1	24.9	2.8	2.7
G-2-11	58.6	57.3	6.5	6.5	0.6	0.6	1.6	1.3	68.9	70.3[b]	21.8	20.8	3.2	3.4
G-2-2	58.9	58.4	5.9	5.5	0.6	0.5	2.0	2.2	73.0	71.8	18.8	19.6	3.9	3.7
G-2-22	55.1	56.4	6.1	6.2	0.5	0.5	1.7	1.3	75.8	75.8	15.6	15.6	4.9	4.9
G-2-23	53.5	58.6[b]	5.8	5.7	0.7	0.7	1.4	1.4	72.1	73.4	18.8	18.5	3.8	4.0
G-2-25	60.3	57.9	5.5	5.8	0.5	0.5	2.3	2.0	75.6	74.3	16.0	17.1	4.7	4.4
G-2-26	59.0	65.0[b]	6.2	5.8	0.5	0.5	1.8	1.9	72.4	74.5	18.8	16.6	3.9	4.5[b]
G-2-27	55.7	58.3[b]	6.9	7.0	0.7	0.7	1.7	1.5	70.1	74.4[b]	16.8	15.9	4.2	4.7
G-2-7	58.8	59.3	6.5	6.6	0.6	0.6	1.7	1.7	69.7	68.2	21.1	22.4	3.3	3.1
G-3-12	62.7	61.5	6.2	6.3	0.5	0.5	1.8	2.1	71.1	69.3	20.1	21.6	3.5	3.2
G-3-24	55.4	60.0[b]	6.3	6.1	0.7	0.6	1.4	1.5	71.4	73.1	20.6	18.5	3.5	4.0
G-3-28	65.1	56.2[b]	6.2	6.5	0.5	0.6	2.0	1.8	71.2	71.5	19.6	18.5	3.6	3.9
G-3-3	55.6	53.4	6.2	6.3	0.8	0.7	2.1	2.2	72.0	70.5	18.3	19.3	4.0	3.7
G-3-4	57.5	55.7	5.8	5.6	0.5	0.5	1.7	1.7	67.0	65.7	23.0	25.2[b]	2.9	2.6
G-3-5	58.6	60.6	5.7	5.9	0.5	0.6	2.3	2.5	75.0	78.7[b]	16.5	12.1[b]	4.6	6.6[b]
G-3-65	56.2	48.3[b]	6.0	6.0	0.6	0.6	2.0	1.9	73.5	73.0	17.4	18.1	4.2	4.0
G-3-8	53.6	53.0	6.2	6.2	0.6	0.4[b]	1.7	1.1[b]	76.6	71.4[b]	15.5	19.8[b]	5.0	3.6[b]
G-4-10	61.6	58.7	5.8	5.4	0.5	0.4	2.1	1.9	75.4	78.1	15.3	13.8	5.0	5.7
G-4-3	61.8	54.2[b]	6.5	6.6	0.6	0.5	1.5	1.2	68.9	68.2	22.0	23.1	3.1	3.0
G-5-18	51.8	64.1[b]	6.5	6.2	0.5	0.5	2.0	1.8	71.1	72.5	19.2	18.6	3.7	3.9
G-5-2	54.1	53.5	5.9	6.1	0.4	0.5	2.3	1.4[b]	74.1	77.0[b]	17.0	14.3[b]	4.4	5.4[b]
G-5-25	59.0	60.1	5.9	6.0	0.6	0.5	1.8	1.7	73.2	71.5	17.1	19.4	4.3	3.7
G-6-14	56.9	58.4	5.4	5.5	0.4	0.4	1.5	1.5	75.1	76.7	14.9	15.7	5.1	4.9
G-6-24	58.5	56.2	6.6	6.7	0.6	0.6	2.0	2.4	69.7	69.2	20.3	20.4	3.4	3.4
G-6-39	57.3	60.0[b]	5.6	5.5	0.5	0.5	1.6	1.5	76.4	77.2	14.9	15.0	5.1	5.2
H-1-108	54.6	51.3	6.0	5.9	0.5	0.5	1.9	2.1	71.2	69.9	20.2	20.6	3.5	3.4
H-1-81	55.9	62.6[b]	5.4	5.7	0.5	0.5	2.0	2.0	76.4	76.9	15.0	14.4	5.1	5.3
H-2-111	58.1	59.7	5.8	6.0	0.6	0.6	1.8	1.8	76.0	76.5	15.1	14.5	5.0	5.3
H-3-37	60.3	63.2[b]	5.5	6.0[b]	0.6	0.6	1.7	1.7	76.1	77.4	15.2	14.0	5.0	5.6
H-3-39	60.0	61.5	5.9	5.5	0.5	0.5	1.7	2.2	75.6	76.5	17.1	15.2	4.4	5.1[b]
I-1-95	57.0	63.4[b]	6.4	6.6	0.5	0.5	2.5	1.7[b]	73.1	71.1	17.6	19.2	4.2	3.7
I-2-12	57.0	60.8[b]	6.0	5.9	0.5	0.5	2.0	1.8	70.9	72.1	19.5	19.4	3.6	3.7
I-3-10	56.8	56.9	6.5	6.7	0.5	0.5	2.1	2.1	71.8	71.3	18.3	18.5	3.9	3.9
I-3-11	54.9	54.6	6.1	6.3	0.6	0.6	1.9	1.9	74.8	75.1	16.8	15.9	4.5	4.7
I-3-27	56.2	58.5	5.7	5.8	0.6	0.6	2.3	2.7	78.0	78.1	12.2	12.5	6.4	6.2
I-3-65	50.7	53.0[b]	6.5	6.6	0.5	0.5	1.5	1.7	70.6	71.0	18.5	19.2	3.8	3.7
I-3-67	56.9	59.4	5.6	6.1[b]	0.5	0.5	2.4	2.4	73.9	71.7	17.7	19.0	4.2	3.8

[a] Oil content is given as percentage of kernel dry weight; fatty acid composition is given as percentage of total oil content. [b] Significant difference at $P < 0.01$ between the yearly means of each component for every genotype.

in four different regions (*3*), oil content varied significantly among locations, although no environmental reasons could be given to explain these differences because of the range of important production factors varying at the different sites. The study concluded that only kernel moisture showed no differences for all genotypes at all locations. In spite of this site variability, the environmental stability of oil content depends first on the genotype characteristics (*3*), and the lack of a year effect in our study indicates that oil content in almond shows a high environmental stability. Nevertheless, the significant interaction year × genotype indicates different genotypic behavior in relation to the environment: oil content of 'Cambra' and 'Soleta' was consistently high during the two years, while that of G-3-65 was low.

The study of the fatty acid composition of kernel oil for these genotypes has shown that almond oil has a low concentration of the ensemble of saturated fatty acids (SFA) (palmitic and stearic), intermediate for the polyunsaturated fatty acids (PUFA) (linoleic), and high for MUFAs, especially oleic acid (**Table 2**). In 2002, the values were 5.4−6.9% of the total kernel oil for palmitic acid; 0.3−0.8% for palmitoleic acid; 1.2−2.8% for stearic acid; 63.1−78% for oleic acid; and 12.2−25.7% for

Table 3. Analysis of Variance for Kernel Oil and Fatty Acid Composition for Almond Genotypes Studied in 2002 and 2003[a]

source	df	sum of squares	mean square[b]	F value	P > F
		Oil Content			
genotype	55	1736.74	31.58***	17.08	<0.0001
year	1	0.34	0.34 ns	0.18	0.6702
genotype × year	55	1179.92	21.45***	11.60	<0.0001
error	112	207.1	1.84		
		Palmitic Acid			
genotype	55	29.55	0.54***	4.64	<0.0001
year	1	0.08	0.08 ns	0.71	0.4056
genotype × year	55	8.42	0.15 ns	1.32	0.1071
error	112	12.95	0.11		
		Palmitoleic Acid			
genotype	55	1.45	0.03***	7.29	<0.0001
year	1	0.02	0.02**	5.44	0.0214
genotype × year	55	0.25	0.004 ns	1.25	0.1637
error	112	0.41	0.0036		
		Stearic Acid			
genotype	55	16.82	0.31***	8.73	<.0001
year	1	0.09	0.09 ns	2.47	0.1191
genotype × year	55	5.54	0.10***	2.87	<0.0001
error	112	3.92	0.035		
		Oleic Acid			
genotype	55	2041.28	37.11***	29.89	<0.0001
year	1	14.41	14.41**	11.61	0.0009
genotype × year	55	279.24	5.08***	4.09	<0.0001
error	112	139.04	1.24		
		Linoleic Acid			
genotype	55	1744.03	31.71***	43.34	<0.0001
year	1	1.19	1.19 ns	1.63	0.2039
genotype × year	55	173.36	3.15***	4.31	<0.0001
error	112	81.94	0.73		

[a] Oil content is given as percentage of kernel dry weight; fatty acid composition is given as percentage of total oil content. [b] ns, *, **, ***: not significant or significant at $P < 0.05$. 0.001, 0.0001.

linoleic acid. In 2003, the values were 5−7.1% for palmitic acid; 0.3−0.7% for palmitoleic acid; 1.1−2.7% for stearic acid; 63.4−78.7% for oleic acid; and 12.1−27.1% for linoleic acid. The range of variability of each major fatty acid herein reported agrees with those already reported (*3, 13, 15*).

In almond the most important SFAs are palmitic and stearic acids (*5, 15*). The SFAs give more stability to the fat, but they are considered harmful to the heart and blood vessels (*16*), especially palmitic acid, which is recognized as a major contributor to the buildup of serum cholesterol (*17*). In general the values of this fatty acid are lower than in chestnuts (14−18% (*16*)), and olive (12−21% (*18*)) but higher than in rapeseed oil (3.5−4.5% (*19*)). On the other hand, the most important MUFA in almond was oleic acid (*4, 5*). Recently it has been reported that MUFAs were as effective as PUFAs in the reduction of low-density-lipoprotein cholesterol in humans (*20*), mainly for oleic acid (*2*). All these considerations point out that the use of almond in the human diet is of great benefit to health and nutrition because the fatty acid profile of almonds is very similar to the actual health recommendations for reducing the risk of cardiovascular disease.

Analysis of variance for all fatty acids studied showed significant differences ($P < 0.0001$) among genotypes for all acids, but no significant differences were observed for palmitic, stearic, and linoleic acid composition between the two years (**Table 3**). The year effect has been reported to be significant for all major fatty acids except for palmitoleic acid, and small but significant differences were found among genotypes and production regions for stearic, oleic, and linoleic acids (*3*). In our study, even if the year effect was significant ($P < 0.001$) for the content of oleic acid, most genotypes contained a similar proportion in 2002 as in 2003. Thus, the environmental effect is small on the expression of this trait. This is probably explained, first, by the high correlation coefficient of all the tested genotypes grown at the same location in 2002 and 2003 (**Table 4**), and second, by the lack of significance of the year effect for palmitic, stearic, and linoleic acids and the small effect, although significant, for palmitoleic and oleic acids ($P < 0.0001$). Thus, fatty acid composition in almond primarily depends on the genotype, as previously reported (*4*). In olive oil, fatty acid composition depends primarily on the cultivar (*21*), with a high environmental effect on their expression (*23*).

Some selections (G-2-26, G-3-12, G-3-28, G-1-41, and G-1-58) showed significant differences between the two years (**Table 2**). These fluctuations may explain the significant interaction year × genotype (**Table 3**) and indicate a different genotypic behavior in relation to the environment, as already pointed out in other almond cultivars for different climatic conditions (*3*). In almond, fatty acid metabolism is controlled by a large number of diverse genes that may react differently to these stresses (*23*), as a plant is a biologic entity not behaving mechanically every year (*24*).

The O/L ratio is considered an important criterion to evaluate kernel quality (*7*). This ratio has shown large variability among genotypes because of the high variability in the contents of oleic and linoleic acids (**Table 2**). This ratio was generally slightly higher in 2003 than in 2002. However, although some differences were observed in a number of genotypes, their ranking remained similar (**Figure 1**). Especially interesting were the cultivar 'Cambra' and selections G-4-10, G-6-14, and I-3-27, with a consistently high O/L ratio, probably because of their high oleic acid content.

Due to the high number of selections coming from the cross 'Felisia' × 'Bertina' (36 genotypes), analysis of variance was applied only to these progeny, showing large variability in all fatty acids, as confirmed by the significant differences found among the selections (**Table 5**). Consequently, the variability found in the ensemble of selections is not only inherited from the parents but also due to each genotype. Thus, genotypic and year-to-year variation in the contents of palmitoleic, stearic, and oleic acids suggests that these contents could be under polygenic and environmental control. The same conclusion can be advanced in the case of linoleic acid, even if the year effect was not significant, but the significant genotype × year interaction shows that the content of this acid is also affected by the environmental conditions depending on the genotype. Although the genetic determinism and the transmission of these traits are unknown in almond, in other species, such as peanut (*25*) and sunflower (*26*), it has been reported that fatty acid composition is quantitatively inherited.

The correlation coefficients for all the character combinations showed a high consistency between the years (**Table 4**). The significant positive correlation between the contents of oil and of oleic acid, and the low or negative correlation with the remaining fatty acids, suggest that genotypes tend to accumulate more oleic acid than the other fatty acids. A high oleic acid content is interesting from both the quality and stability points of view, as it increases the nutritional value and the stability of the fat against rancidity. These results agree with those reported in other species (*22*). Especially interesting was the highly significant negative correlation between oleic and linoleic acids (**Table 4**). Correlation coefficients greater than 0.71 or smaller than −0.71 have been suggested to be biologically meaningful (*27*). In the literature it has been reported that the pool of oleic

Table 4. Correlations between Oil Content and the Different Fatty Acid Concentrations in 2002 and 2003 and of the Contents between the Two Years[a]

component	oil content	palmitic acid	palmitoleic acid	stearic acid	oleic acid	correlation between years
oil content	–					**0.37***
palmitic acid 2002	**−0.25***	–				
palmitic acid 2003	−0.23					**0.49***
palmitoleic acid 2002	−0.16	**0.33***	–			
palmitoleic acid 2003	−0.13	**0.45***				**0.73****
stearic acid 2002	0.13	−0.11	**−0.27***	–		
stearic acid 2003	0.16	−0.12	−0.21			**0.41***
oleic acid 2002	**0.28***	**−0.59****	0.07	−0.03	–	
oleic acid 2003	**0.30***	**−0.55****	0.02	−0.02		**0.73****
linoleic acid 2002	−0.08	**0.55****	−0.09	0.03	**−0.96****	
linoleic acid 2003	−0.16	**0.49****	−0.11	0.09	**−0.97****	**0.80****

[a] Correlations shown in boldface type are significant at $P = 0.1$ (*) and 0.01 (**), respectively.

Table 5. Analysis of Variance for Oil Concentration and Different Fatty Acids in Progeny of 'Felisia' × 'Bertina' in 2002 and 2003

source	df	sum of squares	mean square[a]	*F* value	Pr > *F*
		Oil Content			
genotype	35	1131.95	32.34***	23.30	<0.0001
year	1	19.93	19.93**	14.36	0.0003
genotype × year	35	960.34	27.44***	19.77	<0.0001
error	72	99.92	1.38		
		Palmitic Acid			
genotype	35	20.79	0.59***	5.88	<0.0001
year	1	0.01	0.01 ns	0.12	0.7342
genotype × year	35	3.22	0.09 ns	0.91	0.6117
error	72	7.27	0.10		
		Palmitoleic Acid			
genotype	35	1.07	0.03***	7.69	<0.0001
year	1	0.02	0.02*	3.95	0.0408
genotype × year	35	0.13	0.001 ns	0.92	0.6045
error	72	0.285	0.004		
		Stearic Acid			
genotype	35	12.68	0.36***	11.24	<.0001
year	1	0.17	0.17**	5.39	0.0031
genotype × year	35	1.53	0.04 ns	1.35	0.1393
error	72	2.32	0.032		
		Oleic Acid			
genotype	35	1215.81	34.72***	26.31	<0.0001
year	1	79.80	79.80**	60.43	0.0002
genotype × year	35	594.37	16.98***	12.86	<.0001
error	72	95.08	1.32		
		Linoleic Acid			
genotype	35	1041.39	29.75***	37.98	<.0001
year	1	1.16	1.16 ns	1.48	0.2285
genotype × year	35	90.61	2.59***	3.3	<0.0001
error	72	56.41	0.78		

[a] ns, *, **, ***: not significant or significant at $P < 0.05$, 0.01, 0.0001.

acid appears to be controlled by its conversion to linoleic, probably as a result of the enzymatic activity of oleic desaturase. In pistachio, it has been assumed that this enzyme controls the variation in the fatty acids of the nut (*28*).

The great stability of genotype ranking for the O/L ratio during the two years (**Figure 1**) means that in almond it is possible to establish a ranking of cultivars as a function of oleic and linoleic acid concentration and to incorporate this ratio in a selection schedule. The O/L ratio is of great importance in determining oil stability in almond (*7*). Linoleic acid is less saturated and less stable than oleic acid, as shown by the strong negative correlation between linoleic acid content and oil stability in almond (*7*), as well as in pistachio (*28*). The O/L ratio has been increased in peanut (*29*) and olive (*22*) by use of classical breeding methods.

Oil content and fatty acid concentrations of all genotypes were highly correlated between 2002 and 2003 (**Table 4**). These results suggest that the values obtained in one year could be reliable indicators of the values obtained in the following years. This may result in a reduction of the time and, probably, the cost of evaluation in an almond breeding program, as already pointed out in olive (*18, 22*).

The wide variability observed for the concentration of all the fatty acids and the O/L ratio represents a very promising base to obtain new almond cultivars with higher oil quality, as asexual propagation allows the preservation of the most interesting plants once selected. However, further experimentation is needed to clarify the inheritance of fatty acids in almond and to determine the best breeding strategy to generate superior genotypes with optimal added value, in which direction efforts need to be enhanced.

ABBREVIATIONS USED

DW, dry weight; MUFA, monounsaturated fatty acid; FAME, fatty acid methyl ester; SFA, saturated fatty acid; PUFA; polyunsaturated fatty acid; O/L, oleic acid/linoleic acid ratio.

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