Performance of Hazelnut Cultivars from Oregon, Italy, and Spain, in Northeastern Spain

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SUMMARY. Eleven hazelnut (*Corylus avellana*) cultivars, four Spanish (Clon La Masó, Negret N-9, Negret Primerenc, and Pauetet), four Italian (San Giovanni, Tonda Italiana, Tonda di Giffoni, and Tonda Romana), and three cultivars from Oregon State University's (OSU) breeding program (Clark, Lewis, and Willamette), were evaluated in northeastern Spain over a period of 15 years (2001–14). The trial was planted at the Institute of Agriculture and Food Research and Technology (IRTA)-Mas de Bover Station (Constantí, Spain) in 2001, using own-rooted material, in single-trunk, 6 × 3.5-m spacing, and fitted with drip irrigation. Tree vigor, sucker production, early bearing, and total crop were recorded during the first 9 years. Nut traits were studied over 7 years and nutritional composition analyzed in 3 years. The best agronomic performance was observed in 'San Giovanni', 'Pauetet', 'Clon La Masó', and 'Tonda Italiana' that scored the highest total crop and canopy volume, but 'San Giovanni' and 'Clon La Masó' produced a high number of suckers. The best industrial value of the kernel was given by 'Tonda di Giffoni', 'Negret N-9', 'Willamette', and 'Clark' with high roasting aptitude and high fat content, although 'Negret N-9' was a little poor in monounsaturated fatty acids. The three cultivars from the Oregon breeding program had good agronomic behavior and industrial potential, but were not an improvement on the traditional Mediterranean cultivars.

Hazelnut production worldwide was more than 700,000 t in 2014. Turkey has the highest production with over 450,000 t, followed by Italy, Georgia, United States, Azerbaijan, China, Islamic Republic of Iran, and Spain. Spanish hazelnut production was about 13,500 t in 2014 (Food and Agriculture Organization of the United Nations, 2017).

The production area in Spain has decreased in the last 10 years, from 20,395 ha in 2004 to 13,591 ha in 2014 (Ministerio de Agricultura y Pesca, Alimentación y Medio Ambiente, 2017), mainly due to a drop in prices. The main Spanish cultivar is 'Negret', planted in 70% of commercial orchards (Tous et al., 2009). In the last 15 years, interesting cultivars from different countries, mainly Italy, have been introduced

in new orchards. Some of these materials have been studied in the cultivar collection at IRTA-Mas de Bover (Garcia et al., 1983; Tous and Rovira, 2004; Tous et al., 1987). However, the research here was to conduct a comparative trial of these Italian cultivars with native Spanish cultivars and cultivars from the main breeding program based at OSU in the United States, from which several cultivars have been released (McCluskey et al., 1997, 2001, 2009; Mehlenbacher, 1995, 2007), most of them with high resistant to eastern filbert blight (*Anisogramma anomala*), the major fungal disease in this country (Thompson et al., 1996).

Hazelnut characteristics vary between cultivars and also according to the environment. Trials assessing cultivars from around the world, in specific climates and soil conditions, have been carried out in different countries: Australia (Baldwin, 2009; Baldwin et al., 2001, 2005), Croatia (Miljkovic, 1994), Chile (Ellena et al., 2014; Grau and Bastias, 2005; Grau et al., 2001), Italy (Baratta et al., 1994; Cristofori et al., 2014), The Netherlands (Wertheim, 1994), Portugal (Santos et al., 1994), Romania (Turcu and Botu, 1997), Slovenia (Solar and Stampar, 1997, 2009), the U.S. (McCluskey et al., 2001, 2005), and Serbia (Miletic et al., 1997). These trials are useful to know the behavior and adaptability of the cultivars in different areas of hazelnut production. The results are important for both researchers and growers because the outcome can help to decide the best cultivars to plant in new orchards. Our results show the performance of the three cultivars from OSU, compared with eight Mediterranean cultivars from Italy (four) and Spain (four), in the same environmental conditions.

Materials and methods

MATERIAL. In 2001, a hazelnut comparative trial was established at IRTA-Mas de Bover, Constantí [Tarragona, northeastern Spain (lat. 41°10'9"N, long. 1°10'28"E, altitude 110 m)], an area with a Mediterranean coastal climate. Over the trial period (2001–14), the average of absolute monthly maximum and minimum temperatures were 26.5 and 4.8 °C, respectively, with 15.8 °C being the average monthly temperature. Average annual rainfall and reference evapotranspiration (Eto) for

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.4047	acre(s)	ha	2.4711
29.5735	fl oz	mL	0.0338
0.3048	ft	m	3.2808
0.0283	ft ³	m ³	35.3147
2.54	inch(es)	cm	0.3937
25.4	inch(es)	mm	0.0394
6.4516	inch ²	cm ²	0.1550
0.4536	lb	kg	2.2046
0.0703	lb/inch ²	kg·cm ⁻²	14.2233
28.3495	oz	g	0.0353
0.9072	ton(s)	t	1.1023
(°F – 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

this period were 579 ± 131 and 1039 ± 31 mm, respectively. The trial was established in a loamy-sandy soil texture (U.S. Department of Agriculture), classified as Typic Xeropsamments (Comisión del Banco de Datos de Suelos y Aguas, 1983). It is an alkaline soil pH (>8), with low organic matter content (1% of 0–50 cm) and medium-high active lime content (>7%), without excess of salinity and low or very low phosphorus and potassium content.

One-year-old rooted plants were propagated by the tie-off layering method and planted at a spacing of 6×3.5 m in a single-trunk system. Trees received fertilizers recommended for this species (Tous et al., 1994), and drip irrigation was calculated each year according the methodology proposed by Allen et al. (1998). Eleven own-rooted cultivars were chosen (Table 1): ‘Clon La Masó’, ‘Negret N-9’ [a clonal IRTA selection (Rovira et al., 2006)], ‘Negret Primerenc’, and ‘Pauetet’ from the Tarragona area in Spain (Tasias,

1975); ‘San Giovanni’, ‘Tonda di Giffoni’, ‘Tonda Romana’ (Manzo and Tamponi, 1982), and ‘Tonda Italiana’ from Italy (this last one, an IRTA selection from Italian material); and ‘Clark’, ‘Lewis’, and ‘Willamette’ from the hazelnut breeding program at OSU (Mehlenbacher et al., 1991, 2000, 2001).

AGRONOMIC CHARACTERISTICS.

The following measurements were evaluated annually over a 9-year period (2003–11): the number of suckers (basal shoots), trunk cross-sectional area [TCSA (square centimeters)] measured at 20 cm above ground level, tree height (centimeters), tree diameter (centimeters), canopy volume (cubic meters), nut yield (kilograms), and yield efficiency (total yield per square centimeter of TCSA) calculated in 2011. This was the year when the trees reached the maximum available space between trees.

NUT CHARACTERISTICS. Several parameters including nut weight (grams), kernel weight (grams), kernel

percentage [(kernel weight/nut weight) $\times 100$], kernel size > 12 mm (percent), and some defects [percent (blanks, shrivel and glassy appearance)] were studied each year of the trial using randomized samples of 100 nuts. These traits were studied during the period 2005–12. The ease of pellicle removal was also evaluated in 2011, following the methodology proposed by Thompson et al. (1978). The index value of pellicle removal (I_2) scores the percentage of kernels with more than 50% of pellicle removed.

KERNEL COMPOSITION AND NUTRITIONAL VALUE. Nutritional value (fat content, crude protein, minerals, crude fiber, total sugar, and fatty acid composition) was analyzed in 3 years (2008, 2013, and 2014).

Moisture content was determined by heating 5 g of sample at 105 °C to constant weight. Fat content was analyzed by the Soxhlet method, using 5–6 g of crushed kernels (with skin) and petroleum ether

Table 1. Description of 11 hazelnut cultivars in a trial planted in 2001, at 6×3.5 -m (19.7×11.48 ft) tree spacing, at the Institute of Agriculture and Food Research and Technology (IRTA)-Mas de Bover Station (Constantí, Spain).

Cultivar	Origin	Growing area	Reported highlights
Clark	U.S. [Oregon State University (OSU) breeding program]	Oregon	High percent kernel, kernels blanch well
Clon La Masó	Spain (Tarragona)	local cultivar	High productivity, round nut, high percent kernel
Lewis	U.S. (OSU breeding program)	Oregon	Earlier maturity
Negret N-9	Spain (Tarragona)	Tarragona	IRTA clonal selection. The major cultivar planted in the Tarragona area. Highly appreciated for industry uses. Kernels blanch very well
Negret Primerenc	Spain (Tarragona)	local cultivar	Similar to ‘Negret’, more productive and fruits mature earlier
Pauetet	Spain (Tarragona)	Tarragona and southwest France	Important in Tarragona area. High productivity. Sometimes the nut is mixed with ‘Negret’ in industry
San Giovanni	Italy	Campania	High productivity, earlier maturity. Well adapted to Tarragona area
Tonda di Giffoni	Italy	Campania	Well adapted to Tarragona area, nut for industry, and table consumption. Kernels blanch well
Tonda Italiana	Italy (IRTA selection from Italian material)	Tarragona	High productivity
Tonda Romana	Italy	Lazio	Appreciated for industrial uses
Willamette	U.S. (OSU breeding program)	Oregon	Good for blanched kernel market. Excellent quality for use in pastries and confectionary

(boiling point 40 to 60 °C) for 7 h in Soxhlet apparatus.

Crude protein was analyzed by the Kjeldahl method 950.48 (Helrick, 1990). The ground sample (1 g) was digested using hot 96% sulfuric acid (H₂SO₄) in a digester (B-426; Büchi, Flawid, Switzerland) coupled to a distiller (B-323, Büchi). Nitrogen is transformed to ammonium ion which was diluted with water and mixed with 35% sodium hydroxide (NaOH) to produce ammonia which is distilled and loaded into an excess of 0.1 N H₂SO₄. Nonreacting sulfuric acid is titred with 0.1 N NaOH using Tashiro's indicator. Protein content was computed using a 6.25 factor.

Crude fiber was measured using 1 g of ground sample by adding boiling 0.26 N H₂SO₄ (30 min) followed by boiling 0.23 N potassium hydroxide (30 min). The extracted residue was dried at 103 °C (3 h) and the dried sample weighed, put in a furnace (550 °C for 3 h), and finally the ashes were weighed.

The mineral fraction was determined by burning 4 g of sample in a furnace at 550 °C for 4 h [AOAC method 942.05 (Helrick, 1990)].

The total sugar content was analyzed using the Luff-Schoorl method. For this, 2.5 g of crushed sample was extracted with ethanol (1 h) and then 5 mL of Carrez I and 5 mL of Carrez II solutions added (1 min each). After ethanol evaporation, the extract was diluted

in 200 mL of warm water to obtain a solution were total sugars after inversion will be analyzed by the Luff-Schoorl method. In essence, this consists of boiling 25 mL of solution for 10 min, adding 10 mL of potassium iodide and 25 mL of 6 N H₂SO₄, and then titrating with 0.1 N sodium thiosulfate solution to neutralize. This value was compared with an equivalent solution, but not boiled.

Fatty acids were analyzed by gas chromatography with flame ionization detector (GC-FID) using a capillary column. The fatty acid methyl esters (FAMES) were prepared by transesterification with KOH, following the official method UNE-EN ISO 5509:2000. FAMES (1 mL) were separated using a gas chromatograph (HP 6890; Agilent Technologies, Barcelona, Spain) equipped with an FID detector and a capillary column [30 m × 0.25 mm i.d. (HP-Innowax, Agilent Technologies)]. The carrier gas was helium and the flow rate was 1 mL·min⁻¹. The injector and detector temperatures were 220 and 275 °C, respectively. The FAME identification was based on retention time relative to those of a standard FAME mixture (Sigma-Aldrich, Madrid, Spain).

STATISTICAL ANALYSIS. For agronomic and nut characteristics, the experimental design was a randomized, complete, block with 11 cultivars, 11 replicates, and 1 tree per

replicate and treatment. For nutritional values and oil composition, the experimental design was as previously mentioned, but with two replicates, one tree per replicate, and treatment for 3 years.

Analysis of variance and principal component analysis (PCA) were performed on data sets using SAS (version 9.2; SAS Institute, Cary, NC). Mean separation was using Duncan's multiple range test ($P \leq 0.05$).

Results and discussion

AGRONOMIC CHARACTERISTICS. Significant differences were found in all parameters assessed. 'Willamette' and 'Pauetet' were notable for the low number of suckers (3.4 and 4.7 suckers/tree per year, respectively). In contrast, the Italian cultivar Tonda Romana had the highest number of suckers during the years of the study (Table 2), as has been previously observed (Radicati et al., 1994). Sucker production is important in orchard management. With mechanization of cultural practices in modern orchards, the presence of suckers is a problem requiring four to five herbicide sprays per year and hand removal in winter (Tous et al., 2009). Cultivars with low sucker production are desirable in new orchards, also to reduce the environmental impact and the labor cost.

Referring to trunk cross section (square centimeters), tree height (centimeters), tree diameter (centimeters),

Table 2. Sucker production, trunk cross-sectional area (TCSA), tree height, tree diameter, and canopy volume of 11 hazelnut cultivars planted in 2001, at 6 × 3.5-m (19.7 × 11.48 ft) tree spacing, at the Institute of Agriculture and Food Research and Technology (IRTA)-Mas de Bover Station (Constantí, Spain).

Cultivar	Suckers 2003–11 (no./yr) ^z	TCSA 2011 (cm ²) ^y	Tree ht 2011 (cm) ^x	Tree diam 2011 (cm)	Canopy vol 2011 (m ³) ^x
Clark	6.6 efg ^w	149.8 ab	332.7 bc	359.1 de	22.9 cd
Clon La Masó	9.9 cd	178.7 a	292.7 de	410.9 ab	26.0 bc
Lewis	11.3 bc	107.4 bc	308.8 cd	350.0 de	19.8 def
Negret N-9	12.5 b	121.3 b	270.9 e	351.8 de	17.6 ef
Negret Primerenc	9.5 cd	72.5 c	239.0 f	346.0 e	15.1 f
Pauetet	4.7 fg	157.5 ab	343.0 b	410.0 ab	30.4 b
San Giovanni	11.5 bc	192.5 a	381.8 a	430.5 a	37.4 a
Tonda di Giffoni	6.7 ef	182.4 a	320.9 bc	354.1 de	21.2 cde
Tonda Italiana	7.8 de	157.4 ab	287.0 de	378.0 cd	21.5 cde
Tonda Romana	17.1 a	155.8 ab	294.6 de	340.0 e	18.0 def
Willamette	3.4 g	125.8 b	280.9 e	389.1 bc	22.8 cd

^zMean number of suckers produced per year.

^yTCSA measured at 20 cm (7.9 inches) above the ground level; 1 cm² = 0.1550 inch².

^x1 cm = 0.3937 inch, 1 m³ = 35.3147 ft³.

^wMeans within a column followed by the same letter are not significantly different by Duncan's multiple range test at $P \leq 0.05$.

and canopy volume (cubic meters) in 2011, the Italian cultivar San Giovanni had the highest values, with good agronomic behavior in the Tarragona climatic conditions. Previous studies have shown good performance for this cultivar in this area (Tous and Rovira, 2004). The Spanish native cultivars Negret N-9 and Negret Primerenc had the lowest values. It is known that these cultivars are very sensitive to calcareous soils (Tous et al., 2009), the type of soil in which the trial was planted.

Early bearing (years 3–5 cumulative yield after planting) was also evaluated (Table 3). For this parameter,

‘San Giovanni’ stood out, significantly, for the high yield (near 7 kg in the period 2003–05). Significant differences were also observed for the cumulative yield (2003–11). ‘San Giovanni’ had the highest values (39.7 kg/tree), followed by ‘Tonda Italiana’, ‘Pauetet’, and ‘Clon La Masó’. Cultivars with low cumulative yield were ‘Tonda’ ‘Romana’, ‘Negret Primerenc’, and ‘Willamette’.

Cumulative yield efficiency, measured as total crop from 2003 to 2012 per trunk cross section at year 2011, was highest for the less vigorous trees. ‘Negret Primerenc’, ‘Tonda Italiana’,

and ‘Lewis’ had the best yield efficiency (near 0.28 kg·cm⁻²).

NUT CHARACTERISTICS. Significant differences between cultivars were found in all nut characteristics studied (Table 4). ‘Tonda di Giffoni’ had the highest kernel weight (1.26 g), while the Spanish ‘Negret N-9’, ‘Negret Primerenc’, and ‘Pauetet’ had the smallest nuts and kernels, suitable for industrial processing (Germain and Sarraquigne, 2004; Romero et al., 1997). Two cultivars had high kernel percentage (Clark and Clon La Masó), both with a very thin shell. ‘Tonda di Giffoni’ stood out for the kernel size, with 91.43% of

Table 3. Early bearing, cumulative yield, and yield efficiency of 11 hazelnut cultivars planted in 2001, at 6 × 3.5-m (19.7 × 11.48 ft) tree spacing, at the Institute of Agriculture and Food Research and Technology (IRTA)-Mas de Bover Station (Constantí, Spain).

Cultivar	Cumulative early bearing 2003–05 (kg/tree) ^z	Cumulative total yield 2003–12 (kg/tree) ^y	Cumulative yield efficiency 2003–12 (kg·cm ⁻² TCSA) ^x
Clark	3.45 d ^w	24.52 cd	0.17 cd
Clon La Masó	6.14 ab	34.59 b	0.21 bc
Lewis	4.87 c	26.49 c	0.27 a
Negret N-9	2.90 d	21.48 de	0.20 c
Negret Primerenc	2.92 d	19.45 e	0.28 a
Pauetet	5.30 bc	35.01 b	0.24 ab
San Giovanni	6.74 a	39.72 a	0.21 bc
Tonda di Giffoni	2.98 d	23.92 cd	0.14 de
Tonda Italiana	5.43 bc	37.24 ab	0.28 a
Tonda Romana	1.70 e	19.59 e	0.15 de
Willamette	2.91 d	13.99 f	0.12 e

^zTotal crop per tree from 2003 to 2005; 1 kg = 2.2046 lb.

^yTotal crop per tree from 2003 to 2012.

^xTotal crop per tree from 2003 to 2012 related to trunk cross-sectional area (TCSA), measured at 20 cm (7.9 inches) above the ground level, at the end of the year 2011; 1 kg·cm⁻² = 14.2233 lb/inch².

^wMeans within a column followed by the same letter are not significantly different by Duncan's multiple range test at $P \leq 0.05$.

Table 4. Nut and kernel weight, kernel percentage, kernel size [>12 mm (0.47 inch)], defects, and roasting, of 11 hazelnut cultivars planted in 2001, at 6 × 3.5-m (19.7 × 11.48 ft) tree spacing, at the Institute of Agriculture and Food Research and Technology (IRTA)-Mas de Bover Station (Constantí, Spain). Mean values from 2005 to 2012.

Cultivar	Nut wt (g) ^z	Kernel wt (g)	Kernel percentage (%) ^y	Kernels >12 mm (%)	Defects (%) ^x	Roasting I_2 2011 (%) ^w
Clark	2.25 d ^v	1.15 c	50.86 a	88.70 ab	9.38 b	97 a
Clon La Masó	2.15 e	1.11 d	51.46 a	88.34 b	8.49 b	21 e
Lewis	2.31 d	1.07 e	46.34 f	75.67 c	9.78 ab	80 ab
Negret N-9	2.01 f	0.99 f	49.14 c	54.55 e	7.77 b	97 a
Negret Primerenc	1.86 g	0.92 g	49.52 c	28.16 f	8.49 b	91 ab
Pauetet	2.05 f	1.01 f	49.07 c	76.27 c	7.59 b	73 bc
San Giovanni	2.28 d	1.09 de	47.26 e	63.20 d	11.91 a	53 d
Tonda di Giffoni	2.72 b	1.26 a	46.14 f	91.43 a	9.97 ab	95 a
Tonda Italiana	2.78 a	1.07 e	38.21 g	76.33 c	9.36 b	90 ab
Tonda Romana	2.48 c	1.17 c	46.96 e	89.18 ab	7.67 b	60 cd
Willamette	2.47 c	1.20 b	48.27 d	84.82 b	8.82 b	90 ab

^z1 g = 0.0353 oz.

^y(kernel weight/nut weight) × 100.

^xBlanks, shrivel and glassy appearance kernels.

^w I_2 = percentage of kernels with more than 50% of pellicle removed (Thompson et al., 1978).

^vMeans within a column followed by the same letter are not significantly different by Duncan's multiple range test at $P \leq 0.05$.

nuts >12 mm. The results of the nut characteristics for ‘Negret N-9’, ‘San Giovanni’, ‘Tonda di Giffoni’, and ‘Tonda Romana’ were similar to those proposed by other authors (Cristofori et al., 2008; Manzo and Tamponi, 1982) for the same cultivars. However, values of nut and kernel weight of ‘Tonda di Giffoni’ and ‘Tonda Romana’ were higher than those reported by Farinelli et al. (2001) in Umbria (Italy), but lower than those observed by Ciarniello et al. (2014). Nut traits for ‘Clark’ were in agreement with the results obtained

by Germain and Sarraquigne (2004) and Mehlenbacher et al. (2001). The characteristics of ‘Pauetet’ and ‘Willamette’ were also similar to those proposed by Germain and Sarraquigne (2004) and McCluskey et al. (2005), respectively. However, values of nut and kernel weight and kernel percentage of ‘Lewis’ were lower than those proposed for that cultivar by Germain and Sarraquigne (2004) and Mehlenbacher et al. (2000). Results of nut weight and kernel percentage of the three cultivars from the OSU hazelnut breeding program (Clark,

Lewis and Willamette) were similar to those obtained by Solar and Stampar (2009) in a trial with cultivars from Oregon in north-eastern Slovenia.

Three cultivars, Negret N-9, Tonda di Giffoni, and Clark, were outstanding for their ease of pellicle removal after roasting. The I_2 calculated values, were, for all of them, higher than 94%. ‘Willamette’ also scored a high value, according to Mehlenbacher et al. (1991), but in disagreement with observations of Ciarniello et al. (2014). This is an

Table 5. Nutritional composition of 11 hazelnut cultivars ($n = 6$), planted in 2001, at 6×3.5 -m (19.7×11.48 ft) tree spacing, at the Institute of Agriculture and Food Research and Technology (IRTA)-Mas de Bover Station (Constantí, Spain). Mean values from crops 2008, 2013, and 2014.

Cultivar	Minerals (%)	Fat content (% db) ^z	Crude fiber (%)	Crude protein (%)	Total sugars (%)
Clark	2.54	65.28 bc ^y	7.84	17.54	4.76 a
Clon La Masó	2.71	64.85 c	8.29	18.38	7.08 bc
Lewis	2.47	66.34 abc	6.94	17.93	4.51 abc
Negret N-9	2.60	67.45 abc	7.69	16.05	3.89 c
Negret Primerenc	2.54	68.36 a	7.46	16.78	3.93 c
Pauetet	2.46	66.29 abc	7.03	17.52	4.62 ab
San Giovanni	2.76	67.10 abc	7.15	17.85	3.86 c
Tonda di Giffoni	2.46	68.02 a	8.08	15.90	3.89 c
Tonda Italiana	2.43	67.57 ab	7.37	17.53	3.94 c
Tonda Romana	2.40	67.08 abc	7.52	17.10	4.06 bc
Willamette	2.51	66.81 abc	7.21	17.13	4.34 abc
ANOVA ($P > F$)					
Cultivar	0.0721	0.0485	0.8414	0.2220	0.0411
Year	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Cultivar $\times$ Year	0.0888	0.0410	0.4186	0.2843	0.0034

^zdb = dry basis.

^yMeans within a column followed by the same letter are not significantly different by Duncan’s multiple range test at $P \leq 0.05$.

Table 6. Major fatty acid composition (%) of 11 hazelnut cultivars ($n = 6$) planted in 2001, at 6×3.5 -m (19.7×11.48 ft) tree spacing, at the Institute of Agriculture and Food Research and Technology (IRTA)-Mas de Bover Station (Constantí, Spain). Mean values from crops 2008, 2013, and 2014.

Cultivar	Major fatty acid composition (%) ^z							PUFA
	C16:0	C18:0	C18:1	C18:2	SAT	INSAT	MUFA	
Clark	5.88 ab ^y	1.73 bc	79.77 bc	11.79 bc	8.34	92.17	80.29 bc	11.88 bc
Clon La Masó	6.11 a	1.98 ab	78.29 c	12.78 b	9.17	91.66	78.79 c	12.87 b
Lewis	5.63 bc	1.73 bc	80.81 abc	11.04 bc	7.58	92.42	81.29 abc	11.12 bc
Negret N-9	5.51 bc	1.78 abc	78.79 c	11.78 bc	9.17	90.83	78.98 c	11.86 bc
Negret Primerenc	8.77 abc	1.58 c	75.64 d	16.24 a	7.87	92.43	76.13 d	16.31 a
Pauetet	5.78 abc	1.76 bc	80.93 abc	10.71 bc	7.77	92.23	81.44 abc	10.79 bc
San Giovanni	5.49 bc	1.51 c	79.48 bc	12.71 b	7.20	92.80	79.99 bc	12.80 b
Tonda di Giffoni	5.43 c	2.00 ab	82.08 ab	9.74 bc	7.65	92.35	82.53 ab	9.82 bc
Tonda Italiana	5.63 bc	1.90 ab	82.71 a	8.98 c	7.77	92.23	83.18 a	9.05 c
Tonda Romana	6.08 a	1.99 ab	80.89 abc	10.25 bc	8.29	91.70	81.37 abc	10.33 bc
Willamette	5.77 abc	2.06 a	82.04 ab	9.32 bc	8.07	91.93	82.53 ab	9.40 bc
ANOVA ($P > F$)								
Cultivar	0.0021	0.0007	<0.0001	0.0032	0.5167	0.5167	<0.0001	0.0033
Year	<0.0001	0.3028	<0.0001	<0.0001	0.8780	0.8780	<0.0001	<0.0001
Cultivar $\times$ Year	0.0579	0.0865	0.0003	0.0234	0.8252	0.8252	0.0003	0.0233

^zC16:0 = palmitic acid; C18:0 = stearic acid; C18:1 = oleic acid; C18:2 = linoleic acid; SAT = saturated fatty acids; INSAT = unsaturated fatty acids; MUFA = monounsaturated fatty acids; PUFA = polyunsaturated fatty acids.

^yMeans within a column followed by the same letter are not significantly different by Duncan’s multiple range test at $P \leq 0.05$.

Table 7. Minor fatty acids composition (%) of 11 hazelnut cultivars ($n = 6$) planted in 2001, at 6×3.5 -m (19.7×11.48 ft) tree spacing, at the Institute of Agriculture and Food Research and Technology (IRTA)-Mas de Bover Station (Constantí, Spain). Mean values from crops 2008, 2013, and 2014.

Cultivar	Minor fatty acid composition (%) ^z						
	C14:0	C16:1	C17:0	C17:1	C18:3	C20:0	C20:1
Clark	0.038 a ^y	0.280 a	0.037	0.073	0.082 bc	0.110 b	0.165 a
Clon La Masó	0.037 ab	0.261 ab	0.041	0.076	0.089 ab	0.120 ab	0.161 ab
Lewis	0.034 abcd	0.238 bc	0.038	0.075	0.080 bc	0.110 b	0.167 a
Negret N-9	0.031 d	0.243 b	0.037	0.072	0.075 c	0.112 b	0.172 a
Negret Primerenc	0.032 cd	0.257 ab	0.035	0.072	0.074 c	0.097 c	0.160 ab
Pauetet	0.032 cd	0.272 a	0.038	0.070	0.076 c	0.120 ab	0.168 a
San Giovanni	0.026 e	0.277 a	0.033	0.073	0.092 a	0.093 c	0.165 a
Tonda di Giffoni	0.025 e	0.217 c	0.040	0.073	0.078 c	0.113 b	0.160 ab
Tonda Italiana	0.033 bcd	0.242 b	0.040	0.075	0.072 c	0.108 b	0.158 ab
Tonda Romana	0.034 abcd	0.280 ab	0.040	0.072	0.077 c	0.112 b	0.150 b
Willamette	0.036 abc	0.243 b	0.040	0.077	0.078 c	0.128 a	0.168 a
ANOVA ($P > F$)							
Cultivar	<0.0001	0.0002	0.0712	0.6098	0.0009	<0.0001	0.0349
Year	<0.0001	0.0015	0.0707	0.0002	<0.0001	<0.0001	<0.0001
Cultivar $\times$ Year	0.1237	0.0471	0.7689	0.6091	0.0293	0.0862	0.0275

^zC14:0 = myristic acid; C16:1 = palmitoleic acid; C17:0 = margaric acid; C17:1 = marganoleic acid; C18:3 = linolenic acid; C20:0 = arachidic acid; C20:1 = gadoleic acid.

^yMeans within a column followed by the same letter are not significantly different by Duncan's multiple range test at $P \leq 0.05$.

interesting trait for industrial processing (Di Matteo et al., 2012). Referring to kernel defects, few significant differences between cultivars were observed.

In trials on hazelnut cultivar performance, Tonda di Giffoni has been showed to have the widest adaptability of the genotypes evaluated in southeastern Australia (Baldwin, 2009; Baldwin et al., 2005) and the southeastern region of Slovenia (Solar and Stampar, 1997). Adaptability of this Italian cultivar in our conditions was also good. In the last 15 years, most of the new hazelnut orchards in Tarragona area have Tonda di Giffoni as the main cultivar (M. Rovira, unpublished data).

NUTRITIONAL VALUES AND OIL COMPOSITION. Differences between cultivars were observed for fat and total sugar contents (Table 5). In addition, a major influence of the year was observed for all the compounds, and the interaction with cultivar was less meaningful. In the sense that no crossed effects were observed and only in one of the years the relative differences between cultivars were higher than in the others. Fat content ranged from 64.85% dry basis (db) in 'Clon La Masó' to 68.36% db in 'Negret Primerenc'. These values are generally higher than those reported elsewhere (Cristofori et al., 2008; Parcerisa et al., 1995; Tous et al.,

Fig. 1. Eigenvectors (left) from principal component (PC) analysis for hazelnut nutritional value (circle denotes correlation = 1). Biplot (right) of two first PCs for nutritional value [first PC (PRIN1) in the horizontal axis retains 32% of total variability; second PC (PRIN2) in the vertical axis explains 28%].

2001), even though relative differences between cultivars are the same, but the fat content of 'Tonda Romana' and 'Tonda di Giffoni' were slightly lower than those published by Farinelli et al. (2001).

Total sugars content ranged from 3.86% in 'San Giovanni' to 7.08% in 'Clon La Masó'. Relative differences between the cultivars were equivalent to those reported by Cristofori et al. (2008), but the mean values were lower in our study.

Fatty acid composition (Tables 6 and 7) was significantly different, depending on the cultivar and the characteristics of the year. Interaction cultivar $\times$ year was significant for many compounds, but did not affect the mean value of each cultivar because these values were more related to the fact that variations between years were higher in some cultivars. For instance, the group of Spanish cultivars (Clon La Masó, Negret N-9, Negret Primerenc, and

Pauetet) had up to 10% variation in oleic acid content between years, while the other cultivars only varied 5% to 7%. The cultivar richest in polyunsaturated fatty acids (PUFAs) was Negret Primerenc (16.31%) while 'Tonda Italiana' was the poorest (9.05% in average). In general, PUFA had the highest variability with 23% of CV, while minor fatty acids were less variable (lower than 10% CV), although there were some significant differences between cultivars and years for these compounds (Table 6). The observed values were very similar to those reported by Cristofori et al. (2008), Farinelli et al. (2001), Parcerisa et al. (1995), and Tous et al. (2001).

No differences between cultivars were observed for mineral content, crude fiber, or crude protein, although there were significant variations between years.

PCA showed (Fig. 1) that the main differences in nutritional composition between the studied cultivars was related to fatty acid composition: PUFA and MUFA, which are highly correlated to first principal component (PRIN1), crude protein content, correlated to positive values of second principal component (+PRIN2) and fat content, and correlated to negative values of second principal component (-PRIN2). Four different groups with a similar composition could be highlighted: the "Negret" group ('Negret N-9', 'Negret Primerenc'); "Tonda" group ('Tonda di Giffoni', 'Tonda Italiana', 'Tonda Romana'); a third group with 'Lewis', 'Pauetet', and 'Willamette'; and the last group with 'Clark', 'Clon La Masó', and 'San Giovanni'.

Conclusions

Results obtained in this hazelnut trial revealed interesting behavior of different cultivars in northeastern Spain. The best agronomic performance was observed in 'San Giovanni', 'Pauetet', 'Clon La Masó', and in 'Tonda Italiana' scoring the highest total crop and canopy volume, even though 'San Giovanni' and 'Clon La Masó' produce a high number of suckers. According to fruit traits, the kernels with the best industrial value were those of 'Tonda di Giffoni', 'Negret N-9', 'Willamette', and 'Clark' with high roasting aptitude and high fat content, even though

'Negret N-9' is a little poor in MUFA. The studied hazelnut cultivars from Oregon had good agronomic behavior and industrial potential, but were no better than the traditional Mediterranean cultivars.

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