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Research Paper

Suitability of Spanish almond cultivars for the industrial production of almond oil and defatted flour

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ABSTRACT

The combined evaluation of almond oils and flours obtained by cold pressing provides a comprehensive approach about the nutritional and industrial interest of Spanish almond cultivars for these production purposes. Almonds of ten different cultivars were collected from the same plot to remove the environmental and agricultural management effects on almond chemical traits. Results show that oil yield was similar for all the selected cultivars, however, obtained oils showed significant differences in their fatty acid profile, including essential fatty acids of main nutritional interest. According to the triglyceride profile, significant differences were found for main tri-unsaturated triglycerides (mainly, OOO and OLL) but not for OLO. The concentration of minor components with health promoting properties also was different in the oil obtained from different cultivars. For the selection of the optimal cultivar for oil production, three parameters are proposed as main parameters to consider: iodine value, oxidative stability and oil yield. According to these parameters, the varieties *Guara, Ferragnes* and *Belona* would be the most appropriate cultivars for almond oil production. Regarding almond flours obtained, large differences were found in the content of available carbohydrates (276.4–156.1 g/kg) and proteins (581.3–379.4 g/kg) resulting in flours with different potential uses. The total mineral content in flours and the presence of specific minerals (as Fe and Zn) also showed significant differences among cultivars.

1. Introduction

The almond (*Prunus dulcis*) is the most important nut in terms of commercial production. Almond tree cultivation is focused mainly in three regions: California, the Mediterranean basin and central Asia – Middle East. Cultivation distribution is limited due to the specific characteristics of hot and dry conditions where the tree produces the highest yields of high quality almonds. Almond production has increased drastically in the last years, from 1,251 billion tons in 2003 to 2,917 billion tons in 2013. The United States and Spain are the larger almond producers, producing, respectively, 43% and 7% of the total almond produced in the last decade (FAO, 2016).

In almond seeds, lipids appear stored in oil droplets (Gallier et al., 2012) and they account from 40 to 67 g/100 g of dry almond weight (Yada et al., 2011). Substantial quantities of triacylglycerol have been reported in almond oil (Martín-Carratalá et al., 1999; Cherif et al., 2004). The proportion of proteins (14–26%) and carbohydrates (2–8%) in the dry almond seed are lower than lipid content, although high variability has been described (Roncero et al., 2016a).

Extensive research has been developed regarding the fatty acid profile of almond oils. Almond oil is mainly composed of mono and di-unsaturated fatty acids (Roncero et al., 2016b). Differences in almond oil fatty acid profile attending to almond origin have been widely described (García-López et al., 1996; Kodad and Socias I Company, 2008; Yada et al., 2011; Maestri et al., 2015). In order of importance, the main fatty acids that appear in almond oil are oleic (50–80%), linoleic (11–37%), palmitic (5–16%) and stearic (1–4%) acids (Askin et al., 2007). Linolenic acid appears in concentrations lower than 0.1% (Maestri et al., 2015) although percentages higher than 11% have been reported in some cultivars (Askin et al., 2007). Almond breeding programs have shown promising results of superior genotypes that could be selected for almond oil production although further work will be needed (Kodad and Socias I Company, 2008; Zhu et al., 2016).

Minor components, as sterols or tocopherols are decisive for almond oil quality (Maestri et al., 2015). Almond oil sterols are almost entirely composed by β-sitosterol (95% of total sterols) and minor concentrations of campesterol and stigmasterol. Previous research found that tocopherol concentration in the Spanish genetic bank varies from 350

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Table 1
Cultivar differences regarding the oil content and oil yield (g/100 g), fatty acid profile and iodine value (I_2V).

Cultivar	Oil content	Oil yield	C18:1	C18:2	C16:0	C18:0	C16:1	I_2V
Antoñeta	55.62^{abc} ± 0.68	32.22 ± 1.51	69.14^{de} ± 0.71	19.57^{cd} ± 0.89	6.72^{b} ± 0.45	3.21^{a} ± 0.15	0.59^{cd} ± 0.04	98.25
Ayles	48.19^{e} ± 1.21	32.78 ± 1.99	65.37^{g} ± 0.56	23.42^{a} ± 1.06	6.95^{b} ± 0.38	2.92^{b} ± 0.12	0.73^{b} ± 0.03	101.98
Belona	56.88^{a} ± 0.62	34.92 ± 1.92	70.99^{bc} ± 0.75	19.87^{bcd} ± 0.81	5.87^{c} ± 0.29	2.47^{cd} ± 0.14	0.55^{d} ± 0.03	100.41
Ferraduel	53.96^{cd} ± 0.24	32.87 ± 2.51	67.52^{ef} ± 0.98	21.47^{b} ± 1.18	6.64^{b} ± 0.04	2.63^{c} ± 0.15	0.70^{b} ± 0.03	100.35
Ferragnes	54.14^{bcd} ± 1.56	33.86 ± 2.92	71.81^{ab} ± 0.89	17.62^{ef} ± 0.97	6.49^{bc} ± 0.32	2.24^{e} ± 0.09	0.81^{a} ± 0.03	97.33
Guara	56.28^{ab} ± 1.62	32.81 ± 1.80	72.99^{a} ± 0.71	16.90^{f} ± 1.19	6.64^{b} ± 0.47	2.54^{c} ± 0.14	0.54^{d} ± 0.03	96.81
Marcona	53.20^{d} ± 1.10	34.65 ± 2.64	67.90^{e} ± 1.10	19.20^{de} ± 0.70	6.36^{bc} ± 0.16	1.97^{f} ± 0.07	0.63^{c} ± 0.02	96.49
Penta	56.18^{ab} ± 1.72	33.73 ± 2.52	65.92^{fg} ± 1.18	23.54^{a} ± 0.40	7.64^{a} ± 0.40	2.28^{de} ± 0.09	0.70^{b} ± 0.03	102.67
Tardona	56.52^{a} ± 0.58	34.62 ± 2.93	70.06^{cd} ± 1.54	20.62^{bcd} ± 1.04	6.55^{b} ± 0.27	1.98^{f} ± 0.11	0.86^{a} ± 0.05	101.25
Vairo	55.65^{abc} ± 1.25	34.19 ± 2.45	68.78^{de} ± 0.72	21.08^{bc} ± 0.62	6.89^{b} ± 0.49	2.24^{e} ± 0.08	0.59^{cd} ± 0.04	100.67
P	***	NS	***	***	***	***	***	

Abbreviations: C16:0, palmitic acid; C16:1, palmitoleic acid; C18:0, stearic acid; C18:1, oleic acid; C18:2, linoleic acid; I_2V, iodine value. Mean values (± standard deviation) of three independent measurements. Different letters on the column indicate significant differences ($p < 0.05$) among cultivars (Duncan test). NS, not significant.
*** Significant at $P < 0.001$.

to 550 mg/kg oil, with major presence of α-tocopherol (Kodad et al., 2014). Differences in the content of tocopherol homologues in almonds grown in Spain and Morocco were found, but total tocopherol content remained (Kodad et al., 2011). The active role of tocopherols in the oil protection against lipid oxidation makes them an important quality parameter in almond oil.

Beyond cultivar effect, other factors such as soil and climate have proven to have influence on almond oil (García-López et al., 1996; Yada et al., 2013; Kodad et al., 2014). The effects of irrigation on almond oil content have also be analyzed, but studies lead to different results, with some finding a significant influence of irrigation supplement on almond oil composition (Schirra and Aggabio, 1989; Sánchez-Bel et al., 2008), while others report opposite results (Egea et al., 2009).

Cultivar selection and the growing region have been reported to have both a significant effect on almond quality and nutritional value (Kodad et al., 2011). Our proposal is the selection of the optimal almond cultivar for production of almond oil and flour considering some of the main cultivars grown in a continental Mediterranean climate in Spain attending to nutritional and industrial production parameters.

2. Materials and methods

2.1. Plant material

Almond seeds were collected at an experimental orchard in the Instituto Técnico Agronómico Provincial of Albacete in the southeast Spain in 2015. Ten different cultivars (*Antoñeta*, *Ayles*, *Belona*, *Ferraduel*, *Ferragnes*, *Guara*, *Marcona*, *Penta*, *Tardona* and *Vairo*) were analysed. One kilogram of almonds were collected from every one of the three trees analyzed within each cultivar. Almonds were picked at the most appropriate harvest date for each cultivar. By considering almond seeds that have all being grown at the same plot, result deviations that could appear on almond oil and flour production due to differences in local environmental conditions (Kodad et al., 2011) or land management, such as irrigation (Sánchez-Bel et al., 2008; Kodad et al., 2011), are controlled. Thus, the observed differences are related to the cultivar effect.

Although almond tree cultivation is mainly concentrated in areas with Mediterranean or Mediterranean type climates, differences in water deficit (Zhu et al., 2015) and temperatures (Kodad et al., 2006) should always be considered, as they have major influence in almond production and characteristics. Analysis on the most adequate almond cultivar for oil and flour production must always be linked to the characteristics of a geographic location.

2.2. Oil extraction

Almonds were cracked and shelled manually in controlled conditions for immediate drying. Moisture was calculated after drying in a desiccation oven for 12 h at 100° C. Three samples for each genotype were processed.

Oil extraction was carried out using a hydraulic press (MECAMAQ Modelo DEVF 80, Vila-Sana, Lleida, Spain) at pressures of 50, 100, 150 and 200 bar with increasing pressure every 5 min (Rabadán et al., 2017a). One kilogram of ground almonds were placed each time on the hydraulic press. After pressing, oil was centrifuged to remove remaining solids. Oil was stored in dark glass bottles at 5° C to avoid degradation until analysis (Rabadán et al., 2017b).

The remaining pressing cake was ground and sieved to obtain a flour with particle size lower than 1 mm.

2.3. Oil and flour analysis

Oxidative stability was evaluated by the Rancimat method (Gutiérrez, 1989). Stability was expressed as the oxidation induction time (hours), measured with the Rancimat 743 apparatus (Metrohm Co., Basel, Switzerland). An oil sample of 3.5 g was used, warmed to 100 °C under an air flow of 10 l h^{-1}.

In order to determine fatty acids composition (%), the methyl-esters were prepared by vigorous shaking of a solution of oil in hexane (0.2 g in 3 ml) with 0.4 ml of 2 N methanolic potassium hydroxide solution, and analysed by GC with a Hewlett-Packard (HP 6890) chromatograph equipped with a FID Detector. A fused silica column (50 m length × 0.25 mm i.d.), coated with SGL-1000 phase (0.25 µm thickness; Sugerlabor), was used. Helium was employed as a carrier gas with a flow through the column of 1 ml min^{-1}. The temperatures of the injector and detector were set at 250 °C with an oven temperature of 210 °C. An injection volume of 1 µl was used (Regulation EEC 2568/91, corresponding to AOCS method Ch 2-91).

Sterols were determined with a Hewlett-Packard (HP 6890) gas chromatograph with a capillary column (25 m length × 0.25 mm i.d.) coated with SGL-5 (0.25 µm thickness; Sugerlabor). Working conditions were as follows: carrier gas, helium; flow through the column, 1.2 ml min^{-1}; injector temperature, 280 °C; detector temperature, 290 °C; oven temperature, 260 °C; injection volume 1 µl (Regulation EEC 2568/91, corresponding to AOCS method Ch 6-91).

The concentration of total polyphenols (ppm) was estimated using the method proposed by Bail et al. (2008) based on the determination of total phenols of oil using the Folin–Ciocalteau colorimetric method. The absorption of the solution was measured on a spectrophotometer Hewlett-Packard 8450 A UV/vis.

The tocopherol content (mg/kg) was analysed by HPLC (model 360, Kontron, Eching, Germany) in accordance with the IUPA2432 method (IUPAC, 1987). 1.5 g oil was dissolved in the mobile phase (10 ml) of 0.5% isopropanol in *n*-hexane. A normal phase column Lichrosphere Si60 (250 mm length, 4.6 mm i.d. and 5 µm particle size) was used with