GENOTYPE AND ENVIRONMENT EFFECTS ON LINEAR RATE OF INCREASE OF SUNFLOWER HARVEST INDEX AND ITS DURATION

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Summary

The slope of the daily linear harvest index increase (DHI) can provide a simple means to predict grain growth and yield in field crops. For sunflower, it has been proposed that this attribute is relatively stable across genotypes and environments and could be used with some confidence in crop simulation models. In a companion paper we have reported that genotype × environment (G×E) interactions observed for sunflower in Argentina involve the variation of several traits. In this paper, the effects of contrasting environments on DHI and its duration were explored using a reference set of 10 sunflower hybrids, to determine whether these attributes are constant for sunflower or if they contribute to the observed G×E interactions, and to assess the association between the end-points of HI increase and grain filling.

Mean values for DHI were 0.0125 d^{-1}, 0.0130 d^{-1} and 0.0119 d^{-1} for the environments analyzed, while mean linear HI increase durations were 36.3 d, 38.2 d and 32.8 d. A significant G×E interaction for DHI was found. Principal component analysis on environment-standardized matrices of DHI showed that this trait presents similar patterns of discrimination among genotypes to those for oil yield, indicating that the response of the dynamics of HI to environment may contribute to the observed G×E interactions. The duration of DHI showed a weak positive association with the duration of grain filling in the central portion of the head. These results allow us to conclude that DHI is not a stable attribute across genotypes and environments.

Introduction

During grain filling, grain biomass may be considered as a product of total above ground biomass and harvest index (HI). Grain growth can then be defined as a function of the rate of daily HI increase (DHI) and the day of onset of the increase in HI. It has been proposed that DHI is relatively stable across genotypes and environments and could be used with some confidence in crop simulation models (Bindi *et al*., 1999). Chapman *et al*. (1993) used this approach in a crop simulation model of sunflower growth and development (QSUN). In this model, they had HI increasing daily at a constant linear rate of 0.0113 d^{-1} during the linear phase of grain filling to determine final HI and yield. Bange *et al*. (1998) reported in sunflower that the slope of daily linear HI increase was relatively stable across genotypes and environments (mean 0.0125 d^{-1}), except at very low temperatures. In a companion paper (de la Vega *et al*., 2000) we have reported that the genotype × environment (G×E) interactions observed for central (C) and northern (N) sunflower growing regions of Argentina involve the variation of several traits related to oil yield. In this paper, the effects of contrasting environments on the daily rate of HI increase and its duration were explored using a reference set of 10 sunflower hybrids. The objectives were (i) to determine whether these attributes are constant for sunflower or if they contribute to the observed G×E interactions; and (ii) to assess the association between the end-points of HI increase and grain filling.

Materials and Methods

A reference set of 10 sunflower single-cross hybrids were grown in two C-environments of Argentina (Venado Tuerto October planting 1996/97, VT7, and 1998/99, VT9) and one managed-environment previously shown to be a good surrogate for the N mega-environment (Venado Tuerto, December planting 1996/97, V27). The details of the experimental material and test environments are given in de la Vega *et al.* (2000). Above-ground dry matter accumulation was followed from flowering to maturity by taking samples of two plants per experimental unit every week. Above-ground biomass was sun dried in a glasshouse at more than 50ºC for more than 5 days. Crop biomass measurements were corrected for oil synthesis costs using the production values given by Penning de Vries *et al.* (1983) and assuming that the biomass of non-grain organs contained 2.5% lipids. After discounting a mass of lipid equivalent to 2.5% of the non-oil portion of the grain, the remaining lipid in the grain was assumed to be replaced by a 97.5:2.5 (w/w) carbohydrate:lipid mixture. The result is termed oil-corrected biomass (CBI) in this paper. HI was calculated for each harvest date as the ratio of oil corrected grain yield (OCY) to CBI.

In all experiments the dynamics of individual grain weight were followed during the entire grain-filling period. Samples were harvested every 3 to 4 days in three different portions of the head: upper periphery, intermediate and center of the floral disk. At each harvest, 5 (VT7 and V27) or 3 (VT9) randomly selected plants per plot were subsampled and 3 (VT7 and V27) or 5 (VT9) grains were harvested. The grains were dried at 70ºC for at least 48 h and weighed.

TBLCURVE (Jandel TBLCURVE, 1992) was used to fit piecewise bi-linear regression models to individual HI/time and grain weight/time relationships to estimate the rates and durations of linear HI increase and grain filling. ANOVA was conducted to examine the partitioning of sums of squares to G, E and G×E interaction for each attribute. Principal component analysis (PCA) was aplied to the environment-standardized matrix of genotypes and environments for daily linear HI increase. The principal components (PCs) of the squared Euclidean distance matrix were estimated using a singular value decomposition procedure (Gabriel, 1971). A biplot of the first two PCs for each attribute was constructed from this analysis (Gabriel, 1971). Mean values of rate and duration of linear HI increase were regressed on the oil yield values for each genotype-environment combination. Correlations between end-points of linear HI increase and grain filling in the three portions of the head were calculated.

Results

Mean values of daily HI increase were 0.0125d^{-1}, 0.0130d^{-1} and 0.0119 d^{-1} for VT7, VT9 and V27 respectively (Table 1). These values are similar to those found by Bange *et al.* (1998) and larger than that used by Chapman *et al*. (1993) in the simulation model QSUN. Genotypic effects for this trait were significant for V27 (P = 0.0064). A significant G×E interaction for this attribute was found (P = 0.0025). The result of the PCA of the environment-standardized matrix for DHI is presented in the biplot of the 1st and 2nd principal components (PC) (Figure 1). Entries that are close together are similar in DHI across environments. For any particular environment, genotypes can be compared by projecting a perpendicular from the genotype markers to the environment vector, i.e. entries that are further along in the positive direction of the vector show higher rates of linear HI increase and vice versa (Kroonenberg, 1997). Acute angles between any two environmental vectors indicate positive associations, i.e. they influence the genotypic relative DHI in a similar manner; 90º angles indicate no association; and angles greater than 90º indicate negative associations. VT9 and VT9 showed a positive association, indicating that they discriminate among genotypes for DHI in a similar way, while they associated negatively with V27, indicating contrasting effects on the genotypic relative performance for this trait. Treatments 1, 6 and 9 showed a possitive association with the vectors of VT7 and VT9, indicating that they improve their relative performance in these environments. These hybrids constituted a group of C-adapted hybrids identified by hierarchical agglomerative clustering over 21 testing environments of Argentina (de la Vega *et al*., 2000). The N-adapted and broadly-adapted genotypic groups associated positively to V27. Mean values of linear HI increase duration were 36.3 d, 38.2 d and 32.8 d for VT7, VT9 and V27 respectively (Table 1). We did not detected a significant G×E interaction for this attribute (P = 0.0740).

Table 1. Rate and duration of harvest index linear increase for each genotype-environment combination. Environments are Venado Tuerto october planting 1996/97 (VT7), and 1998/99, (VT9) and Venado Tuerto, December planting 1996/97 (V27)

Genotype		Daily harvest index increase			Time from full anthesis to the end of linear harvest index increase (d)		
		VT7	V27	VT9	VT7	V27	VT9
1	Contiflor 15	0.0138	0.0099	0.0131	33.1	33.8	34.4
2	Aguará	0.0127	0.0135	0.0128	36.9	29.5	34.7
3	GV23105	0.0121	0.0120	0.0131	35.6	34.3	31.9
4	GV25015	0.0122	0.0134	0.0125	39.6	29.4	31.0
5	GV25086	0.0124	0.0128	0.0124	37.0	31.1	33.8
6	TC 2001	0.0129	0.0099	0.0137	35.1	33.8	31.0
7	GV23146	0.0125	0.0129	0.0128	37.1	32.4	33.6
8	GV22510	0.0124	0.0116	0.0120	35.0	35.6	33.2
9	Contiflor 9	0.0127	0.0104	0.0148	38.8	35.8	31.3
10	Morgan 734	0.0108	0.0124	0.0134	35.0	32.2	32.9
Mean		0.0125	0.0119	0.0130	36.3	32.8	32.8

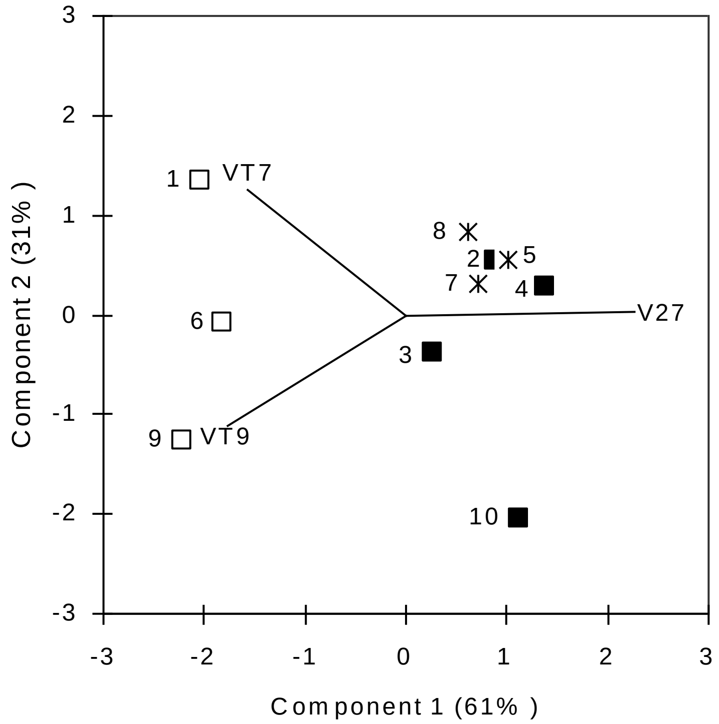

Figure 1. Biplot of the 1st and the 2nd principal components for of daily linear HI increase of 10 sunflower hybrids grown in 3 environments. Genotypes are represented by points and environments are represented by vectors. Same entry markers indicate genotype groups with members of a similar response pattern for oil yield over 21 environments of Argentina (de la Vega *et al*., 2000): N adapted hybrids (2, 3, 4, 10), C adapated hybrids (1, 6, 9), broadly adapted hybrids (5, 7, 8). Environments are Venado Tuerto October planting 1996/97 (VT7), and 1998/99, (VT9) and Venado Tuerto, December planting 1996/97 (V27).

Table 2. Time from full anthesis to the end-point of grain filling in three portions of the floral disk for each genotype-environment combination. See Table 1 for genotype names. Environments are Venado Tuerto october planting 1996/97 (VT7), and 1998/99, (VT9) and Venado Tuerto, December planting 1996/97 (V27)

Genotype	Periphery			Intermediate portion			Center		
	VT7	V27	VT9	VT7	V27	VT9	VT7	V27	VT9
1	34.8	26.4	30.5	36.4	25.6	36.7	38.3	34.9	38.7
2	27.6	27.2	31.5	35.2	32.7	37.0	42.8	34.1	43.7
3	29.7	25.3	25.6	32.9	31.7	29.9	40.2	31.6	35.0
4	25.1	24.3	24.1	31.1	27.6	28.0	37.5	32.5	31.6
5	34.5	28.4	30.7	38.1	28.9	35.7	37.8	39.8	40.3
6	30.6	23.8	25.9	34.4	26.1	33.1	40.8	33.2	37.4
7	27.4	26.4	29.6	34.9	30.2	35.0	36.0	32.4	38.1
8	34.0	27.1	31.4	38.0	31.9	35.8	41.1	33.5	40.4
9	33.7	25.4	32.8	35.7	24.5	37.1	42.2	39.4	41.4
10	29.3	25.6	29.3	33.6	33.8	34.3	34.7	37.6	38.8
Mean	30.7	26.0	29.1	35.0	29.3	34.3	39.1	34.9	38.5

The values of grain filling duration for the three portions of the head for each genotype-environment combination are detailed in Table 2. Significant G×E interactions for rate (intermediate portion: $P = 0.0004$) and duration (intermediate portion: $P = 0.0028$) of grain filling were found. Oil yield showed a significant association with daily HI increase, and lack of association with duration of linear HI increase (Figure 2). The time elapsed between full anthesis and the end-point of the linear HI increase showed a weak positive association with the time elapsed between full anthesis and the end-point of grain filling in the central portion of the head (r = 0.36, $P < 0.05$), while it did not associate with the time elapsed between full anthesis and the end-points of grain filling in the periphery (r = 0.27, NS) and the intermediate portion (r = 0.25, NS) of the head. On average, the end-point of the linear HI increase (34.0 d) was intermediate to the end-points of grain filling in the intermediate (32.9 d) and the central portion (37.5 d) of the floral disk.

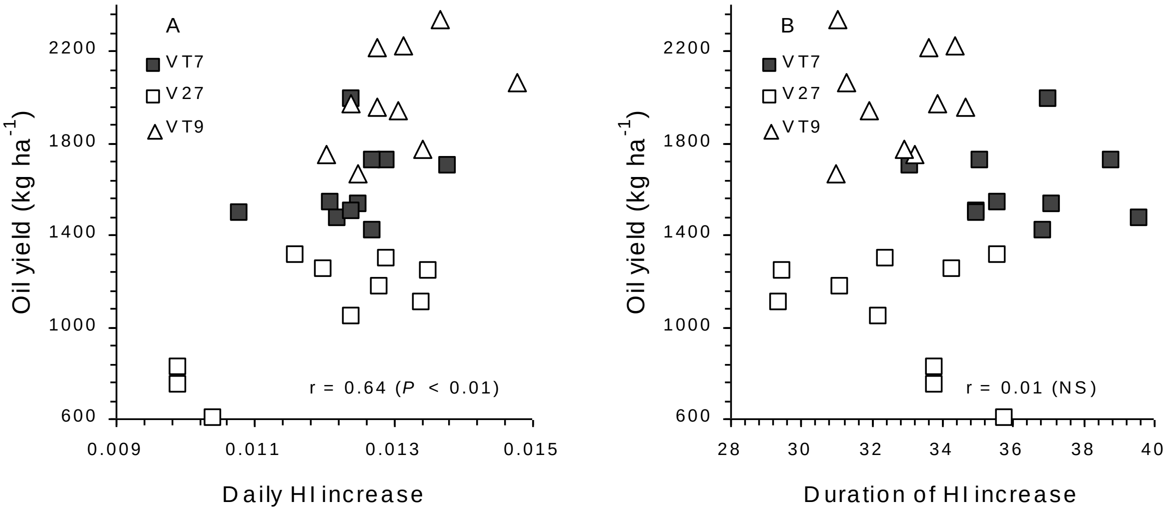

Figure 2. Oil yield/daily harvest index increase (A), and oil yield/time elapsed between full anthesis and end of linear harvest index increase (B) relationships for 10 sunflower hybrids grown in three environments of Argentina. Environments are Venado Tuerto October planting 1996/97 (VT7), and 1998/99 (VT9), and Venado Tuerto, December planting 1996/97 (V27).

Discussion

Principal component analysis on environment-standardized matrices of rate of linear HI increase revealed that this trait shows similar patterns of association among environments and discrimination among genotypes to those found for oil yield by de la Vega *et al.* (2000). This suggests that the response of the dynamics of HI increase to environment may contribute to the observed G×E interactions. Figure 3 shows the HI/time from anthesis relationships for three genotypes of contrasting responses for rate an duration of linear HI increase and two contrasting environments. Treatment 1, which improved its relative performance in VT7, strongly decreased the rate of HI increase in V27, while treatment 10, which showed a contrasting relative performance across environments in comparison to treatment 1, increased the rate of HI increase in this environment. This Figure also clearly shows that the finally achieved HI showed a stronger association with rate of HI increase than with the duration of linear HI increase. We conclude that, for sunflower, the rate of linear HI increase is not a stable attribute across genotypes and environments.

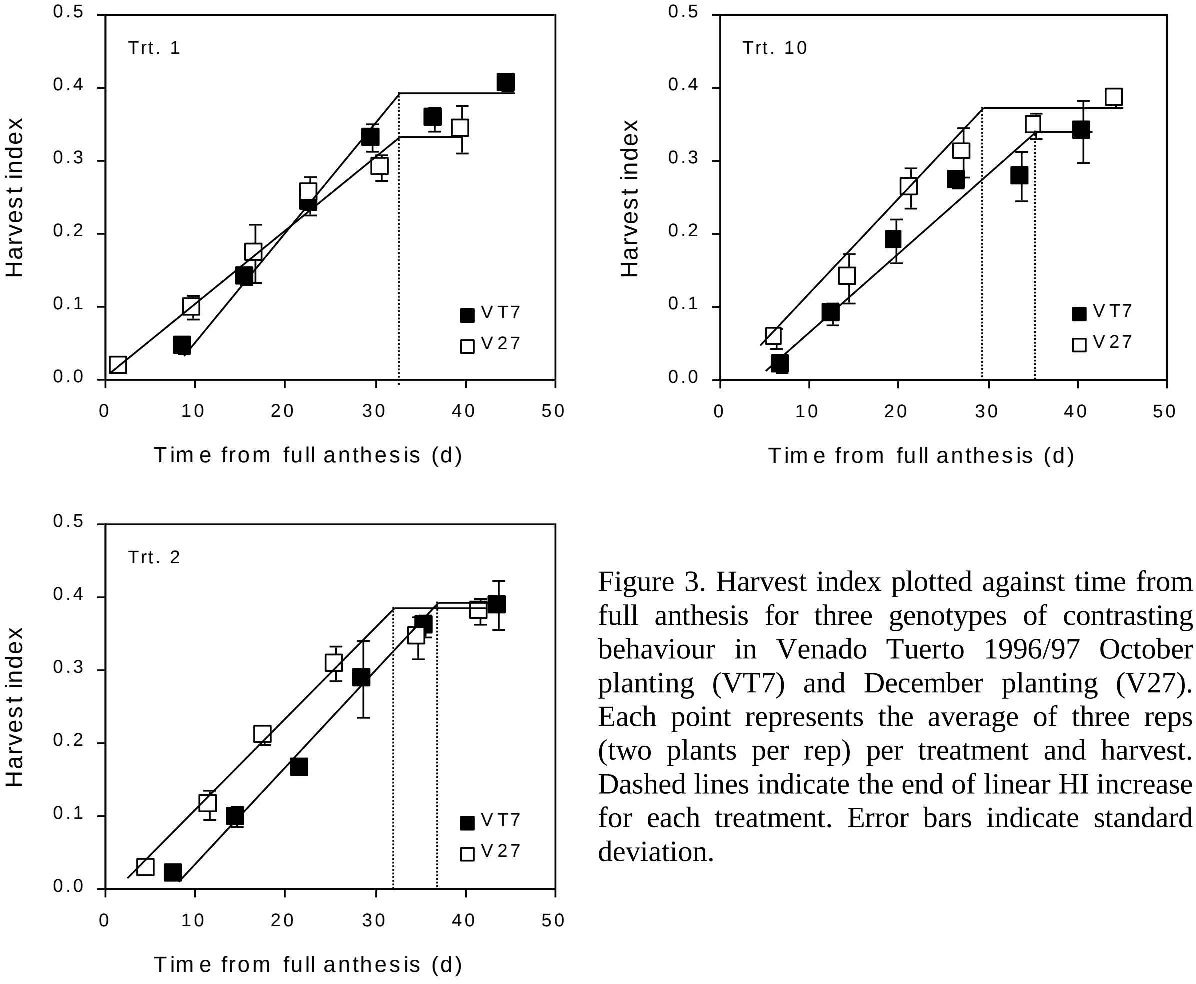

Figure 3. Harvest index plotted against time from full anthesis for three genotypes of contrasting behaviour in Venado Tuerto 1996/97 October planting (VT7) and December planting (V27). Each point represents the average of three reps (two plants per rep) per treatment and harvest. Dashed lines indicate the end of linear HI increase for each treatment. Error bars indicate standard deviation.

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