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Fatty acid composition of high oleic sunflower hybrids in a changing environment

Patricia Angeloni[a], María Mercedes Echarte[b,c,d], Gustavo Pereyra Irujo[b,c,d], Natalia Izquierdo[b,d], Luis Aguirrezábal[b,d,*]

[a] Facultad de Ciencias Agrarias, Universidad Nacional del Nordeste, Corrientes, Argentina
[b] Laboratorio de Fisiología Vegetal, Facultad de Ciencias Agrarias, Universidad Nacional de Mar del Plata (FCA-UNMdP), Ruta 226 Km 73.5, 7620 Balcarce, Argentina
[c] Instituto Nacional de Tecnología Agropecuaria, INTA, Ruta 226 Km 73,5, Balcarce, Argentina
[d] Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Argentina

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ABSTRACT

High oleic hybrids of sunflower are widely cultivated around the world. The effect of temperature on oleic acid percentage of these hybrids is a concern, since oils with oleic acid percentage above a threshold receive a prime over the regular price. The objective of this work was to identify the main avenues for the genetic improvement of oleic acid percentage of high oleic hybrids of sunflower, both in current and future global warming scenarios. A data set obtained in a trial network allowed to explore the oleic acid percentage response to temperature of high oleic hybrids in the argentine sunflower growing region (between 29 and 38° LS, 46 trials in 15 locations during the period 2005/06–2012/2013). A similar data set was used to evaluate the variability in phenology. Mean values and stability across environments of oleic acid percentage differed among the studied high oleic hybrids. Differences in the parameter values of a sigmoid equation evidenced the variability in the response of oleic acid to temperature. Oleic acid percentage was simulated with a model that included this equation coupled to a phenology module, for different sowing dates and locations with contrasting temperature, under current conditions and a global warming scenario. It was possible to identify a low number of temperatures and field environments useful to reproduce the rankings of hybrids obtained with a wide range of temperatures. This information could be used to phenotype for high oleic percentage with a low number of experiments and reduce the efforts to identify better high oleic genotypes. Simulations show that the maximum oleic acid percentage is currently not attained in 50% of the studied hybrids in some sowing dates, even at the warmest locations, while in a future global warming scenario it would not be attained in 30% of the studied hybrids in the colder locations. Sensitivity analysis was performed for parameters of the sigmoid equation and the phenology module determining when the critical period for fatty acid composition occurs. In both in current and future scenarios, phenology parameters showed a null or low effect on oleic acid percentage. Two parameters of the sigmoid equation showed a significant impact, which differed between current and future scenarios. Simulations suggest that the stability of oleic acid percentage could still be a concern in the future. However, selecting for key parameter values for a given scenario could help to obtain better high oleic hybrids of sunflower.

1. Introduction

The gene pool of cultivated sunflower (*Helianthus annuus* L.) has been subjected to intense selection for a specific oil composition (Putt, 1997; Burke et al., 2005). For oil quality purposes, oleic and linoleic are the most important fatty acids because they constitute almost 90% of the total fatty acids in sunflower oil. Sunflower fatty acid composition has been modified by breeding and mutagenesis (Fernández-Martínez et al., 1989; Lagravère et al., 1998; Lacombe

* Corresponding author at: Laboratorio de Fisiología Vegetal, Facultad de Ciencias Agrarias, Universidad Nacional de Mar del Plata (FCA-UNMdP), Ruta 226 Km 73.5, 7620 Balcarce, Argentina.
E-mail address: laguirre@mdp.edu.ar (L. Aguirrezábal).

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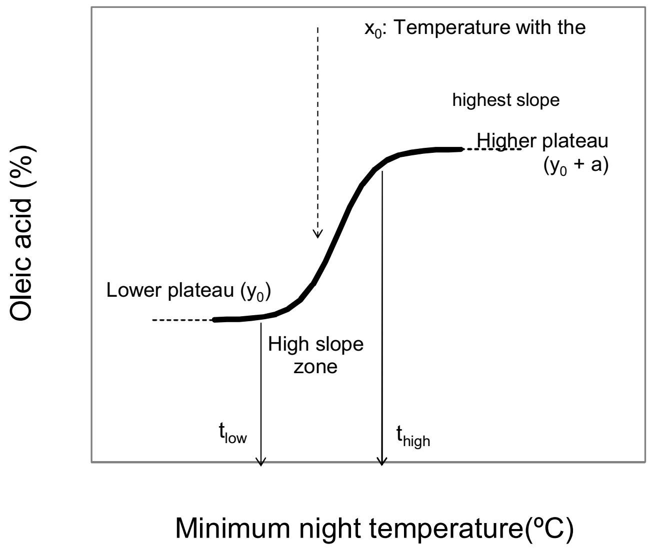

Fig. 1. Schematic representation of the response of oleic acid percentage to minimum night temperature during the 100–300 °C day after flowering period and some parameters useful to compare the response of different hybrids (from Izquierdo and Aguirrezábal, 2008).

and Bervillé, 2000; Haddadi et al., 2013), and high oleic cultivars with oleic acid (OA) percentage above 80% have been obtained. Currently, the area sown with high oleic hybrids has increased to almost 2 million hectares, representing about 11% of the total sunflower area around the world (Labalette et al., 2012).

Stability of fatty acid composition across environments is generally higher for high oleic hybrids than traditional ones (Izquierdo et al., 2002). However, high oleic hybrids showed differences in their response to the environment and their maximum oleic acid percentage attainable (Triboï-Blondel et al., 2000; Luquez et al., 2002; Roche et al., 2006). Although the effect of the environment on fatty acid composition in these genotypes is smaller than in traditional ones, it can still be a concern, especially with strict oil market standards, since oils with oleic acid percentage above a threshold receive a prime over the regular price.

Models have long been used to describe, analyze and predict the response of plant traits to the environment (Jones, 2014). They can range from detailed mechanistic descriptions to simple response curves to environmental variables, which represent "meta-mechanisms" at the plant or crop level (Tardieu, 2003). If models are robust enough, one set of parameters represents one genotype (Hammer et al., 2006), and thus they can be used to analyze complex traits with significant genotype by environment interaction or pleiotropic effects. Given the same functional expression characterizing the response of several hybrids, the analysis of the variability of model parameters provides important information about the nature of the observed genotype by environment interactions and provides new traits (parameters) that are independent of the environment.

Oleic acid percentage in sunflower oil is closely related to minimum night temperature during a short period during grain filling (between 100 and 300 °C days after flowering; MNT; base temperature 6 °C). The response of oleic acid percentage to minimum night temperature (MNT) follows a sigmoid function (Izquierdo and Aguirrezábal, 2008, Fig. 1), and is subjected to genetic variability among traditional hybrids as evidenced by differences in the parameters of this function (minimum and maximum attainable oleic acid percentage, maximum slope and range of temperatures in which oleic acid percentage changes with temperature). The only high oleic hybrid tested so far showed lower sensitivity to temperature as evidenced by smaller difference between the parameters for minimum and maximum oleic acid percentage (Izquierdo and Aguirrezábal, 2008). Up to date, whether this model is also useful for analyzing the variability among genotypes with modified fatty acid composition is unknown.

As previously described, oleic acid percentage in traditional hybrids of sunflower showed a continuous, nonlinear response to temperature during a specific period late in the crop growth cycle. For a given sowing date, the rate of crop development determines the moment of the year in which this process occurs. Since temperature also affects the rate of crop development in a nonlinear fashion (Parent and Tardieu, 2012), it becomes difficult to predict the outcome of an increase in temperature on oil quality. Many works evidence the effect of climate variability and global warming on plant development and their interactions with different plant processes, both by empirical measurements and simulations (Chmielewski and Rötzer, 2001; Sadras and Monzon, 2006; Pereyra-Irujo and Aguirrezabal, 2007). Moreover, crop development and oil fatty acid composition are related to different temperature variables (daily mean or minimum night temperature, respectively), which are expected to be differently affected by global warming (Rusticucci and Barrucand, 2004).

Identifying which parameter of the sigmoid function relating oleic acid percentage to temperature could have the highest impact on oil composition when modified, could be valuable information for the improvement of sunflower oil quality (Aguirrezábal et al., 2014). Moreover, simple models that simulate the whole crop cycle (e.g. Pereyra-Irujo and Aguirrezábal, 2007) could be useful for analyzing complex processes, such as the interaction of different temperature variables (i.e. minimum, mean, and maximum) on the determination of crop development and fatty acid composition. Also, phenotyping has become a bottleneck for further genetic improvement, especially of complex traits, because it can be often technically difficult, expensive, or time consuming (Hall and Richards, 2013). The use of such models could be helpful to identify key temperatures and environments for phenotyping oleic acid percentage of high oleic hybrids of sunflower. The objective of this work was to identify the main avenues for the genetic improvement of oleic acid percentage of high oleic hybrids of sunflower, both in current and future global warming scenarios.

2. Materials and methods

2.1. Experiments

A first data set, originated from the Argentine National Trial Network of Commercial Sunflower Hybrids (INTA), allowed exploring the response of oleic acid (OA) percentage to temperature in high oleic hybrids grown throughout the Argentine sunflower growing region (between 29 and 38° S; Table 1), with minimum night temperature (MNT) values ranging from 12.9 to 21.2 °C. The data set included 46 trials in 15 locations during the period 2005/2006–2012/2013 (Table 1).

Hybrids were laid out in randomized complete-block or alpha-lattice designs, with three replicates. Seventeen commercial hybrids were selected and considered for analysis (Table 1). A plot size of three or four rows 5.5 m long and inter-row spacing of 0.50 or 0.70 m was used. The plots were over-planted and later thinned to 45,600–55,000 plants ha^{-1}. Mostly no-tillage sowing was used in the trials. Weeds, insects and pests were controlled chemically or mechanically. All trials were conducted under rainfed conditions and nutrient deficiencies were overcome through fertilization. Sowing dates were as close as possible to the optimum recommended for each location. Time to anthesis was defined as the moment when 50% of the plot plant population reached full anthesis (R-5.5, Schneiter and Miller, 1981).