DROUGHT SUSCEPTUBILITY INDEX IN SUNFLOWER, A NEW APPROACH

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Summary

Drought limits sunflower production in Southern Europe. Thus, one of the research objectives in Spain, France and Italy is the development of hybrids adapted to this condition. The objective of this study was to analyze the drought susceptibility index (S) in sunflower hybrids, evaluated in irrigation-drought conditions in 7 localities of Southern Europe during 1993 and 1994. There were 58 hybrids planted in a simple latice design with three replicates. Seed yield, oil percentage and oil yield. were measured. The S index, proposed by Fisher and Maurer (1978), was calculated for these same traits. The statistical analysis was made using a bifactorial analysis of variance, linear and non linear regression analysis. The negative significant linear relation, found sometimes between S and yield potential, has been interpreted as the possibility to select genotypes with a high yield and drought resistance. The relative production drought/irrigation can be considered as an indicator of stability. Because S is based on this relation, it should be considered like a stability index also. Stability depends of the genotype x environment interaction (GxE), and this is the result of non additive effects. The GxE interaction could be linear or non linear, depending on the grade of the GxE interaction. Therefore it is not recommended to evaluate only the correlation between S and yield potential under irrigation, but also to evaluate the relation between S and yield under drought, and to search to for linear or non linear relations to understand if there are adaptation mechanisms only manifested in irrigation or drought conditions.

Introduction

One of the main problems that limit sunflower production in Southern Europe is drought (Merrien, 1992). Therefore one of the main research objectives in Spain, France and Italy, the main sunflower European producers, is the breeding and selection of genotypes for water stress environments (Merrien and Grandin, 1990; Snidaro and Danielis, 1993; Alza, 1995; and Gómez-Sánchez, 1998).

The drought susceptibility index (S) has been widely used to quantify drought resistance in many crops (Fisher and Maurer, 1978). These authors proposed the drought susceptibility index as $S = \frac{1-(Sy_d/Sy_p)}{1-(X_d/X_p)}$ where SY_d/SY_p is the proportional yield under drought, SY_d is the yield under drought and SY_p is the yield potential in irrigated conditions of each genotype. The term $1-(X_d/X_p)$ indicates the drought intensity or the reduction of the yield mean under drought conditions, considering all genotypes, Xd is the yield mean of all genotypes under drought and Xp is the yield mean of all genotypes under irrigation. This equation indicates the independent effects of the yield potential and the drought susceptibility from yield under drought for each genotype, in order to explain part of the specific genetic effects as part of the total variation under drought. In these terms a low susceptibility index is considered as a synonymous of a high drought resistance.

It has been demonstrated that the drought susceptibility index (S) was positively correlated with the potential yield under optimal soil water availability in wheat (Fisher and Wood, 1979) and maize (Fisher *et al*., 1984). This relationship suggests that the improvement of the resistance to drought can only be obtained at the expense of potential productivity. Nevertheless in sunflower a negative linear correlation between S and seed yield under drought conditions has been observed (Baldini *et al.*, 1992; Baldini and Vannozzi, 1998; Gómez-Sánchez *et al.*, 1998). Moreover there has been observed also in sunflower an absence of linear correlation between S and seed yield potential (Fereres *et al.*, 1986; Baldini *et al.*, 1991 and Gómez-Sánchez *et al.*, 1998).

These results indicate the concrete possibility to combine drought resistance and high yield potential in a same genotype and that selection for high yield potential in favorable areas should be an efficient selection criterion to identify higher yielding materials for drought stress conditions. Also these results indicate that there were more than one kind of relation between S and seed yield, depending on the level of water availability and from the genotypes studied (Vannozzi *et al.*, 1999). The objective of this study was to analyze the kind of relations between S and seed yield under irrigation-drought conditions in normal and interspecific sunflower hybrids.

Materials and methods

This work has been developed in 7 localities of Southern Europe, 1993 in Sevilla and Córdoba, Spain; and in Auzeville and Montpellier, France; in 1994 in Sevilla and Córdoba, Spain; Montpellier and Ondes, France; and in Lavariano and Valvasone, Italy. The genetic materials utilized were **Group 1:** 15 restorer lines (*H. annuus*) named normal lines, property of the seed companies Arlesa from Spain and Rustica from France. **Group 2:** 15 restorer lines derived from interspecific crosses named interspecific lines (*H. annuus x H. argophyllus, H. annuus x* *anomalus, H. annuus x H. niveus tephrodes, H. annuus x H. debilis, H. annuus x H. praecox, H. annuus x H. niveus canescens*) developed by INRA France. These male lines were crossed with the female cms lines HA89 and 887, developed by USDA and Rustica, respectively. From these crosses were obtained 52 hybrids, 26 normal and 26 interspecific, plus 6 commercial hybrids for a total of 58 hybrids evaluated.

These hybrids were seeded in field trials under controlled irrigation-drought environments. The experimental plots were arranged in a simple latice design with three replicates, and seed yield, oil percentage and oil yield by hectare were measured. The drought susceptibility index were calculated following the equation proposed by Fisher and Maurer (1978). The data obtained were analyzed utilizing a bifactorial statistical model for the factors localities equal to 10, obtained by the combination localities and years and for genotypes equal to 58. Linear and non linear regression and correlation analyses were made to study the kind and grade of relations between the drought susceptibility index with seed yield, oil percentage and oil yield.

Results and discussion

The analyses of variance for the drought susceptibility index calculated for seed yield, oil yield and oil percentage are shown in Table 1. For these three characters differences were highly significant among localities, genotypes and for the interaction localities per genotypes. These significant differences have been also reported in sunflower by Alza (1994) and Gómez *et al.*, (1998), in both cases evaluating other genetic sources and localities.

Table 1. Mean squares for drought susceptibility index (S) for seed yield, oil yield and oil percentage.

Source of variation	df	seed yield	oil yield	oil percentage
Model	599	1.04 ***	1.12 ***	5.08 ***
Localities (environments)	9	42.55	44.23 ***	200.5 ***
Error Rep.(localities)	20	2.91	3.02	3.07
Genotypes (hybrids)	57	0.49 ***	0.55 ***	5.26 ***
Localities x genotypes	513	0.31 ***	0.44 ***	1.7 ***
Error	1140	0.11	0.12	0.74
Total	1739			
C.V		2.99	3.52	7.90
R^2		0.8364	0.8541	0.7820

*** p≤ 0.0001

The relation and correlation between the drought susceptibility index for seed yield and seed yield in irrigation and drought conditions are presented in Table 2. For the group of hybrids HA89 x N under irrigation a significant logaritmic correlation was found and for HA89 x N under drought a significant and negative linear correlation was observed. For the group of hybrids 887 x N a negative and significant linear correlation was observed.

Table 2. Kind of relations and correlations between the drought susceptibility index for seed yield with seed yield, in irrigated and drought conditions, in the groups of hybrids HA89 x Normal and 887 x Normal (cultivated *H. annuus x H. annuus*) and HA89 x Interspecific and 887 x Interspecific (cultivated *H. annuus x Helianthus spp*).

Group of	Irrigation		Drought	
hybrids	Equation	r	Equation	r
HA89 x N	(1) Y = 3197.4 – 1974.8Ln(x)	0.5681 *	(1) Y = 2111.8 – 2563.3Ln(x)	0.7891 ***
HA89 x I	w.r	ns	w.r	ns
887 x N	w.r	ns	(2) Y= 3204.8 – 999.28x	0.6742 *
887 x I	w.r	ns	w.r	ns
Testers	w.r	ns	w.r	ns

(1) Logaritmic, (2) Linear, w.r without relation
* p≤ 0.05, *** p≤ 0.0001

In the Table 3 are shown the relations and correlations between the drought susceptibility index for oil yield with oil yield. significant polynomial correlations for HA89 x N and HA89 x I in irrigation, and for HA89 x N and 887 x N in drought were observed. A significant potential correlation was observed for 887 x I under irrigation.

Table 3. Kind of relations and correlations between the drought susceptibility index for oil yield with oil yield, in irrigated and drought conditions, in the groups of hybrids HA89 x Normal and 887 x Normal (cultivated *H. annuus x H. annuus*) and HA89 x Interspecific and 887 x Interspecific (cultivated *H. annuus x Helianthus spp*).

Group of	**Irrigation**		**Drought**	
hybrids	**Equation**	**r**	**Equation**	**r**
HA89 x N	(3) $Y= 10075x^2 – 21515x + 13078$	0.6185 *	(3) $Y= 8319.7x^2 – 18199x + 10911$	0.7776 ***
HA89 x I	(3) $Y= -5622.9x^2 + 11971x – 4979.6$	0.5616 *	w.r	ns
887 x N	w.r	ns	(3) $Y= -1278.6x^2 + 1546.4x + 862.08$	0.7785 ***
887 x I	(4) $Y= 1360.9x^{0.5827}$	0.6093 *	w.r	ns
Testers	w.r	ns	w.r	ns

(3) Polynomial, (4) potential, w.r without relation, ns not significant
* $p\leq 0.05$, *** $p\leq 0.0001$

The relations and correlations between S for oil percentage with oil percentage are shown in Table 4. In this case we observed significant polynomial correlations for the group of hybrids HA89 x N, HA89 x I and 887 x I, under irrigation; and HA89 x N, 887 x I under drought, and significant Exponential correlations for 887 x N in irrigation; 887 x N and the testers in drought conditions.

Table 4. Kind of relations and correlations between the drought susceptibility index for oil percentage with oil percentage, in irrigated and drought conditions, in the groups of hybrids HA89 x Normal and 887 x Normal (cultivated *H. annuus x H. annuus*) and HA89 x Interspecific and 887 x Interspecific (cultivated *H. annuus x Helianthus spp*).

Group of	**Irrigation**		**Drought**	
hybrids	**Equation**	**r**	**Equation**	**r**
HA89 x N	(3) $Y= -13.806x^2 + 24.759x + 40.602$	0.6928 **	(3) $Y= -13.189x^2 + 21.099x + 40.686$	0.6929 **
HA89 x I	(3) $Y= 1.4466x^2 + 3.0824x + 43.704$	0.7045 **	w.r	ns
887 x N	(5) $Y= 58.093e^{-0.1076x}$	0.7420 **	(5) $Y= 57.98e^{-0.167x}$	0.8657 **
887 x I	(3) $Y= -5.5701x^2 + 17.519x + 33.731$	0.8197 **	(3) $Y= -5.4739x^2 + 14.612x + 33.78$	0.6801 **
Testers	w.r	ns	(5) $Y= 49.848e^{-0.0905x}$	0.8168 *

(3) Polynomial, (5) Exponential, w.r without relation, ns not significant
* $p\leq 0.05$, ** $p\leq 0.001$

The total variation for the drought susceptibility index for seed yield and oil yield had a range between 0.77 and 1.21 (data not shown), very similar to those reported by Fisher and Maurer (1978) in mais and Fereres *et al.*, (1986) in sunflower. Also in sunflower, Alza (1995) reported similar values of S between 0.64 and 1.34 and Gómez-Sánchez *et al.*, (1998) reported values of S between 0.60 and 1.94. In this work the range of S for oil percentage was between 0.50 and 1.99 (data not shown).

Some authors have not found a linear significant correlation between S and seed yield potential and have interpreted this fact as the possibility to select for a high yield potential and drought resistance (Fereres *et al.,* 1986; Alza, 1995). But as is demonstrated in this work, there could be the existence of other kind of significant non linear correlations, that indicate in cases like this, the impossibility to select for high yield and drought resistance at the same time.

Blum (1979) asserted that the relation drought/irrigation yield could be considered as an indicator of stability. Therefore as the drought susceptibility index (S) is based on this relation, it can be considered also like a stability index. It has been demonstrated that the phenotypic stability depends of the Genotype x Environment interaction, as a result of non additive effects, with linear or non linear relations depending on the grade of GxE interaction (Cubero and Flores, 1994; Gómez-Sánchez, 1998).

In this work is confirmed again the results reported by Gómez-Sánchez *et al.,* (1998) utilizing normal and interspecific inbred lines, from a different genetic origin than the genotypes utilized in this work. They also didn't find any kind of significant correlation among S and seed yield in irrigation, but observed a non linear significant correlation between S and seed yield under drought. Corroborating that there are adaptation mechanisms in irrigation that are different and independent from those manifested in drought.

In this way, the equation of Fisher and Maurer (1978) $S = \frac{1-(Sy_d/Sy_p)}{1-(X_d/X_p)}$ could be interpreted in terms of the classic genetic model of Falconer (1970) P= G + E + GE where P (phenotype)= G(genetic SY_p or SY_d) + E (environment drought intensity D= 1-(X_d/X_p)) + GE (genotype x environment interaction drought susceptibility index S). This proposed model fits well both equations, in a first consideration, but will be necessary to find the exactly mathematical correspondence. Fisher and Maurer, (1978); Fereres *et al.*, (1986) and Alza, (1995) have considered only the relation between S with the yield potential (irrigation). But for the reasons exposed before its necessary to make the correlation between S with yield in drought, and search not only the linear correlations, but also the non linear ones.

Conclusions

It can be concluded that to make selection for drought resistance, using the drought susceptibility index S, it is necessary to find the kind of correlation, linear or non linear, negative or positive, or the complete absence of correlation, between the S index for the character studied (seed yield, oil yield, etc.) with the character itself in irrigation and drought.

If there is an absence of correlation, or if there is a negative significant correlation, linear or non linear, that can make possible at the same time the selection for high yield and resistance to drought, the selection will not be made only in optimal environments (irrigation), because this selection will be made considering only the additive or the non additive effects of genes. To make a complete selection, the selection will be made in irrigated-drought conditions, to obtain the drought susceptibility index and therefore select also for the genotype environment interaction.

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