DETERMINATION OF GRAIN WEIGHT AND OIL CONCENTRATION OF SUNFLOWER FRUITS AT DIFFERENT CAPITULUM POSITIONS

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Abstract

We analyzed the effect of plant population (three and six plants per square meter) on post-anthesis source-sink ratio of four commercial sunflower (*Helianthus annuus* L.) hybrids. Grain weight (GW), oil content, and their determinants (i.e., grain filling rate and duration and oil concentration) were determined for fruits located at peripheral and intermediate positions on the capitulum. Increased plant population reduced the source-sink ratio from 144 to 106.5 square cm d per grain, as source capacity (i.e., leaf area duration per plant) was more reduced than sink demand (i.e., grain number per plant). Variations in source-sink ratio accounted for changes in both GW and oil content. Maximum GW (60 mg) and oil content (31 mg per grain) were attained with a source-sink ratio of 154 square cm d per grain. At the highest density, intermediate grains had a lower dry matter accumulation rate (range: 0.041 and 0.054 mg per C d grain) than those in peripheral positions (range: 0.058 and 0.084 mg per C d grain). Final oil concentration (ca. 536 mg per g) was similar among hybrids, so changes in oil content reflected the effects of treatments on dry matter accumulation per grain. When grains grew under limiting source-sink ratios, the different grain size between positions at a similar thermal time would be related to a differential sink demand.

Introduction

Sunflower (*Helianthus annuus* L.) is one of the most important annual oil crops in the world (Putt, 1977). Recent studies revealed that the greatest impact of sunflower improvement in Argentina on both grain and oil yield was based on hybrid release. More grains that are slightly lighter and of greater oil concentration accounted for most of the variation in grain and oil yield between open-pollinated cultivars and hybrids (López Pereira et al., 1999a). Comparisons restricted to hybrids, however, revealed no differences in grain yield or oil concentration, with a grain yield response to grain number saturated at ca. 7,500 grain per square meter. Thus, further increases in oil yield potential could be achieved by maintenance of grain number around this threshold, but increasing grain weight and oil concentration. Both grain mass and grain quality (i.e., protein and lipid contents) are related to the post-anthesis assimilates availability per grain (i.e., source-sink ratio; Andrade and Ferreiro, 1996). Modern hybrids, however, have a more limited source-sink ratio (measured as leaf area duration per grain) than old open-pollination cultivars which imply a higher dependence on reserves of the former to sustain grain demand (López Pereira et al., 1999b). Thus, differences among modern hybrids in the the post-anthesis leaf area duration are positively related to oil grain yield (de la Vega and Hall, 2002). Cultural practices such as plant population (Borrás et al., 2003) or sowing date (de la Vega and Hall, 2002) may modify both grain number (i.e., the sink) and leaf area duration (i.e., the source). Hence, the first objective of our work was to analyze the effect of plant population on the post-anthesis source-sink ratio of four commercial hybrids. Our second objective was to understand the effect of variations of source capacity on grain weight and oil content, considering their determinants, i.e., grain filling rate and duration and oil concentration. Fruits located at different positions of the capitulum may have a different grain demand (Andrade and Ferreiro, 1996), thus we followed dry matter and oil deposition of peripheral and intermediate grains.

Materials and Methods

Three experiments were conducted at the experimental unit of the Department of Plant Production of the University of Buenos Aires (34º 25'S, 58º 25'W), Argentina, under rainfed conditions. In Experiment 1 (E1), three commercial hybrids (Dekalb 3900, Dekalb 4030 and Nidera Paraiso 20) were sown on 26 October 1998 at a population density of six plants per m sq. In Experiment 2 (E2) the same hybrids were sown on 19 October 1999 at two population densities: three and six plants per m sq. In Experiment 3 (E3), hybrids were sown on 10 November 2000 at a density of six plants per square meter; hybrid Dekalb 4030 was replaced by Nidera Paraiso 30. Experiment 1 and E3 were randomized complete block designs with three and four replicates. Experiment 2 was a split plot design (with density as the main plots) with three replicates.

Phenology was recorded on six tagged plants per replicate. Green leaf area at anthesis was measured on tagged plants using a non-destructive method (Pereyra et al., 1982). Green leaf area index (GLAI) was calculated as the product of green leaf area per plant and crop density. Area of senesced leaves (i.e., more than 50% yellow) was discounted to GLAI at anthesis to obtain weekly values of GLAI until maturity. Leaf area duration (LAD) was the integral of the evolution of GLAI values on time. At maturity tagged plants were harvested to determine grain yield, grain number and individual grain weight (GW). Oil concentration at final harvest was determined on a random sample of grains from the whole head per replicate. Source:sink ratio was calculated as LAD/grain number both on plant and crop basis.

In E2 and E3 evolution of grain dry matter and oil deposition were determined. At anthesis several plants per replicate with similar development were tagged for grain sampling. Grain samples were taken every 7 days from first anthesis (R5.0, Schneiter and Miller, 1981) up to physiological maturity. Grains were taken from two positions on the capitulum, peripheral (three to five rows from the border of the head) and intermediate (halfway between the center and the border of the head at R6). Samples were dried at 80C until constant weight. At least four samples during the effective grain filling period and one sample when maximum weight was observed were selected for each position to determine oil concentration using magnetic resonance analysis.

Thermal unit calculations were accumulated linearly from a base temperature of -1C (Chimenti et al., 2001). The nonlinear routine of TBLCurve (Jandel TBLCurve, 1992) was used to fit bilinear regression models to individual GW vs. thermal time relationship to estimate the rates and durations of grain filling (de la Vega and Hall, 2002). A conditional model was used with a first stage where GW= a + b TTA for TTA < C, and a second stage where GW= a + b C. Parameters a and b are the intercept and the slope, respectively, of the linear regression corresponding to the first stage, TTA is thermal time from the anthesis of each fruit position, and the constant C is the unknown breakpoint of the function indicating the end of grain filling. Functions were fitted to data from all replicates per treatment. The same procedure was used to fit bilinear models between oil concentration vs. TTA, LAD vs. GLAI, GW vs. source-sink ratio, and oil content vs. source-sink ratio.

Results and Discussion

The combined effect of hybrids and plant populations determined a range of GLAIs at anthesis from 1 to 6. Although LAD (from 36 to 192 d) was positively related to GLAI, canopies with GLAI greater than 3.7 did not increase LAD value (ca. 159 d) due to a higher leaf senescence. The impoverished light environment perceived by the lowermost leaf stratum of canopies with high GLAIs accelerates leaf senescence (Rousseaux et al., 1999). Increased plant population reduced the source-sink ratio from 144 to 106.5 cm sq. d per grain in E2, as source capacity (i.e., LAD per plant) was more reduced than sink demand (i.e., grain number per plant). Higher source-sink ratios (ca. 224 cm sq. d per grain), however, were observed at six plants per square meter in the E1, where adequate pre-anthesis environmental conditions were reflected by GLAI values (>4).Variations in source-sink ratio accounted for changes in both GW and oil content (Figure 1). Maximum GW (60 mg) and oil content (31 mg per grain) were attained with a source-sink ratio of 154 cm sq. d per grain. Lack of response of grain mass and oil content beyond this value suggests a limitation of the sink (i.e., grain size). Lowering the source-sink ratio up to half of that value (density effect) only decreased GW and oil content by 35%, indicating that additional carbon may have attenuated the effects of less LAD per grain (López Pereira et al., 1999b).

A hybrid x fruit position interaction was detected in GW and oil content. Intermediate achenes of DK3900, DK4030 and Paraiso 30 were lighter and had less oil content than those from the peripheral position (Figure 1 and Table 1). No differences between fruit position in both variables of Paraiso 20 were detected.

The source limitation promoted by the highest plant density in E2 and E3 was reflected in lower filling rates (ca. 0.042 mg per C d grain) than those recorded in plants cultivated at three plants per square meter (ca. 0.051 mg per C d grain) (Figure 2). At the higher density, fruit position effect on final GW differed among hybrids. Intermediate grains of DK4030 and Paraiso 30 had a lower dry matter accumulation rate (0.041 and 0.054 mg per C d grain for DK4030 and Paraiso 30, respectively) than those from peripheral positions (0.058 and 0.084 mg per C d grain for DK4030 and Paraiso 30, respectively). Bilinear models fitted to the DK3900 data set only differed (P<0.09) in parameter a, suggesting a differential initial size of the hull between fruit positions. Thus, as was observed by Andrade and Ferreiro (1996) the largest effect of changes in the source-sink ratios on grain weight was observed for achenes located in an intermediate position.

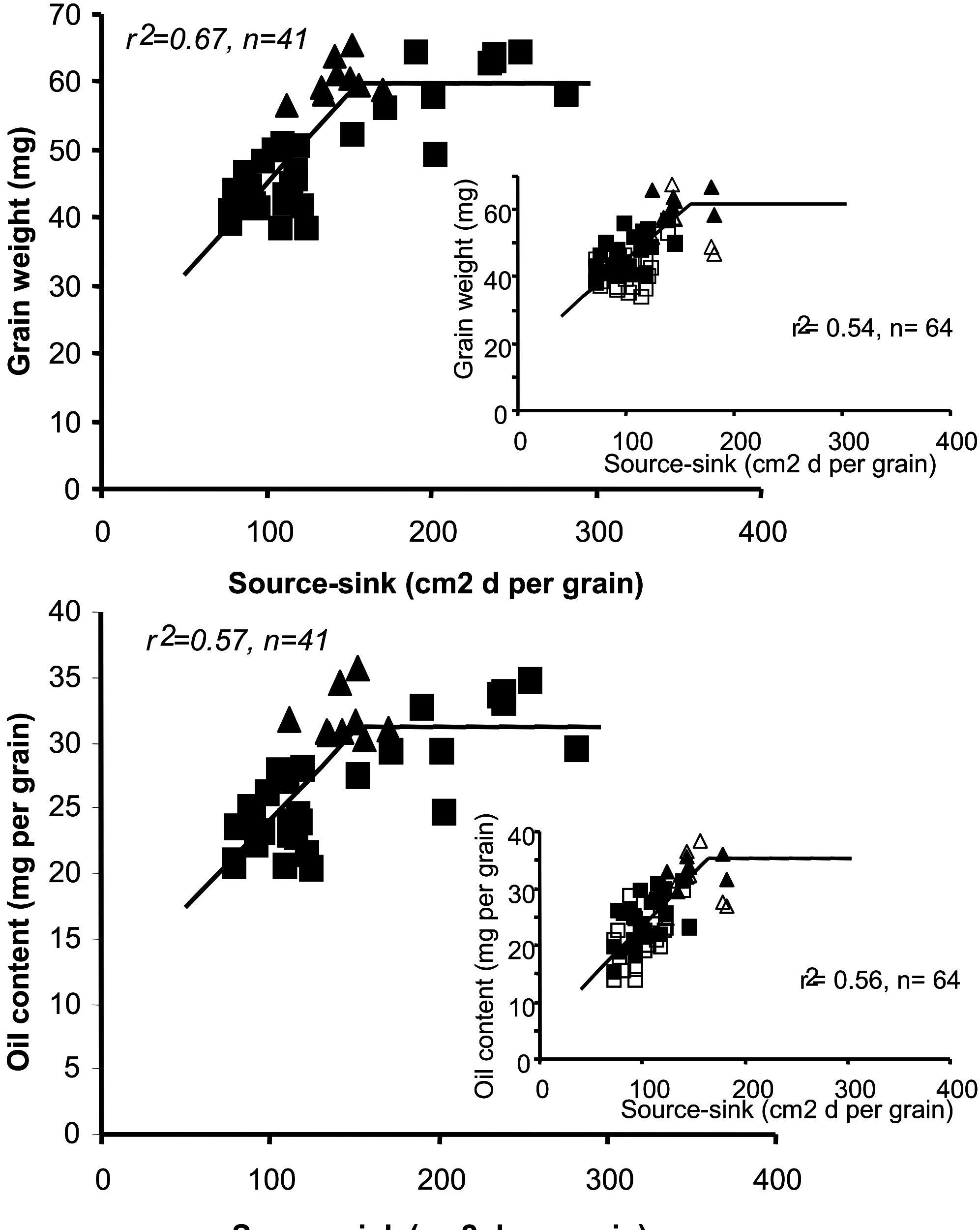

Figure 1. Grain weight and oil content of the entire capitulum of four sunflower hybrids as a function of source-sink ratio (LAD/grain number). Triangles: three plants per m sq.; squares: six plants per m sq. Solid lines indicate the models fitted to data set. Inset figures depict the same relationships for the peripheral (full symbols) and intermediate achenes (empty symbols).

Every fruit position and plant density presented a common oil concentration evolution, with a sharp increase from 106-232C d until 600-700C d after anthesis (Figure 2). Differences among hybrids were detected both in rate and duration of oil concentration increase. A negative relationship between variables (r2>0.97), however, determined a similar final oil concentration among hybrids (ca. 536 mg per g). Hence, changes in oil content reflected the effect of treatments on dry matter accumulation per grain.

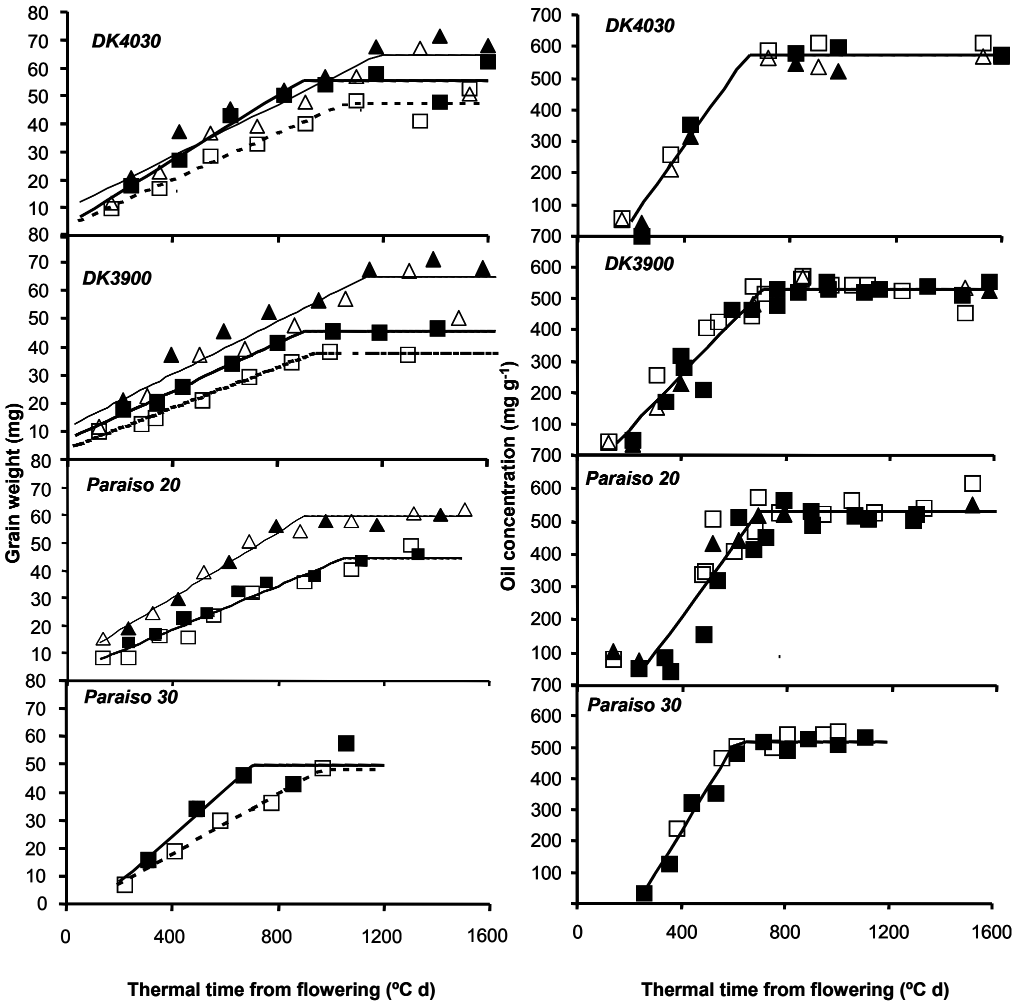

Figure 2. Evolution of dry matter accumulation per grain and oil concentration localized at two capitulum positions (empty symbols: intermediate achenes, full symbols: peripheral achenes), in four sunflower hybrids cultivated at two plant population densities (triangles: three plants per square meter; squares: six plants per square meter). Lines indicate the models fitted to data set.

Table 1. Weight, oil content and oil concentration of achenes localized at two capitulum positions, in four sunflower hybrids cultivated at two plant population densities. Different letters within a column and experiment indicate significant differences (*P*<0.05) between treatments.

Experiment	Hybrid	Plant population (plants/m2)	Capitulum position	Grain weight (mg)	Oil content (mg/ grain)	Oil concentration (mg/g)
1999/2000	DK4030	3	Peripheral	67.7 a	38.5 a	569.2 bcd
			Intermediate	50.4 e	28.8 ef	568.1 bcd
		6	Peripheral	61.9 bc	35.6 ab	574.8 bc
			Intermediate	52.6 de	32.1 bcde	609 a
	DK3900	3	Peripheral	62.2 ab	32.6 bcd	525.9 f
			Intermediate	52.1 de	27.9 f	536.5 ef
		6	Peripheral	56.4 cd	31.2 cdef	553.4 cde
			Intermediate	48.5 e	27.7 f	568.7 bcd
	Paraiso 20	3	Peripheral	62.3 ab	33.3 bcd	534.2 ef
			Intermediate	61.8 bc	34 bc	549.6 e
		6	Peripheral	48.5 e	28 e	580.9 b
			Intermediate	49 e	30 def	613.1 a
2000/2001	DK3900	6	Peripheral	42.7 b	22.5 bc	527
			Intermediate	37.9 c	20.6 d	543.5
	Paraiso 20	6	Peripheral	42.1 b	21.6 cd	514
			Intermediate	41 bc	22.1 bc	538.5
	Paraiso 30	6	Peripheral	51.5 a	26.5 a	513
			Intermediate	42.3 b	23 b	545

Conclusions

Plant population significantly affected the post-anthesis source-sink ratio. Grain weight has a positive response to source-sink ratio up to a threshold value (154 cm sq. d per grain) beyond which potential grain size was attained. Oil concentration was not related to source-sink ratio, thus variations in oil content reflected changes in grain weight. When grains grew under limiting source-sink ratios, a differential grain filling rate was recorded between intermediate and peripheral achenes. In this work, the development of flowering was considered to estimate the duration of the post-anthesis period of each achene position. Hence, the different grain size between positions at a similar thermal time would be related to a differential sink demand.

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