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

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Additional Index Words. Corylus avellana, kernel quality, vigor, early bearing, sucker production, fatty acids, nutritional value

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 (Constant, 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 Gifoni’, ‘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. 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 Gifoni’, ‘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.

Materials and methods

Material. In 2001, a hazelnut comparative trial was established at IRITA-Mas de Bover, Constanti [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

| 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         | ft³                                | m³        | 0.3514  |
| 2.54           | inch(es)                           | cm        | 0.3937  |
| 25.4           | inch(es)                           | mm        | 0.0394  |
| 6.4516         | inch²                              | cm²       | 0.1550  |
| 0.4536         | lb                                 | kg        | 2.2046  |
| 0.0703         | lb/inch²                           | 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 |

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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 de Sueldos 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) × 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 (I2) 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

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**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 (Constanti, 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.            |
| Negret Primerenc | Spain (Tarragona)                                | local cultivar        | Highly appreciated for industry uses. Kernels blanch very well                      |
| Pauetet        | Spain (Tarragona)                                | Tarragona and southwest France | Similar to ‘Negret’, more productive and fruits mature earlier                      |
| San Giovanni   | Italy                                            | Campania              | Important in Tarragona area. High productivity, earlier maturity.                   |
| Tonda di Giffoni | Italy                                              | Campania              | Well adapted to Tarragona area, High productivity, mixed with ‘Negret’ in industry  |
| Tonda Italiana | Italy (IRTA selection from Italian material)      | Tarragona             | Well adapted to Tarragona area, nut for industry, and table consumption.            |
| 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, Flawil, 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 titrated 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 580 °C for 4 h [AOAC method 942.05 (Helrick, 1990)].

The total sugar content was analyzed using the Luff–School 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–School 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 x 0.25 mm i.d. (HP-Innovax, 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).

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 (Constanti, Spain).

| Cultivar            | Suckers 2003–11 (no./yr)* | TCSA 2011 (cm²)  | Tree ht 2011 (cm)  | Tree diam 2011 (cm)  | Canopy vol 2011 (m³)  |
|---------------------|--------------------------|------------------|-------------------|---------------------|-----------------------|
| Clark               | 6.6 cd                    | 149.8 ab         | 327.2 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         | 434.0 b           | 410.0 ab            | 30.4 b                |
| San Giovanni        | 11.5 bc                   | 192.5 a          | 881.8 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               |

*Mean number of suckers produced per year.

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

‡1 cm = 0.3937 inch, 1 m³ = 35.3147 ft³.

§Means within a column followed by the same letter are not significantly different by Duncan’s multiple range test at P ≤ 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-sectional area 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 (Constanti, Spain).

| Cultivar     | Cumulative early bearing 2003–05 (kg/tree) | Cumulative total yield 2003–12 (kg/tree) | Cumulative yield efficiency 2003–12 (kg cm⁻² TCSA) |
|--------------|-------------------------------------------|-----------------------------------------|-----------------------------------------------|
| Clark        | 3.45 d                               | 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 c                                | 19.59 e                                 | 0.15 de                                       |
| Willamette   | 2.91 d                                | 13.99 f                                 | 0.12 e                                        |

*Total crop per tree from 2003 to 2005; 1 kg = 2.2046 lb.

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 (Constanti, Spain). Mean values from 2005 to 2012.

| Cultivar          | Nut wt (g)* | Kernel wt (g) | Kernel percentage (%) | Kernels >12 mm (%) | Defects (%) w | Roasting I² 2011 (%) w |
|-------------------|-------------|---------------|-----------------------|--------------------|---------------|------------------------|
| Clark             | 2.25 d      | 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 c                   |
| 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 c               | 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                  |

*1 g = 0.0353 oz.

*1 (kernel weight/nut weight) × 100.

*Blanks, shrivel and glassy appearance kernels.

*I² = percentage of kernels with more than 50% of pellicle removed (Thompson et al., 1978).

*Means within a column followed by the same letter are not significantly different by Duncan’s multiple range test at P ≤ 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 northeastern Slovenia.

Three cultivars, Negret N-9, Tonda di Giffoni, and Clark, were outstanding for their ease of pellicle removal after roasting. The 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

| Cultivar          | Minerals (%) | Fat content (% db) | Crude fiber (%) | Crude protein (%) | Total sugars (%) |
|-------------------|--------------|--------------------|-----------------|-------------------|-----------------|
| Clark             | 2.54         | 65.28 bc         | 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 x Year | 0.0888 | 0.0410 | 0.4186 | 0.2843 | 0.0034 |

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

| Cultivar          | Major fatty acid composition (%) | C16:0 | C18:0 | C18:1 | C18:2 | SAT | INSAT | MUFA | PUFA |
|-------------------|---------------------------------|-------|-------|-------|-------|-----|-------|------|------|
| Clark             | C16:0 | 5.88 ab | 1.73 bc | 79.77 bc | 11.79 bc | 8.34 | 92.17 | 80.29 bc | 11.88 bc |
|                   | C18:0 | 6.11 a  | 1.98 ab | 78.29 c  | 12.78 b  | 9.17 | 91.66 | 78.79 c  | 12.87 b  |
|                   | C18:1 | 5.63 bc | 1.73 bc | 80.81 abc | 11.04 bc | 7.58 | 92.42 | 81.29 abc | 11.12 bc |
|                   | C18:2 | 5.51 bc | 1.78 bc | 78.79 c  | 11.78 bc | 9.17 | 90.83 | 78.98 c  | 11.86 bc |
|                   | SAT  | 8.77 abc | 1.58 c  | 75.64 d  | 16.24 a  | 7.87 | 92.43 | 76.13 d  | 16.31 a  |
|                   | INSAT| 5.78 abc | 1.76 bc | 80.93 abc | 10.71 bc | 7.77 | 92.23 | 81.44 abc | 10.79 bc |
|                   | MUFA | 5.49 bc | 1.51 c  | 79.48 bc | 12.71 b  | 7.20 | 92.80 | 79.99 bc | 12.80 b  |
|                   | PUFA | 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 | 0.0001 | <0.0001 | 0.0032 | 0.5167 | 0.5167 | <0.0001 | 0.0033 |
| Year     | <0.0001 | 0.0328 | <0.0001 | 0.8780 | 0.8780 | <0.0001 | <0.0001 |
| Cultivar x Year | 0.0579 | 0.0865 | 0.0003 | 0.2825 | 0.2825 | 0.0003 | 0.0233 |

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

C16:0 = 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.

Means within a column followed by the same letter are not significantly different by Duncan’s multiple range test at P ≤ 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 Mas’ 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., 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.

Fat acid composition (Tables 6 and 7) was significantly different, depending on the cultivar and the characteristics of the year. Interaction cultivar × 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...
Giovanni’ and ‘Clon La Mas’ observed in ‘San Giovanni’, ‘Pauetet’, and ‘Willamette’, the kernels with 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 Primerec’), “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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