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Intercepted solar radiation affects oil fatty acid composition in crop species

N.G. Izquierdo [a,b], L.A.N. Aguirrezábal [a,b,*], F.H. Andrade [a,b,d], C. Geroudet [c], O. Valentinuz [d], M. Pereyra Iraola [a]

[a] Unidad Integrada Facultad de Ciencias Agrarias (UNMdP), Estación Experimental Agropecuaria INTA Balcarce, Balcarce, Argentina
[b] Consejo Nacional de Investigaciones Científicas y Técnicas, CONICET, Argentina
[c] Institut National Agronomique de Paris-Grignon, France
[d] Estación Experimental Agropecuaria INTA Paraná and Universidad Nacional de Entre Ríos, Facultad de Ciencias Agropecuarias, Paraná, Argentina

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ABSTRACT

Solar radiation intercepted during grain filling affects growth of grain crops. Its effects on oil fatty acid composition have not been investigated. The objective of this work was to investigate the effect of intercepted solar radiation per plant on oil fatty acid composition in four crops. An experiment including a cultivar of soybean, maize and sunflower was sown at Balcarce, Argentina, during two growing seasons (2001–02 and 2004–05) and two experiments with a rape cultivar were conducted during in 2004 and 2005. The amount of intercepted solar radiation during grain filling was modified by shading (50–80%) and thinning plants (50%). In addition, the same cultivars of soybean and maize were sown in the field at Paraná, Argentina, during the 2004–05 growing season and in growth chambers under different day/night temperatures during grain filling. Regardless of the species, oleic acid percentage increased as intercepted solar radiation (ISR) per plant increased. The highest difference (13%) was observed in sunflower (shading vs. thinning) and the increase in oleic acid was associated with a reduction in both linoleic and linolenic acids. Saturated fatty acid percentage was not affected by intercepted solar radiation per plant. Differences among radiation treatments were observed not only at physiological maturity but also at earlier stages of the grain filling period. In soybean and maize, increasing daily mean temperature increased oleic acid percentage ($r^2 \geq 0.52$). Changes in fatty acid composition in radiation experiments and treatments were not accounted for by variations in temperature (differences among treatments were ≤ 1 °C). In sunflower and maize, the source (ISR)–sink (grain number) ratio during the grain filling period better explained changes in oleic acid percentage than per plant ISR alone. Changes in fatty acid composition due to radiation treatments were as large as variations produced by changes in temperature in soybean and maize, but not in sunflower. Based on these results, management practices that increase intercepted radiation by the plant during grain filling could contribute to obtain oils with higher oleic acid percentage.

Crops cultivated to produce oil such as sunflower, soybean, maize or rape are usually sown in a wide range of environmental conditions. Different years, locations or sowing dates result in variations of temperature and solar radiation during the period of oil synthesis in the grain. It is well known that the synthesis of fatty acids may be affected by the environmental conditions (e.g. Irving et al., 1988; Lajara et al., 1990; Kane et al., 1997; Strecker et al., 1997; Pritchard et al., 2000; Rondanini et al., 2003).

It is generally accepted that temperature accounts for most of the variations in fatty acid composition among years, locations and sowing dates. Temperature modulates the oleate desaturase enzyme, which converts oleic acid to linoleic acid (Garcés et al., 1992; Kabbaj et al., 1996). Increases in temperature increased the oleic–linoleic ratio (Izquierdo et al., 2002; Rondanini et al., 2003). A common result of studies performed in sunflower about the effect of temperature on oil fatty acid composition (e.g. Rochester and Silver, 1983; Izquierdo et al., 2002) was that low temperatures (minimum or night temperature) are the best predictors of oleic acid percentage. Minimum night temperature during the period 100–300 °C day after flowering (base temperature: 6 °C) was selected as a predictor of oleic acid percentage in both traditional and high oleic sunflower hybrids (Izquierdo et al., 2006; Izquierdo and Aguirrezábal, 2008). Although temperature alters fatty acid composition in soybean and maize, the best predictor (i.e., daily mean, minimum temperature, etc.) for oleic acid percentage remains unknown.

Unlike temperature, the relationship between intercepted solar radiation (ISR) and oil fatty acid composition has been less

Abbreviations: ISR, intercepted solar radiation; PAR, photosynthetically active radiation; °C daf, °C day after flowering; OAP, oleic acid percentage.

* Corresponding author at: Unidad Integrada Facultad de Ciencias Agrarias (UNMdP), Estación Experimental Agropecuaria INTA Balcarce, Ruta 226 km 73.5 C.C. 276, 7620 Balcarce, Argentina. Tel.: +54 2266 439100; fax: +54 2266 439101.
E-mail address: laguirre@mdp.edu.ar (L.A.N. Aguirrezábal).

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investigated. Per plant ISR (which depends on incident radiation, crop interception and plant density) modified weight per grain or grain oil concentration in soybean, sunflower and maize (Andrade and Ferreiro, 1996; Dosio et al., 2000; Izquierdo et al., 2008). Although a greater ISR increased the synthesis of lipids in the grain (Harwood, 1994), its effect on grain lipid composition has not been studied.

Knowing the effect of intercepted solar radiation and temperature would help to understand the mechanisms involved in oil fatty acid determination. In addition, it would be useful in designing management practices to obtain a specific oil quality and in improving the predictions of crop models. The main objective of this work was to investigate the effect of intercepted solar radiation per plant during the grain filling period on oil fatty acid composition in sunflower, soybean, maize and rape. Field experiments were conducted with different treatments of intercepted radiation during grain filling. Since radiation treatments could result in changes of temperature, the effect of temperature was quantified and removed to investigate the effect of intercepted solar radiation alone. This was done using relationships between fatty acids and temperature based on experimental and bibliographical data.

1. Materials and methods

1.1. Temperature experiments

Six experiments were conducted with soybean and maize (T1 to T6) in order to establish the relationships between temperature and fatty acid composition (Table 1). Five growth chamber (Refrimax S.R.L., Mar del Plata, Argentina) experiments (T1, T2, T3, T4 and T5) were performed at Balcarce, Argentina (37°52′S, 58°15′W) and a field experiment (T6) was performed in Paraná, Argentina (31°44′S, 60°32′W) using soybean (Asgrow 3901) and maize (Dekalb 615). Exp. T1 included two sowing dates. In the growth chamber experiments, plants were sown on 10 l pots filled with soil. After seedling emergence, plants were thinned to three (soybean) or one (maize) plant per pot. Soybean was inoculated and fertilized with P, S and B. Maize was fertilized with N, P, S and Zn. Pots were irrigated every 12 h to avoid water stress. Phenology was recorded according to Fehr and Cavinness (1977) and Ritchie et al. (1997) in soybean and maize, respectively. Plants were kept under natural conditions until treatments were applied. Plants were exposed to different day/night temperatures during grain filling (Table 1) with 12-h photoperiod and incident radiation of $690 \pm 75\ \mu mol\ m^{-2}\ s^{-1}$ at the top of the plants. Shorter plants were raised in order to receive the same incident radiation. Air temperature of the growth chambers was recorded every 60 s and the hourly average was recorded with data loggers (Cavadevices, Buenos Aires, Argentina).

The same soybean and maize cultivars were sown in Paraná during the 2004–05 growing season (T6, Table 1). The soil was an Acuic Argiudoll. Soybean was sown in rows 0.52 m apart with a final density of 25 pl m^{-2} with two replicates. Maize was sown on two dates, in rows 0.7 m apart with a final density of 7.5 pl m^{-2} with two and three replicates in the first and second sowing date, respectively.

Table 1
Dates of sowing, flowering (R5.1: sunflower; R1: maize), R4 (soybean), duration of the grain filling period, mean plant density of the control and applied treatments in sunflower (cv Dekasol 3881), soybean (cv Asgrow 3901) maize (cv Dekalb 615) and rape (cv Eclipse, RAD 3; cv Teddy, RAD 4) for temperature experiments (T1–6) and radiation experiments (RAD 1–4).

Exp.	Specie		Sowing date	Flowering date[a]	Grain filling period (days)	Density (pl m^{-2})	Treatments
T1	Soybean	1st	12/03/2001	02/12/2002	56	–	28/20 °C, 25/23 °C, 20/28 °C
		2nd	01/16/2002	04/09/2002	66	–	20/28 °C
	Maize	1st	12/18/2001	02/28/2002	48	–	28/20 °C, 25/23 °C, 20/28 °C
		2nd	01/25/2002	04/15/2002	50	–	28/20 °C, 20/28 °C
T2	Soybean		01/29/2004	03/28/2004	54	–	26/16 °C, 22/20 °C, 16/26 °C
	Maize		02/05/2004	04/10/2004	53	–	26/16 °C, 22/20 °C, 16/26 °C
T3	Soybean		11/21/2002	01/30/2003	54	–	25/23 °C, 21-16 °C, 22/22 °C[b]
	Maize		10/29/2002	01/15/2003	57	–	25/23 °C, 22/22 °C, 24/22 °C, 22/24 °C,
T4	Soybean	–	08/30/2004	12/11/2004	52–64	–	28/26 °C, 16/14 °C
	Maize	–	09/13/2004	12/01/2004	38–43	–	28/26 °C, 16/14 °C
T5	Soybean	–	01/12/2005	03/28/2005	60	–	18/17 °C, 16/14 °C
	Maize	–	01/25/2005	04/08/2005	47	–	18/17 °C, 16/14 °C
T6	Soybean	–	12/07/2004	01/30/2005	62	25	–
	Maize	1st	12/07/2004	02/07/2005	37	7.5	–
	Maize	2nd	01/28/2005	03/21/2005	35	7.5	–
RAD 1	Sunflower		11/28/2001	02/10/2002	42–44	6.3	S80, S50, Th, control
	Soybean		11/28/2001	02/08/2002	72–81	14	S80, S50, Th, control
	Maize		11/12/2001	01/25/2002	71–76	6.8	S80, S50, Th, control
RAD 2	Sunflower		10/25/2004	01/12/2005	48	5.3	S80, S50, Th, S50 + Th, control
	Soybean		11/12/2004	01/24/2005	50–55	17	S80, S50, Th, S50 + Th, control
	Maize		10/25/2004	01/14/2005	57	6.6	S80, S50, Th, S50 + Th, control
RAD 3	Rape		06/17/2004	10/02/2004	62	100	S80, Th, control
RAD 4	Rape	1st	05/26/2005	10/30/2005	47	115	S80, control
		2nd	07/05/2005	11/29/2005	36–48	89	S80, control

Treatments consisted in different day/night temperature during grain filling (T1–T5) or different levels of intercepted solar radiation during grain filling (RAD 1–4). S80: 80% shaded; S50: 50% shaded; Th: thinning. The grain filling period was considered as flowering-physiological maturity in sunflower and maize, R4-physiological maturity in soybean and end of flowering-physiological maturity in rape.

[a] In soybean the date corresponds to R4 stage.

[b] This treatment included two replications.