CROP PHYSIOLOGICAL DETERMINANTS OF YIELD IN OLD AND MODERN SUNFLOWER HYBRIDS

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Abstract

This paper reports the results of a four-year study (2000-2003) conducted in three locations in France (Clermont-Ferrand, Montpellier, Toulouse) to determine the contribution of pre-and post-anthesis phases to grain yield build-up for a broad range of old and modern sunflower cultivars. The key factors of potential yield related to the variability observed among the cultivars studied were light interception and photosynthetic activity from flowering to plant maturity. A large leaf area index (LAI) at anthesis, and its maintenance, with only a limited decrease of leaf nitrogen content during grain filling appear to be the main characteristics of the high-performance cultivars. An increased efficiency of leaf to light interception was also observed among modern cultivars.

Introduction

A multilocal four-year study (2000-03) was conducted to determine the main crop physiological variables responsible for genetic improvement among sunflower hybrids commonly grown in France since 1970. A preliminary study in 2000-01 on a wide experimental network showed that the yield potential has increased by 40 % since 1970 (0.035 t ha/yr or 1.3 % per yr) with an acceleration of gain in recent years (Vear et al., 2003). Increased disease (*Sclerotinia* head rot, *Phomopsis*) and lodging resistance contributed to yield gain with modern cultivars. Improvement in seed yield was due to increased seed number m sq. in the period 1975-1985, but then to an increase in seed size. However, no obvious increase in seed oil content was observed.

Another way to break down yield from a perspective of functional analysis of genetic improvement, is to define grain yield (GY) using five key variables (Bange et al., 1996): crop duration (n, in days), incidence of photosynthetically active radiation on day j (PARj, MJ/m sq.), fraction of radiation (PAR) intercepted on day j (FRIj), radiation use efficiency j (RUEj), harvest index (HI). TDM = total aboveground dry matter.

$$GY = TDM \text{ x } HI = \left(\sum_{j=1}^{n} PARj \text{ x } FRI_j \text{ x } RUE_j\right) \text{ x } HI$$

According to Beer's law, the fraction of radiation intercepted by the canopy (FRI) depends on leaf area index (LAI) and the canopy extinction coefficient (k).

The objectives of this experimental study were firstly to determine the variability of LAI, k, RUE and HI for old and modern sunflower hybrids and secondly to identify indicators of increased productivity useable in sunflower breeding programmes.

Materials and Methods

Genotypes. Twenty sunflower genotypes were grown in Clermont-Ferrand (CLF) in 2000-01 and Toulouse (TLS) in 2001, then a selection of these genotypes was evaluated at Montpellier (MTP) in 2001-02, Clermont-Ferrand (2002-03) and Toulouse (2002-03). Most of the cultivars were chosen because they were widely grown for a number of years and because they represent the French sunflower crop over the last 30 years (Vear et al., 2003):
1- Peredovik (1960), 2- INRA6501 (1970), 3- Remil (1974), 4-Airelle (1973), 5-Relax (1975), 6-Mirasol (1978), 7-Primasol (1979), 8-Cargisol (1983), 9-Viki (1984), 10-Frankasol (1984), 11-Albena (1988), 12-Vidoc (1989), 13-Euroflor (1988), 14-Santiago (1993), 15-DK3790 (1994), 16-Rigasol/Prodisol (1995), 17-Melody (1996), 18-LG5660 (1998), 19-AllStar (1999), and 20-Heliasol (2000).

Crop Management. The field experiments (13 trials) were arranged in randomised three-block designs and differed by nitrogen and water availability (soil depth, annual rainfall, evaporative demand, irrigation, N-fertilization). Potential yield (> 4 t/ha) was obtained at CLF (deep soil), MTP-2001 (full irrigation) and TLS-2002 (irrigated and highly fertilised management). Weeds and diseases were controlled to prevent severe crop damage.

Measurements. Each genotype was characterised by 10-15 individual plants selected and ringed for *in situ* measurements throughout the season or from early anthesis onwards. Leaf area (LA) was determined from early anthesis (F1) to physiological maturity (M3) by measuring the length and width of leaves (active + senescent). The fraction of PAR intercepted by the canopy resulted from measurements using the Picqhelios apparatus (Toulouse) and the LAI-Meter LICOR 2000 (Montpellier) as soon as soil covering was sufficient. The extinction coefficient was calculated by an exponential adjustment between FRI and LAI values. Total aboveground biomass (TDM) and achene yields (GY) were measured at harvest and HI was calculated as the ratio of GY to TDM. The radiation use efficiency (RUE) was determined as the ratio of TDM to cumulated intercepted PAR during a given phenological phase.

Results and Discussion

Maximal Leaf Area (LA). In spite of large variations in maximal plant leaf area (4,000-10,000 cm sq. for cv. Melody) due to differences in weather, soil depth, irrigation, nitrogen applied and plant density between the 13 situations, the relative ranking of the genotypes was mostly stable (Table 1).

Table 1. Productivity Index (PI=% grain yield of Melody), Position of the largest leaf (high/low), Leaf number (LN) and Plant leaf area (LA, cm²) for 20 cultivars and a range of weather and management conditions. LA is relative to that of Melody, the most productive cultivar.

Cultivar	PI	Largest leaf	LN	Leaf area								
			TLS	CLF				TLS			MTP	
			2001	2000	2001	2002	2003	2001	2002 **	2003	2001	2002 ***
1-Peredovik	60	high	27.2	82	88	-	-	71	-	-	-	-
2-INRA6501	66	high	26.0	76	105	-	-	71	-	-	-	-
3-Rémil	65	high	23.7	-	79	-	-	77	-	-	-	-
4-Airelle	63	high	28.7	-	85	-	-	82	-	-	-	-
5-Relax	74	low	28.2	-	81	-	-	73	-	-	-	-
6-Mirasol	72	low	31.5	99	93	-	-	102	-	-	91	-
7-Primasol	65	low	28.1	77	83	76	-	72	73	-	-	-
8-Cargisol	77	high	28.3	-	91	-	-	89	-	-	-	-
9-Viki	81	low	31.2	-	95	-	-	93	-	-	-	-
10-Frankasol	75	high	28.4	-	97	-	-	69	-	-	-	-
11-Albena	78	low	31.8	114	82	87	86	80	88	82	96	87
12-Vidoc	72	low	30.8	-	101	94	102	94	85	88	-	114
13-Euroflor	84	high	30.6	112	117	-	-	100	-	-	-	-
14-Santiago	80	low	27.5	68	65	73	73	67	72	62	-	-
15-DK3790	82	low	30.9	-	75	98	-	90	-	-	-	-
16-Prodisol	91	high	25.0	89	94	76	87	78	85	73	75	78
17-Melody	100	high	29.2	100	100	100	100	100	100	100	100	100
18-LG5660	95	high	28.9	98	121	85	108	104	114	105	-	-
19-AllStar	87	low	30.1	-	73	-	-	77	-	-	-	-
20-Heliasol	88	high	26.0	120	116	87	89	90	92	71	75	119
Melody,LA cm²				6730	6623	8994	10627	4008	7843	7018	8639	7944

For instance, relative LA was 0.69 for cv. Santiago, 0.88 for cv. Albena, 0.94 for cv. Vidoc, 1.05 for cv. LG5660. However, the variation of relative LA was large for cv. Heliasol (0.71-1.20) and cv. Prodisol (0.76-0.94). In general, the oldest genotypes (number 1-5) had lower LA with negative consequences on radiation interception, biomass production and seed number. However, for cultivars registered after 1975, genetic improvement was not related to leaf number, vertical distribution of LA (high/low) or LA.

Fraction of Radiation Intercepted (FRI). The seasonal time-course of PAR interception was compared for 5 cultivars at Montpellier (2001) under nonlimiting conditions (Figure 1). PAR interception was greatest for cv. Heliasol and cv. Melody during the first period of leaf area growth. In addition, leaf senescence started later than for cv. Albena, cv. Mirasol (low-types) and cv. Prodisol (low LA). The differences between genotypes occurred mainly during the latest part of the growing season (from stage M1 onwards). Between M1 (yellow head) and M3 (physiological maturity), radiation interception (FRI) averaged 75% for Albena, 78 % for Prodisol, 79 % for Mirasol, 80 % for Heliasol and 89 % for Melody, which is the most

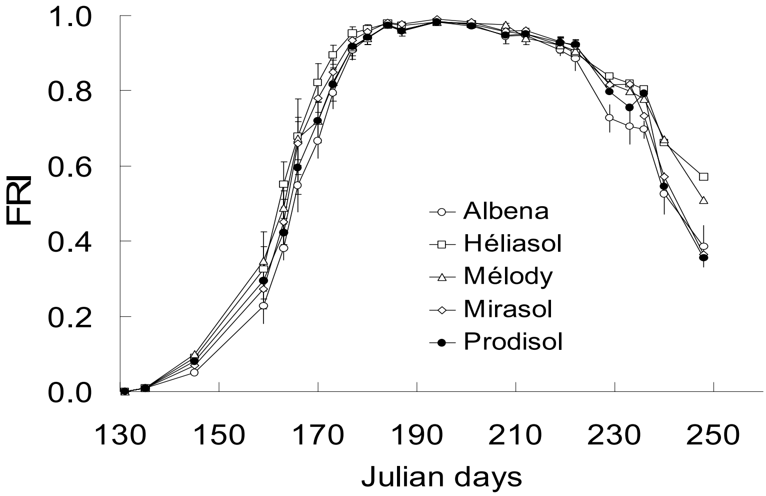

Figure 1. Seasonal time-course of FRJJ for 5 cultivars in nonlimiting conditions (MTP-2001).

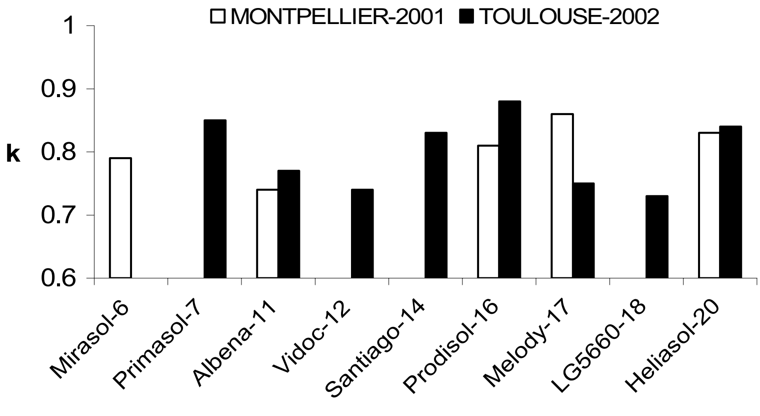

Figure 2. Variation of the extinction coefficient (k) for a range of sunflower genotypes, MTP-2001, TLS-2002.

productive cultivar. This ranking was attributed to a large active LA in the upper part of the canopy during grain filling for high-types (Table 1), but also to the duration of F1-M3 period: 46-47 days (Albena, Mirasol, Prodisol), 49 days (Heliasol), 54 days (Melody).

Another factor of variation between genotypes was the efficiency in intercepting radiation per unit of leaf area. Modern cultivars were more efficient in general which resulted in higher values of the extinction coefficient (Figure 2). This should result in a higher photosynthetic activity and a lower maintenance respiration of leaf area.

Radiation Use Efficiency (RUE). RUE from A2 (emergence) to M0 (beginning of grain filling) was not significantly different among 5 (Montpellier, 2001) and 8 cultivars (Toulouse, 2002). Photosynthesis activity did not appear to be affected by genetic improvement. The mean values were 2.35 g per MJ of intercepted PAR at Montpellier (2.24-2.48) and 2.16 at Toulouse (2.10-2.23), within the range indicated by Sinclair and Muchow (1999) for sunflower. Differences were observed within the season; for instance, at Toulouse (2002), values were 1.66 g per MJ of intercepted PAR from emergence to flower bud (E1), 2.46 from E1 to early anthesis (F1), 2.67 from F1 to M0, and 2.22 from M0 to M3 under nonlimiting conditions. Most of the differences between cultivars were observed between M0 and M3 stages (Figure 3). The decrease of RUE after M0 was associated with the rate of leaf senescence and the decrease in leaf N content in the upper part of the canopy, which were extremely different among cultivars. Old genotypes were characterised by a rapid drop of RUE during grain filling with dramatic consequences on biomass accumulation.

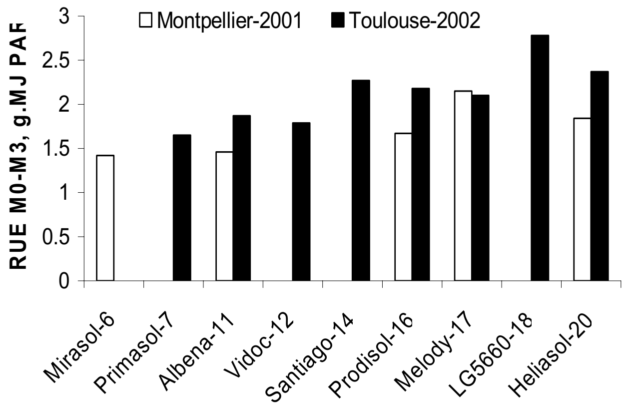

Figure 3. Radiation-use efficiency (RUE) during grain filling for a range of cultivars (MTP-2001, TLS-2002).

Harvest Index. A part of genetic improvement was related to a steady increase of harvest index with the year of cultivar official registration (Figure 4), as a result of more carbohydrate accumulation during grain filling and more redistribution from the vegetative parts (capitulum, stem). Total harvest index and capitulum harvest index were satisfactorily correlated ($r^2 = 0.66$, TLS-2003). Similarly, in Argentina, HI increased from 0.35 to 0.51 for 7 hybrids registered from 1966 to 1993 (Lopez Pereira and Trapani, 1996).

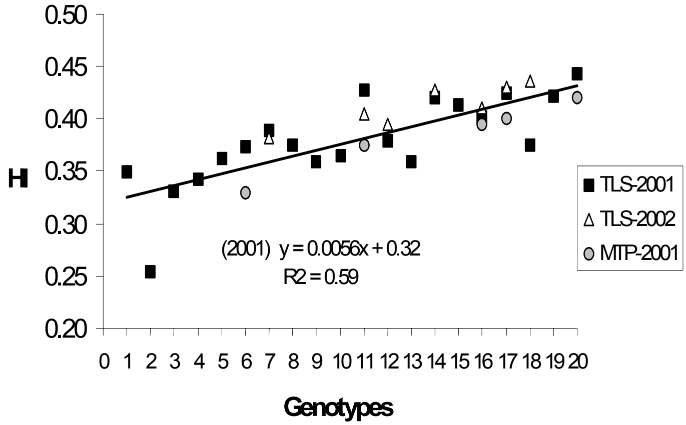

Figure 4. Increase of harvest index with the year of cultivar official registration.

Productivity Index. An index of crop productivity was calculated by multiplying ΣPARi (M0-M3) by RUE (M0-M3) and HI (Table 2). It was demonstrated that the grain filling period was the most discriminating one between old and modern cultivars. Values are given for Montpellier (2001 and 2002) and Toulouse (2002). Albena was chosen as a reference cultivar (100). The crop productivity ranking observed in 2000-2001 using the experimental network composed of 25 French pedoclimatic situations was not very different from the results observed at Montpellier and Toulouse. Cultivars Primasol, Mirasol and Vidoc resulted in yields less than cv. Albena while cv. Melody and LG5660 were found to be the best cultivars. The performances of cv. Heliasol and Prodisol were not correctly represented by the productivity index. Genotype x environment interactions were found with these cultivars. Yield improvement was achieved by increasing ΣPARi (Melody, Heliasol), RUE (Melody, LG5660, Heliasol, Prodisol) and (or) HI (Melody, LG5660, Heliasol, Santiago).

Table 2. Comparison of a genetic gain index (Vear et al., 2003) and a productivity index combining three crop physiological processes measured during grain filling at Montpellier (2001-2002) and Toulouse (2002). Albena = reference (100).

Cultivar	Genetic gain index	Radiation interception index (PARi M0-M3)		Photosynthetic index (RUE M0-M3)		Redistribution index (HI)		Productivity index (PARi x RUE x HI)	
		MTP	TLS	MTP	TLS	MTP	TLS	MTP	TLS
6-Mirasol	92	105	-	86	-	86	-	78	-
7-Primasol	83	-	91	-	86	-	94	-	74
11-Albena	100	100	100	100	100	100	100	100	100
12-Vidoc	92	104	93	97	95	88	98	89	87
14-Santiago	102	-	102	-	99	-	106	-	107
16-Prodisol	116	104	103	109	98	98	102	111	103
17-Melody	128	112	109	120	106	100	107	134	124
18-LG5660	122	-	100	-	113	-	108	-	122
20-Heliasol	112	112	104	109	101	105	116	128	122

Conclusions

The different modifications which have given improved crop productivity among the genotypes studied were determined under near-optimal conditions. These modifications focussed on two processes: (i) light interception and (ii) photosynthesis activity. Both processes have been improved through an increase in duration of the post-floral period, leaf area index, leaf area duration and harvest index. Maintaining a high N content in leaves during grain filling should result also in high values of RUE. The way biomass is allocated to the different organs needs to be analysed in more detail for different genotypes.

Simple indicators of crop productivity are suggested to represent crop functioning during the post-floral period. Total leaf area (LAmax), residual LA (at anthesis + 20 days) and nitrogen decline between F1 and F1+20 days (presented in Triboi et al., 2004) could be possible variables to describe the photosynthetic activity of the sunflower canopy during grain filling. Such indicators would be more suitable for breeding purposes than RUE which is difficult to estimate routinely. A large leaf area index at anthesis, and its maintenance, with only a limited decrease of leaf nitrogen content during grain filling, are key factors of potential yield. The heredity of these leaf characters was evaluated from a breeding perspective (Triboi et al., 2004).

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