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Effect of shading in different periods from flowering to maturity on the fatty acid and phenolic composition of olive oil (cv. Arbequina)

Georgina Lémole[a,*], Antonio M. Weibel[b], Eduardo R. Trentacoste[b]

[a] Estación Experimental Agropecuaria San Juan INTA (Instituto Nacional de Tecnología Agropecuaria), 11 y Vidart, 5427, Villa Aberastain, San Juan, Argentina

[b] Estación Experimental Agropecuaria Junín, INTA (Instituto Nacional de Tecnología Agropecuaria), Carril Isidoro Busquets, La Colonia, 5573, Junín, Mendoza, Argentina

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ABSTRACT

In olive there is insufficient information about how radiation changes throughout different growing periods affect oil quality. The present three-season study was conducted on an 'Arbequina' orchard. In addition to control trees without shading (WS), four other treatments were applied to reduce solar radiation penetration to 50%: continuous shading throughout the experimental period (TS), shading from budbreak to fruit set (S1), from fruit set to pit hardening (S2), and from pit hardening to budbreak in the following season (S3). Shaded tree fruits from pit hardening to harvest had a lower maturity index and higher fruit production than the rest of the shading treatments. Free acidity and peroxide indexes were higher in S2 than in WS. Oleic acid was highest in oil from TS. Higher oleic acid content was found in S1 and S2 compared to S3 and WS. Linoleic and linolenic acids showed an inverse pattern to oleic acid. Phenol content was affected by reduced radiation in S2. Radiation reduction immediately after pit hardening was critical on fruit maturity, and indirectly, on the fatty acid and polyphenol content profile. Orchard design and subsequent canopy management should focus on improving canopy illumination during S1 and S2 where shading reduced both fruit production and oil quality. Shading in S3 markedly reduced oil quality but not fruit production.

1. Introduction

Recent expansion of olive production outside the Mediterranean Basin has provided the possibility of testing olive oil production responses to a wide range of environmental conditions such as solar radiation (Cherbiy-Hoffmann et al., 2012), water availability (Agüero-Alcaras et al., 2016), and temperature (García-Inza et al., 2014). Radiation plays a major role on fruit growth and oil synthesis. In olive trees, studies that relate incident radiation to fruit growth and oil content are recent. Acebedo et al. (2000) in isolated olive trees (cv. Arbequina), and Gómez-del-Campo et al. (2009) and Trentacoste et al. (2015) in olive narrow hedgerows (cv. Arbequina) found that fruits developed in the most illuminated canopy positions presented greater weight and oil content compared to fruits in less illuminated positions. Radiation intercepted by leaves produces assimilates that act as substrate in oil biosynthesis within fruits; consequently, the reduction of radiation intercepted by the canopy directly affects fruit oil synthesis (Connor et al., 2016). Many studies focus on the relationship between radiation and oil biosynthesis (Agüero-Alcaras et al., 2016; Cherbiy-Hoffmann et al., 2012; Trentacoste et al., 2016), but the influence of irradiance on oil quality parameters are scarce.

Olive fruits are characterized by two rapid growth stages (Periods I and III) separated by a period of slow growth (Period II) (Sozzi, 2007). During Period I (after fruit set) intense multiplication and division of mesocarp cells occurs (Manrique et al., 1999). In this phase, seed development and rapid fruit growth take place due to both cell division and enlargement. In Period II, the endocarp is hardened and the mesocarp grows slowly. Period III is mainly characterized by cell expansion of the mesocarp and intense oil accumulation (Conde et al., 2008). At the end of Period III, fruit maturity takes place, mesocarp growth ceases, and decomposition of cell membranes begins.

Fruit oil synthesis and accumulation begins when pit hardening has ended (Lavee and Wodner, 1991). However, recent studies have shown that lipid body formation in mesocarp cells and pit hardening occur simultaneously (Matteucci et al., 2011). Similarly, Bartolini et al. (2014) showed lower lipid body number in the fruits of shaded olive trees prior to pit hardening compared to unshaded trees. García-Inza et al. (2014) found that fruits exposed to high temperatures before pit hardening showed reduced fruit oil content at maturity. Additionally, there is a small oil contribution during fruit maturation (Rondanini et al., 2012). The changes in fruit chemical composition, such as fatty acid profile and phenol content, take place during period III (Rotondi

* Corresponding author.
E-mail address: lemole.georgina@inta.gob.ar (G. Lémole).

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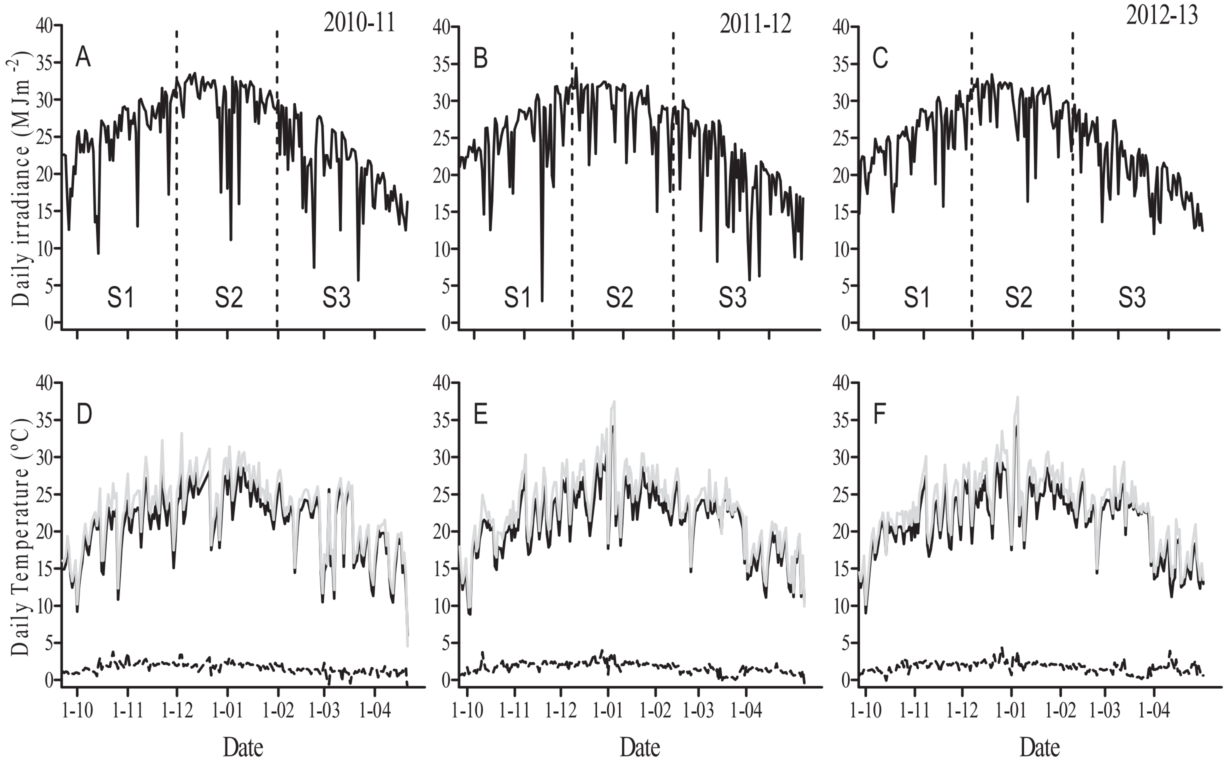

Fig. 1. Upper panels show the variation of daily irradiance during 2010–2011 (A), 2011–2012 (B), and 2012–2013 (C) study seasons. Vertical dotted lines indicate the three shading periods applied: S1 from budbreak to fruit set, S2 from fruit set to pit hardening, and S3 from pit hardening to budbreak of the following season. Lower panels are the average daily temperature outside (light gray lines) and inside (black lines) the shade structure during three consecutive seasons (D, E and F). The difference between outside and inside temperatures is shown with dotted lines in lower panels.

et al., 2004) and could be affected by environmental factors such as radiation. However, critical periods where oil quality depends on radiation remain unclear.

Hernández et al. (2008) evaluated the effects of two irradiance levels on olive callus lipid metabolism. They observed a reduction in the desaturation of oleate to linoleate at low irradiance, suggesting a direct effect on activity of microsomal oleate desaturase enzymes which convert oleic into linoleic acid. Bartolini et al. (2014) observed that the activity of enzyme β-glucosidase (involved in phenol synthesis) was affected by high levels of incident radiation. In another study, Gómez-del-Campo and García (2012) evaluated oil composition from a wide range of canopy positions of N–S and E–W oriented 'Arbequina' hedgerow olive orchards. Their observations revealed that oleic acid percentage was highest in the least illuminated canopy position, while linoleic acid, oxidative stability, and phenol content were highest in the most illuminated portion of the canopy. In a recent temperature manipulative study, García-Inza et al. (2014) observed a lower content of oleic acid percentage in fruits on branches exposed to higher temperatures (6–7 °C) during Period III of fruit growth (from January to April, Southern Hemisphere) with respect to control branches exposed to ambient temperature. Fatty acid composition could be modulated by temperature and irradiance through different mechanisms (Rondanini et al., 2006), so fatty acid and phenol content could be affected by radiation in different critical periods.

Physical and chemical indicators involved in olive oil oxidation (free acidity, peroxide index, and ultraviolet spectrophotometric indices) have been widely related to fruit maturity (Monteleone et al., 1995; Rotondi et al., 2004). Incident irradiance on fruit affects the ripening process (Proietti et al., 2012), and consequently, can indirectly influence oil oxidation. Maturity also has been related to assimilate availability, trees with high production presented less maturity than trees with low production (Trentacoste et al., 2010).

Olive production in Argentina is carried out in a wide range of environments. Olive oil composition could be related to the ability to capture and use radiation in different environments, which could be determined by regions and orchard design management (e.g. tree spacing, training system, and pruning). In addition, it is possible to obtain a specific oil characteristic that complies with the quality required by the market and consumers. The aims of this work were (i) to determine the influence of artificial shading- imposed over the entire growing season- on fruit maturity, fatty acid profile and total phenol content in olive oil compared with trees without shading, and (ii) to evaluate the effect on oil quality of artificial shading imposed during three short phenological periods (from flowering to fruit set, from fruit set to pit hardening, and from pit hardening to harvest).

2. Material and methods

2.1. Orchard characteristics and shading periods

The study was carried out in the experimental field of E.E.A Junín INTA, northeast of Mendoza province, Argentina (33° 06′ S, 68° 29′ W, 653 m.a.s.l) on 'Arbequina' olive trees, during the 2010–2011, 2011–2012 and 2012–2013 growing seasons. 'Arbequina' was specially selected for its early fruit bearing (precocity) and reduced vigor, which is adapted to high density systems (Marino et al., 2017). Twenty trees were planted in spring 2008, spaced 15 × 15 m, in two rows oriented north-south. This planting distance allowed having isolated plants with no shading effect from contiguous plants or rows. From planting, trees were irrigated with 2.0 L/h emitters spaced at 0.5 m intervals along two drip lines per row. Irrigation was applied to restore 100% of crop evapotranspiration over the whole growing season calculated given the size canopy cover of unshaded trees. During the three seasons, the soil was manually fertilized by applying 100 and 80 kg/ha of N and K, respectively.

Different shading treatments were applied by using black plastic