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Effect of cultural conditions on yield, oil content and fatty acid composition of sunflower kernel

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Summary: Fatty acid composition is a major aspect for sunflower oil use. Industrial demands in terms of fatty acid balance are largely diversified: high oleic acid content associated with low polyinsaturated fatty acids content is required for food uses, stearic acid is frequently required for cosmetic products, while paint products industries need oil with high linoleic acid proportion. Sunflower produces high oil seed content and furthermore fatty acid composition varies according to genotypes and environmental conditions.

The objective of this study is to characterize yield, oil content and fatty acid contents under different water availabilities and climate conditions. Two sunflower cultivars with specific fatty acid balance are tested ("oleic+" and "current" cultivars). Field experiments are carried out in the "Rotations-Quality" device located in the INRA Toulouse-Auzeville center. Data are collected during three years distinguishable by climatic sequences (rainfall and temperature) during reproductive phase.

As expected, yield, oil content and fatty acid proportion are significantly influenced by environnmental conditions. Water stress during seed filling is generally associated with an increase of palmitic and stearic acid contents. The unsaturated fatty acid accumulation appears highly sensitive to environmental conditions: temperature enhancement has a significant effect on the oleic/linoleic balance. These compounds present an opposed behaviour: an increase of linoleic acid content occurs with a decrease of oleic acid content when temperatures are lower. Depending on cultural conditions, cultivars exhibit different sensitivity to environmental conditions: for fatty acids composition the "oleic+ cultivar" seems more stable than "current" cultivar.

These three years data clearly show that, in addition to the genotype choice, fitted cultural conditions must be established to obtain a specific production which satisfies the industrial demand.

Résumé: La composition en acides gras est prépondérante pour l'utilisation de l'huile de tournesol. En fonction des débouchés industriels, la composition exigée est variable (teneur élevée en acide oléique et faible en acide gras polyinsaturés pour des débouchés alimentaires, teneur importante en acide stéarique souhaitée dans la conception de produits cosmétiques ou recherche d'une huile riche en acide linoléique pour la fabrication des peintures). Le tournesol présente une teneur importante en huile et une composition en acides gras variable selon les génotypes et conditions environnementales.

L'intérêt de l'étude est d'évaluer l'impact des conditions culturales (apport hydrique en phase post-florale) et climatiques sur le rendement, la teneur en huile et la composition en acides gras de l'akène et ce pour 2 cultivars présentant des teneurs en acides gras spécifiques (cultivars "oléique" et "classique"). Les essais ont été réalisés en champ sur le dispositif "Rotations-Qualité" de l'INRA Toulouse-Auzeville, au cours de 3 années bien différenciées par les pluies et les températures pendant la phase de remplissage.

Comme attendu, rendement, teneur en huile et proportion des acides gras sont significativement influencés par les conditions du milieu. Un déficit hydrique durant le remplissage des graines est généralement associé avec une augmentation de la teneur en acides palmitique et stéarique. L'accumulation des acides gras insaturés présente une grande sensibilité aux conditions culturales : l'élévation de température modifie significativement le rapport oléique/linoléique. Ces 2 acides gras ont un comportement antagoniste: l'augmentation de la teneur en acide linoléique correspond à une baisse de l'acide oléique en particulier lorsque la température est basse pendant la phase de remplissage. Dans les différentes conditions de culture, la composition de la graine de la variété "oléique" est plus stable.

Ces données pluriannuelles confirment qu'outre le choix génotypique, des conditions culturales adaptées doivent être établies pour l'obtention d'une production spécifique répondant à la demande industrielle.

Introduction

The diversification of sunflower production for human and non-food purposes (cosmetics, paints, etc.) demands that the oil and fatty acid composition of the seed be adapted to these uses.

This adaptation can be brought about ; (1) by the selection of improved genotypes and/or (2) by the use of appropriate cropping practices. Our work involves the latter, and seeks to maintain optimum yield AND a given fatty acid content. Recent reports have underlined the impact of water stress (Tyankova et al., 1987) and temperature (Ungaro et al., 1997) on fatty acid composition. Our study evaluates the impact of cropping practices on the biochemical makeup of the seed.

Materials and Methods

The trials were carried-out on the 540 m2 multi-use "Quality/Rotation" experimental design (loamy clay) at the Toulouse-Auzeville INRA and established since 1994. These plots were set-up to evaluate different cropping practices, mainly irrigation scheduling, seeding date, reduced inputs and the effects of improved genotypes on yield and seed quality.

Two genotypes were compared ; a "classic" one (cv. Select) and an improved selection (Proléic 204, or "Oleic+") in terms of oleic acid content. Two water regimes were installed over the three years (1995 - 1997) of the study ; (1) a budgeted, post-flowering irrigation based on 70% of the water needs of the sunflower so as to limit disease and lodging, and promote the translocation of the assimilates, and (2) a non-irrigated check.

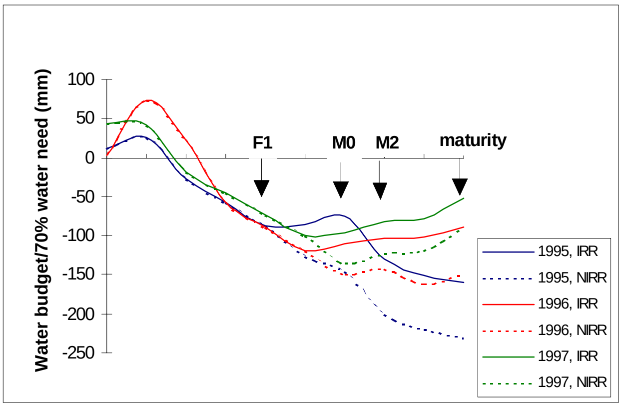

figure 1: hydric budget during the growth cycle

Stages	1995		1996		1997	
	T° sum	*mean T°*	*T° sum*	*mean T°*	*T° sum*	*mean T°*
em-F1	988	18.9	895	17.7	938	18.6
F1-M0	303	23.8	211	23.7	271	21.9
M0-M2	252	**24.1**	170	**22.5**	169	**24.8**
M2-Mat	194	19.0	545	19.6	403	22.8

tableau 1: Sum of temperatures and mean temperatures during the growth cycle

Growth cycle criterion: **em**: emmergence, **F1**: flowering beginning, **M0**: Flowering end, **M2**: seed humidity=20-25% and the back of the head is yellow, **Maturity**: seed humidity= 10% and all organs of the plant are brown

The climate and water-stress data are presented in Table 1 (sum of temperatures and mean temperatures) and Figure 1 (Water budget at the different stages of the growth cycle). The contrast between the three years was appreciable. For instance, temperature differences of up to 2.3 C were observed at the MO-M2 growth stage critical for oil accumulation (Champolivier and Merrien, 1996). Grain filling was also distinctive as a result of different yearly water regimes. For instance, under irrigated conditions in 1995, excess water was observed between F1 and M0, but only between M0 and M2 in 1996 and 1997. In 1995 and under non-irrigated conditions water deficits were continuous through-out the reproductive cycle.

The measured yield components were the following ; yield at 0% residual humidity at maturity, achene RMN-determined oil content, the ratio between the differing fatty acids and the CPG-determined lipid fraction.

The effects "variety", "year" and "water regime" were estimated via a three-way ANOVA, whereas the relationships between the various measured yield components were estimated using a Sigmastat linear regression.

Results and Discussion

a) Yield - achene oil content relationship

	Yield 0% RH (q/ha)			Oil Conteznt (% seed DM)			
Genotype	Mean	Max	Min	Mean	Max	Min	r
Classic	25.5 a	34.0	16.0	52.3 a	55.3	44.4	0.79 **
Oleic+	23.7 b	31.6	16.9	50.06 b	52.8	46.6	0.58*

Table 2: Yield and seed oil content (mean, maximum and minimum) and correlation coefficients (r) of yield-oil content relationship (*: significant, α=0.05 **: highly significant, α=0.01), values with the same letter are not significantly different (Tukey test)

In general, the classic variety yielded more and had a significantly higher oil content that the Oleic+ cultivar. *(*Table 2***)*.**

The relationship is significantly positive for both varieties, though it is less so for the Oleic+ cultivar. Though their yield response is similar, the mean distribution is greater for Oleic+ indicating that its response to environmental conditions is less than that of the classic variety. The effect of the water regime on this latter relationship is presented in Figure 2.

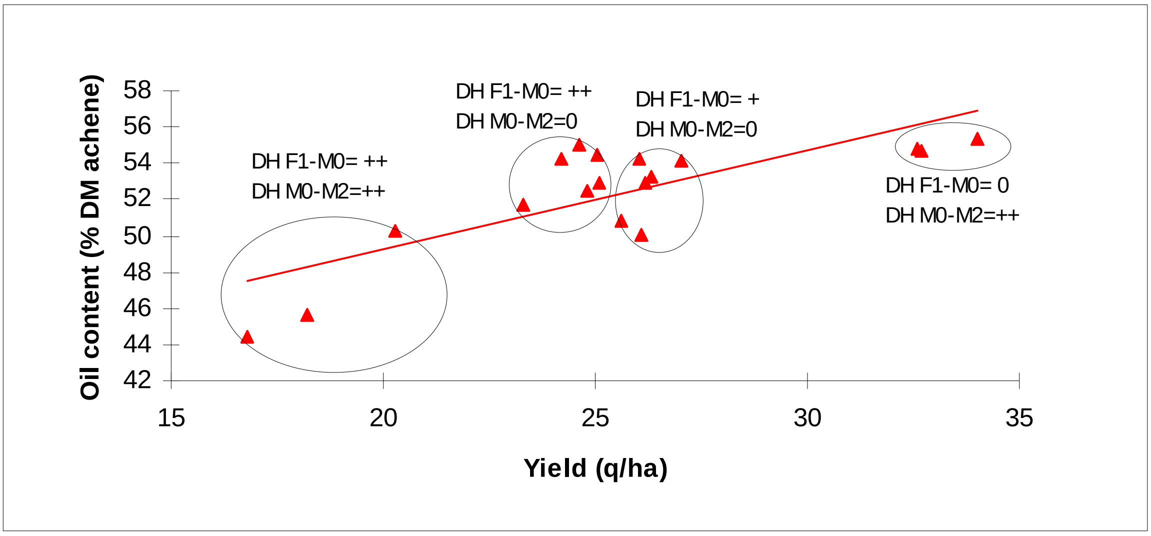

Figure 2. The relationship between yield and oil content of the classic cultivar, DH= Hydric Deficit measured between F1-M0 and M0-M2 stages. 0= no deficit, += deficit<-25mm, ++= Deficit>-50mm

It is the post-flowering water regime that induces this changing relationship.

However, yield is the most sensitive variable, especially between F1 and M0 when water stress can reduce the number of seeds / m2, an essential yield component (Steer and Hocking, 1987).

In general, water stress is most important between F1 and M2 when it can abort seeds and thus reduce yield, or prevent achene filling and thus reduce oil content. In fact, lipidogenesis being the result of metabolite assimilation towards the end of the growth cycle, a late water stress induces early senescence of the canopy and reduces the flux of photosynthates otherwise allocated to lipidogenesis (Flénet et al., 1994).

b) Oil content and saturated fatty acid lipid fraction relationship

	Content (%)		Relation with oil content	
Genotype	Classic	Oleic+	Classic	Oleic+
% Oil	52.3 a	50.1 b		
% satured	9.9 a	7.0 b	-0.70 **	-0.54 **
%C16:0	5.73 a	3.46 b	-0.56 **	-0.02
%C18:0	3.45 a	2.66 b	-0.70 **	-0.70 **
%C20:0	0.67 b	0.84 a	-0.78 **	-0.41

Table 3: Oil content (% seed DM), fatty acids ratio in the oil fraction (%), correlation coefficients (r) of oil-fatty acids relationship (**: highly significant, α=0.01), values with the same letter are not significantly different (Tukey test)

The classic genotype is richer in oil and saturated fatty acids, especially so as a result of stearic and palmitic acid accumulation by the achene. The Oleic+ variety has a higher (92.1%) proportion of saturated fatty acids that the classic one (89.1%).

There is an inverse relationship between the oil and saturated fatty acid contents of both genotypes. However, this negative relationship is stronger for the classic variety (Table 3).

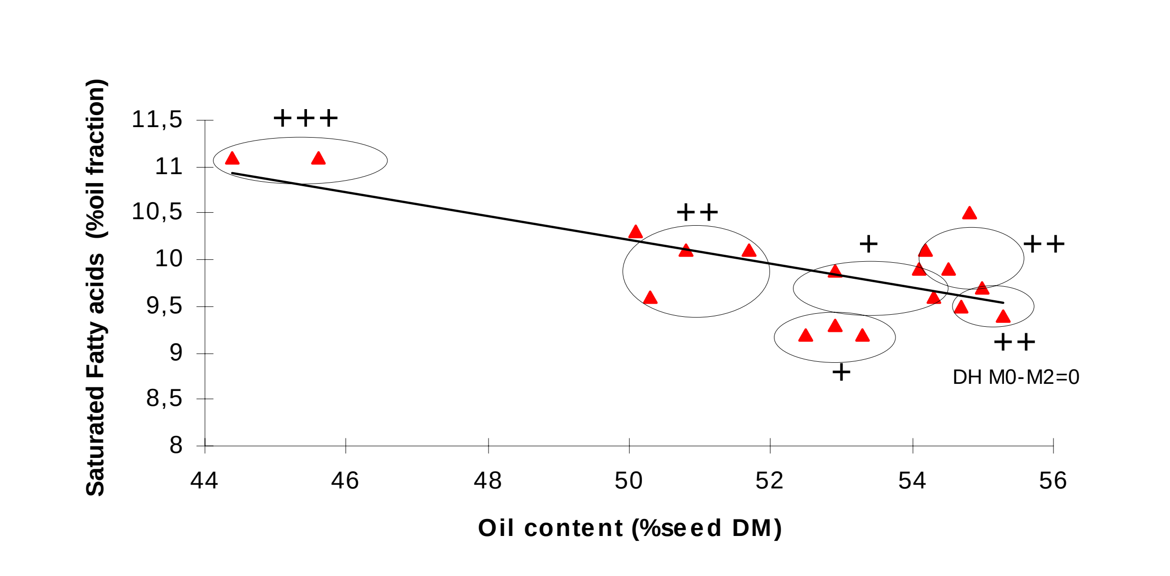

Figure 3. The relationship between oil content and fatty acids ratio in the oil fraction,of the classic cultivar, DH= Hydric Deficit measured between M0 and M2 stages. +=DH<-15mm, ++= -40<DH<-60mm, +++=DH>-100mm

The changing %Oil *vs* SFA relationship as a result of water stress during grain filling is illustrated in Figure 3.

Temperature had no effect on either variable thus confirming the results of Champoliver and Merrien (1996).

High oil contents appear to depend on the water status of the plant during the F1-M0 period, and later during the M0-M2 period. The SAF ratio appears to be governed by the water regime between the F1 and M2 stages, though no single critical growth stage was identified. There results are in accordance with those obtained with soybean (Piva, personal communication).

c) Oleic and linoleic fatty acid proportions equilibrium :

	C18:1 (% oil fraction)			C18:2 (% oil fraction)			
Génotype	Mean	Max	Min	Mean	Max	Min	r C18:1-C18:2
Classic	32.2 b	36.1	26.7	57.1 a	62.0	51.7	-0.966 **
Oleic+	87.1 a	88.2	85.7	5.04 b	6.3	3.7	-0.762**

Table 4: Oleic and linoleic acids ratio in the oil fraction (mean, maximum and minimum) and correlation coefficients (r) characterizing the C18:1-C18:2 relationship (**: highly significant, α=0.01), values with the same letter are not significantly different (Tukey test)

This relationship is significantly negative for both varieties (Table 4).

The percentage difference between the maximum and minimum values indicate that these proportions are less variable for Oleic+ that for the classic variety ; i.e. 2.5 and 2.6 % for C18:1 and C18:2, respectively, for Oleic+ as compared to 9.4 and 10.3% for the classic variety. This stability of Oleic+ can be explained by the low activity of the *oleate denaturase* enzyme in the Oleic+ cultivar ; this enzyme is responsible for the synthesis of linoleic acid from its oleic precursor. On the other hand, the C18:1 / C18:2 variations in the classic cultivar (Figure 4) are a result of this enzyme's sensitivity to environmental conditions (Cheesbrough, 1989)

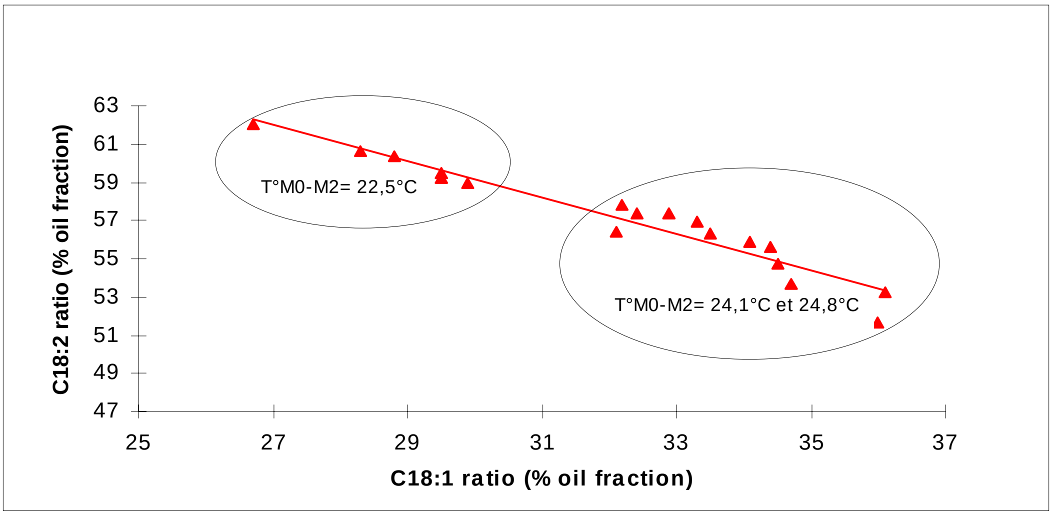

Figure 3. The relationship between oleic and linoleic acids ratios of the classic cultivar, T°M0-M2= mean temperatures between M0 and M2 stages

The inverse relationship between these fatty acids is a function of temperature. In 1996, during which the highest C18:2 contents were attained, the average temperature during fatty acid accumulation (M0-M2) was the lowest of three years (ie. 22.5 C as compared to 24.8 in 1997 and 24.1 in 1995). The increase in temperature limits the activity of *oleate desaturase* via a reduction in oxygen solubility (Cheesbrought, 1989). These field observations demonstrate that a difference in temperature 2 C less than those reported by

Canvin (1965) and Champolivier et al. (1996) (ie. 5 C) can nevertheless modify the C18:1 / C18:2 equilibrium.

Conclusion

Genotype and environment have pronounced impacts on the biochemical makeup of the sunflower seed. Adapted cropping practices can thus be used to obtained seed of predefined quality, and in particular the use of post-flowering irrigation that favors both yield and oil content while reducing the relative abundance of saturated fatty and linoleic acids.

The effect of temperature on biosynthesis as observed can be modulated using various seeding dates. In this respect a late-April seeding would ensure that the M0-M2 growth stage occurs in mid-July / early-August, time at which mean temperatures are the highest in south-western France ; the relative oleic acid content should thus increase.

The tested cultivars vary differently to similar environmental conditions, the Oleic+ cultivar being less variable than the classic one.

The next step in our study will be to establish water deficit and temperature "thresholds" that can be used to modify biochemical synthesis and makeup of sunflower seeds via the use of a greater number of genotypes and cropping pratices, and in particular seeding dates.

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