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Night temperature and intercepted solar radiation additively contribute to oleic acid percentage in sunflower oil

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ABSTRACT

Oil fatty acid composition of sunflower (*Helianthus annuus* L.) closely depends on the environmental conditions during grain filling. Temperature and solar radiation are main environmental factors driving oil chemical composition, as revealed by experiments in which the effects of these variables were investigated separately. The present work aims at investigating whether both temperature and irradiance act independently or they interact in exerting their effects on oleic acid percentage of sunflower oil. With this purpose, minimum night temperature (MNT) and intercepted solar radiation (ISR) per plant were together modified during the grain filling period of the traditional sunflower hybrid ACA 885. Two experimental approaches were performed: (a) radiation was modified in three locations at different latitudes (location × radiation experiments), (b) radiation and temperature were modified in a factorial design within one location by using field shelters (*in situ* temperature × radiation experiments). Regardless location or year effect, oleic acid percentage increased with ISR per plant up to a maximum value, which depended on MNT. *In situ* temperature × radiation experiments showed that plant heating increased oleic acid percentage under any radiation condition assayed, while plant shading produced a drop in oleic acid that was independent of MNT. Statistically significant interaction between MNT and ISR per plant was not detected. A mathematical relationship that considered that MNT and ISR per plant additively contribute to oleic acid percentage was established and verified using data from location × radiation experiments. This equation predicted well independent experimental data from *in situ* temperature × radiation experiments.

Results obtained in this work could improve model prediction of oil quality of sunflower grown under different environmental conditions, and contribute to unravel the mechanisms underlying oleic acid percentage in sunflower oil.

1. Introduction

Fatty acid composition of vegetable oils determines their quality and potential uses. Sunflower oil is one of the most widely used vegetable oils because of its nutritional and industrial attributes. Sunflower oil quality is often considered in terms of oleic acid content, since this is nowadays the preferred fatty acid for both edible purposes and biodiesel production (Heyden, 1994; Marvey, 2008; Mensink and Katan, 1989; Mensink et al., 2003).

Environmental factors have a decisive influence on sunflower oil quality (Izquierdo et al., 2006, 2009; Roche et al., 2006). It has long been known that temperature is the main environmental factor affecting the proportion of oleic acid in the oil of traditional sunflower cultivars (Canvin, 1965). Variations in oleic acid concentration obtained under field conditions have been related to different expressions of temperature (i.e., maximum, minimum, daily mean temperature) in several works (Harris et al., 1978; Nagao and Yamazaki, 1983; Seiler, 1986; Sobrino et al., 2003). Further understanding of this response has been recently provided by Izquierdo et al. (2006), who reported that minimum night

Abbreviations: MNT, minimum night temperature; ISR, intercepted solar radiation; PAR, photosynthetically active radiation; °Cd af, °C day after flowering.

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temperature (MNT) during an early period of grain filling is the best temperature predictor of oleic acid percentage in sunflower oil. Oleic acid percentage showed a sigmoid response to MNT between 100 and 300 °C day after flowering (base temperature 6 °C, Izquierdo and Aguirrezábal, 2008).

Empirically obtained relationships between oleic acid percentage and MNT (Izquierdo et al., 2002, 2006; Izquierdo and Aguirrezábal, 2008) were integrated in a crop growth, development and yield simulation model in order to predict and simulate sunflower yield and oil quality interactions (Pereyra-Irujo and Aguirrezábal, 2007), and biodiesel quality (Pereyra-Irujo et al., 2009). These relationships were also useful for assessing interspecific (Izquierdo and Aguirrezábal, 2008) and intraspecific (Izquierdo et al., 2009) genetic variability of oleic acid percentage response to temperature. Following this approach, relationships between quality traits and their best environmental drivers can be established and validated in order to improve oil quality prediction and better understand the mechanisms underlying oil quality responses to environmental factors. However, this is often difficult because (i) the quality trait can be driven by more than one environmental factor, (ii) the degree of variation of these environmental factors under natural fluctuating conditions may be correlated and (iii) these environmental factors could interact in determining the value of the studied quality trait.

Environmental factors other than temperature have been shown to affect oil fatty acid composition (Irving et al., 1988; Pritchard et al., 2000; Steer and Seiler, 1990). A positive correlation between oleic acid percentage and incident solar radiation has been reported for sunflower (Seiler, 1986) and soybean oil (Kane et al., 1997). Intercepted solar radiation (ISR) per plant during grain filling linearly increased oleic acid percentage in several crop species. In sunflower, differences in oleic acid percentages driven by this factor could be higher than 10 percentage points (Izquierdo et al., 2009).

Previous results show that the effect of ISR per plant on oleic acid percentage was not due to a correlative effect of temperature (Izquierdo et al., 2009). In these experiments, differences found in fatty acid composition were not accounted for by the small variations in temperature observed among treatments applied to modify ISR per plant. Although evidence suggests separate effects of temperature and solar radiation on fatty acid composition of sunflower oil, the way these factors exert their effect together remains unsolved. When two environmental factors influence a given response, their effect may be either additive or multiplicative, or alternatively they may interact (Salisbury and Ross, 1992). Discerning between these different possibilities is important to improve modeling of oleic acid variations in sunflower oil under different environmental scenarios (i.e. high differences in the simulated values could be obtained if considering these different ways of action, Whisler et al., 1986). In this sense, we hypothesized that changes in minimum night temperature during grain filling, achieved by cultivating sunflower either at different latitudes or under shelters set at one single location, would not modify oleic acid percentage response to intercepted solar radiation per plant. The objective of this work was to assess whether MNT and ISR per plant exert their effect on oil oleic acid percentage in an independent manner or they interact in any way.

2. Materials and methods

The traditional sunflower hybrid ACA 885 was grown under optimal nutrient and water conditions at Unidad Integrada Balcarce INTA-FCA (37°S, 58°W, hereafter named Balcarce), Estación Experimental Agropecuaria INTA Paraná (31°S, 60°W, hereafter named Paraná) and Estación Experimental Agropecuaria INTA Sáenz Peña (26°S, 60°W, hereafter named Sáenz Peña), in Argentina.

Soil fertility in all experiments was enough to attain maximum yields for sunflower crops under non-limiting water conditions (yield >5000 kg ha^{-1}; Andrade et al., 2000; Sosa et al., 1999). Soil characteristics at the experimental sites are depicted in Table 1. According to Díaz Zorita (2005), soil analysis indicated that N fertilization was not necessary in Balcarce and Paraná, while urea (80 kg ha^{-1}) was added in Sáenz Peña at sowing. Although P concentration was high enough in all three locations, diamonic phosphate (60 kg ha^{-1}) was added as a starter in Sáenz Peña, where seedling emergence often occurs under stressing conditions. Rainfall was complemented with irrigation to avoid water deficit. Soil water content was monitored every 5–7 days using a neutron probe (Troxler 4300, Troxler Electronic Laboratories, Inc., Research Triangle Park, NC). Irrigation was applied to maintain soil water above 40% available water in the first 0.60 m of the soil profile during the entire growing season. Pests, diseases and weeds were adequately controlled.

At flowering, bags were used to prevent cross-pollination. Flowering of a plant was defined by the appearance of stamens in all florets from the outer ring of the capitulum (R5.1 stage, Schneiter and Miller, 1981). Flowering of the experimental unit was considered when more than 50% of the plants had reached R5.1 stage. To estimate physiological maturity, 15 seeds from rows 4 to 19 of three capitula were harvested twice a week along grain filling. Seed removal was repeated on the same plant as long as total removal did not exceed 5% of average final capitulum grain number. Grains were oven-dried at 60 °C and weighted. Physiological maturity was determined as the time when average dry weight per grain did not further increase (Aguirrezábal et al., 2003).

2.1. Measurements

Global daily incident radiation was measured with pyranometers (LI-200SB, LI-COR, Lincoln, NE) from weather meteorological stations close to the experiments. Daily incident photosynthetically active radiation (PAR) was calculated as 0.48× global daily incident radiation (Bonhomme, 1993). The proportion of photosynthetically active radiation (PAR) intercepted by the crop at noon (±1 h) was calculated according to Gallo and Daughtry (1986) as (1 − Rb/Ro), where Rb is the radiation measured below the oldest green leaf, and Ro is the radiation measured above the canopy. Rb was measured weekly with a line quantum sensor (LI-191SB, LI-COR, Lincoln, NE, USA) positioned across the rows (the length of the sensor was modified according to the distance between rows: 0.7 m). Three measurements were done per plot. In accordance with Charles-Edwards and Lawn (1984), the daily proportion of PAR intercepted was estimated as the proportion of PAR intercepted at noon × 2/(1 + proportion of PAR intercepted at noon). This correction allowed a substantial improvement on the error arising from a single measurement at noon (Trapani et al., 1992). Daily proportion of intercepted PAR between measurements was calculated by linear interpolation. Daily intercepted solar radiation per plant was calculated as the product of daily incident PAR and daily proportion of PAR intercepted divided by the plant density. ISR accumulated per plant from R6 (Schneiter and Miller, 1981) to physiological maturity was calculated as described by Dosio et al. (2000).

Air temperature was measured using thermistors (Cavadevices, Buenos Aires, Argentina) at the capitulum level every 60 s and hourly averaged. Thermistors were protected by shields to prevent absorption of solar radiation. Measurements began after flowering and finished at physiological maturity and were recorded by data loggers (Cavadevices©, Buenos Aires, Argentina). Thermal time after flowering (°Cd af) was calculated from air temperature using a base temperature of 6 °C (Kiniry et al., 1992).