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Grain yield, yield components and oil content of safflower (*Carthamus tinctorius* L.) growing under semiarid conditions in Argentina

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ABSTRACT

Safflower has attracted significant interest as an alternative oil seed crop in the semiarid region of central Argentina. Grain yield and oil content are the most important factors for successful introduction of safflower to a new area. The purpose of the present work was to determine the developmental stages when grain yield components are fixed and their contribution to the grain yield and oil content of safflower plants under rainfed conditions. The cultivar CW99 OL was sown in late winter (August) during two growing seasons (2008 and 2009). Numbers of flowers and fruit potential size were fixed before anthesis, and maximum number of heads/plant was achieved at anthesis. The final size and dry weight of the fruits were established between 6-7 and 20-24 days after anthesis, respectively. These results were similar in both years. Grain yield differences between years were mainly explained by the number of grains/plant, being similar the number of heads/plant. Oil content (26-37%) was similar to those reported for other safflower cultivars. The results show much of the yield potential of safflower was established before and during anthesis rather than during the post anthesis period.

Keywords: Grain yield, Oil content, Safflower, Yield components

Safflower (*Carthamus tinctorius* L.) is an annual plant belonging to the Asteraceae family and is cultivated mainly as an oil seed crop. It is adapted to dry climatic conditions owing to a deep root system which enables the plant to obtain moisture from levels not available for most of the crops (Weiss, 2000). Considering this characteristic, safflower has attracted significant interest as an alternative oil seed crop in the semiarid region of central Argentina (Luayza *et al.*, 1997).

Safflower grain is made up of 33-60 % pericarp and 40-67 % seed where the oil is synthesized and accumulated (Ekin, 2005; Lyon *et al.*, 2007). Safflower oil is one of the highest quality edible oils because, as a predominately unsaturated fat, it has beneficial effects in preventing cardiovascular disease (Dajue and Mündel, 1996). It can be high in oleic or linoleic fatty acids. The oil content depends on the genotype (Douglas *et al.*, 2004) but it is also affected by environmental differences (Kizil *et al.*, 2008) and sowing time (Çosge *et al.*, 2007).

Grain yield and oil content are the most important factors to consider when introducing safflower to a new area (Yau, 2009). Grain yield components of safflower are No. of capitula/plant, No. of grains/head and weight/grain (Jajami *et al.*, 2008; Yau, 2009). It is critical to know the developmental period during which each yield component is defined in order to understand the yield process and the interactions of genotype and environmental conditions for yield and oil content determination (Jajami *et al.*, 2008; Yau, 2009). In safflower, the developmental stage when the maximum number of branches/plant, the number of flowers/head, the potential size (end of pericarp cell division) and the final size (end of pericarp growth), and weight (end of seed growth) of grains has not been comprehensibly studied.

The purpose of the present study was to determine the developmental stage when the main yield components are fixed and the grain yield/plant and oil content in a safflower cultivar under semiarid conditions in Argentina.

MATERIALS AND METHODS

Field experiments were conducted under rainfed conditions at the experimental field of the Agronomy Department-University of the South (38°45'S; 62°11'W), Bahía Blanca, Argentina. The cultivar CW99 OL developed by CAL WEST, Woodland California USA, was sown in late winter (August) during 2008 and 2009 growing seasons. Rainfall during each growing season was 176 mm in 2008 and 196 mm in 2009. The soil was a typic Ustipsamment (Soil Survey Staff, 1999). Row spacing was 35 cm and plant spacing was 10 cm. Weeds were controlled by hand weeding when necessary.

The developmental stage when the maximum number of branches and heads/plant, number of flowers/ head, and size and weight of grains were achieved was determined by periodically sampling plants and inflorescences before and after anthesis. The dynamics of grain dry weight was determined by sampling grains from anthesis to harvest maturity. Ten to fifteen grains from the main head of two plants were taken on each sampling date. The seeds were separated from the pericarp, dried (60°C, 72 h) and weighed. Pericarp histogenesis was studied during 2008 growing season. Cross sections of ovaries and pericarps were obtained according to conventional histological techniques (Ruzin, 1999).

Grain yield components (number of grains and heads/plant, and grains dry weight/plant) were determined on 10 representative plants at harvest maturity (mid January) in both the experimental years.

Grains of CW99 OL were taken from plants grown at two experimental sites: 35-Rout (38°37'S; 62°23'W) and Ascasubi (39°23'S; 62°37'W). At the 35-Rout site sowing was made under a no-tillage system in August 2008. Row spacing was 37 cm and plant density was adjusted to 72 plants/m^2. The soil type was sandy and rainfall was 80 mm during the growing season. In Ascasubi, plants were sown in a sandy-loam soil with phreatic level to a depth of 1.20 m, under a conventional tillage system at the end of August 2009. A pre-sowing irrigation was applied. Rainfall was 109 mm during the growing season. The row spacing was 20 cm and plant density was 35-40 plants/m^2. Two samples of ten grams of dried safflower grains were taken once a week between anthesis and harvest maturity. Oil content was analyzed by the soxhlet oil technique (AOCS, 1996) using hexane as solvent.

A completely randomized design with plants as replicates was used. The experimental results of each variable were processed by analysis of variance and differences between years were evaluated with t-test (Di Rienzo *et al.*, 2009). Dynamics of pericarp and seed dry weight was analyzed by non lineal regression (Di Rienzo *et al.*, 2009).

RESULTS AND DISCUSSION

The number of flowers was fixed between 30 and 40 days before anthesis, when the stem was still elongating and before branches start to form in both years. At anthesis (4 December 2008 and 11 December 2009), the number of branches, hence the number of heads, was fixed. At the same time, the number of cell layers of the future pericarp was already fixed (Fig. 1) indicating that fruit potential size was achieved, as observed in other safflower material (Ebert and Knowles, 1968).

The pericarp and seed dry weight rate accumulation were similar in both experimental years ($p>0.10$; Fig. 2). Final size and final dry weight of the grain were achieved between 6-7 and 20-24 days after anthesis (DAA), respectively during both growing seasons (Fig. 2). Pericarp anatomy showed that maximum sclerification was reached two days (9 DAA) after the maximum grain dry weight was achieved (Fig. 1 and 2). From that moment on there were no variation in pericarp anatomy, except for a slight increment on cell wall thickness (20 DAA, Fig. 1). Similar results were observed in sunflower grains (Lindström *et al.*, 2007).

Grain yield/plant was higher in 2008 than in the 2009 growing season (Table 1). Eventhough the number of heads has been reported as one of the most important safflower yield components (Uslu *et al.*, 1998; Pahlavani, 2005; Beyyavas *et al.*, 2011), grain yield in this study was mainly explained by the number of grains per plant, which were nearly 100 % higher during 2008 growing season (Table 1). The number of heads per plant was similar between years (Table 1).

Table 1. Grain yield and yield components/plant determined during 2008 and 2009 growing seasons at the Agronomy Department-University of the South, Bahía Blanca, Argentina

Traits	2008	2009
Grain yield (g)	5.28 b	3.11 a
Number of heads	5.50 a	5.36 a
Weight/grain (mg)	35.91 a	41.87 b
Number of grains	147.00 b	74.00 a

In a row, means followed by the same letter are not significantly different at $p > 0.05$.

Oil content expressed on a dry weight basis did not vary between sampling dates during 2008 growing season, and values ranged from 26 to 32 % (Fig. 2). During 2009, oil content increased considerably from 13 DAA and reached a maximum of 37% at 33 DAA (Fig. 2). Higher water availability in Ascasubi experimental site (2009) could have contributed to the differences in the dynamics and oil content compared to 35-Rout (2008), as was observed in others safflower cultivars (Nabipour *et al.*, 2007). Oil content percentages were similar to those reported for other safflower cultivars (Çamas *et al.*, 2007; Mailer *et al.*, 2008).

The results presented herein are the starting point to evaluate the effect of genotype and environmental conditions on the different processes involved in the determination of grain yield components and consequently on grain yield of safflower under semiarid conditions in Argentina.

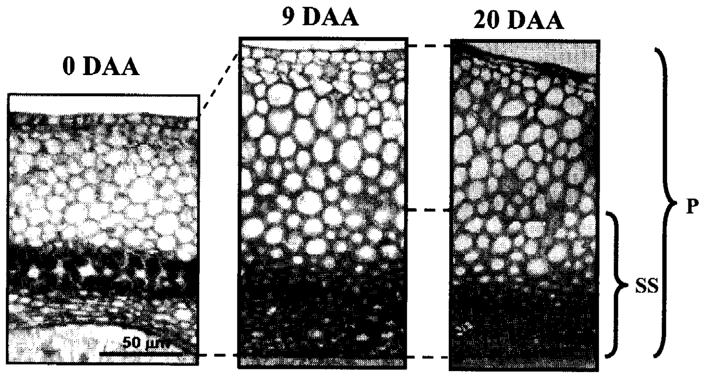

Fig. 1. Pericarp cross sections of CW 99 OL safflower cultivar grown at the Agronomy Department-University of the South (Bahía Blanca, Argentina) and harvested at 0, 9 and 20 days after anthesis (DAA). Scale bars are indicated. P: pericarp; SS: sclerified strata

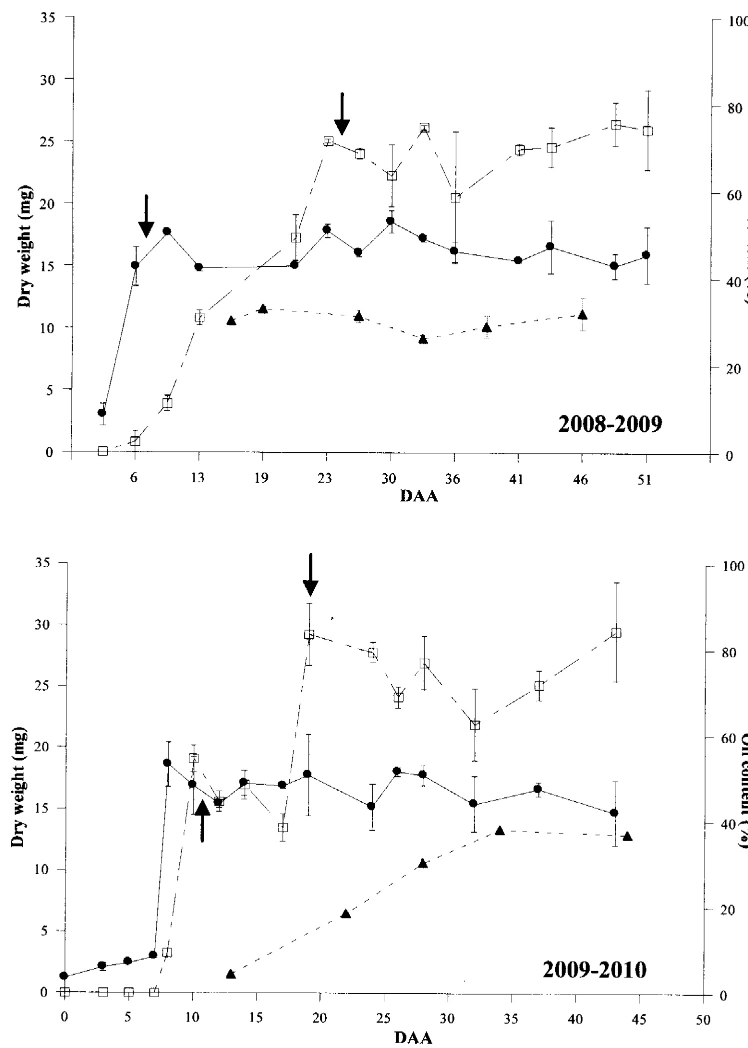

Fig. 2. Pericarp (-•-) and seed (--□--, mg) dry weight and oil content (--▲--, %) of CW99 OL grown at the Agronomy Department-University of the South (Bahía Blanca, Argentina) and measured at different days after anthesis (DAA) during two growing seasons. Arrows indicate maximum dry weight of each variable. Vertical bars are ± 1 S.E.

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