Stability Parameters in Drought Resistance Sunflower Lines Derived From Interspecific Crosses

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Abstract

Some drought resistance traits can be showedor enhanced only under drought conditions. The objective of this work was the study of stability parameters of morphophysiological traits related with drought resistance in sunflower drought resistance lines derived from interspecific crosses. The experiment was established in 1994 at ERSA Center (Pozzuolo, Italy) in two environments (factor A). under irrigated or drought conditions (factor B). There were seeded 20 maintainer lines (factor C) derived from *H. annuus x H. argophyllus*, *H. annuus x H. debilis*, *H. annuus x H. Bolanderi* and *H. annuus*. The experimental design was a split-plot with two replications. After drought induction, during reproductive phase. there were observed significant differences ($p \leq 0.05$ and 0.01) for factors A. B. C, and for the interaction (BC). An analysis of principal component grouped a set of 7 morphophysiological traits, only activated under drought conditions, that revealed an adaptative traits interaction system, as resistance mechanism, for which plants can express direct and indirect correlations with seed yield, . The stability or better response of genotypes in drought conditions depends on the kind and cumulative number of traits for these parameters. GD-02-5 and CIANOC-3-7 had the highest seed yield in both irrigation and drought but without stability. GD-23-10 and HA89 showed stability but with lower seed yield .

Key words: Sunflower. inter-specific crosses, stability parameters, irrigation-drought.

Introduction

The behaviour of a group of genotypes must be studied in different environments in order to: (*i*) Group the genotypes in accord to some variables of interest, in general or in a specific environment; (*ii*) Demonstrate the advantage of a genotype in all the environments or just in some of them; (*iii*) Explain if the presence of the interaction with the environment is or not a genetic characteristic; (*iv*) Estimate the stability parameters for each one of genotypes (Gómez, 1983).

During the last years many morphophysiological traits related to yield under limited water availability have been identified. This has opened the possibility to use these traits as selection criteria to improve drought resistance in sunflower. Among many traits reported some of the most important are: canopy temperature, reproductive index, leaf area index, total dry matter. harvest index, plant growing rate and seed yield (Fereres et al., 1986;

Gimenez and Fereres. 1986; Elizondo, 1991; Gómez et al., 1991; Baldini et al., 1992; Gomez and Elizondo. 1992). Drought resistance traits of functional mechanisms, are expressed only in presence of water deficits (Hanson, 1980; Castañón, 1991). This means that the expression of these traits needs the contribution of the genotype-environment interaction to be manifested. The drought resistance is a quantitative and multifactorial adaptative process that include a genetical component (G) and a genetical-evironment interaction (GE) (Muñoz. 1992). The stability parameters are GE interaction parameters such that $\hat{Y}_{ij} = \mu + g_i + B_i e_j$. where $\hat{Y}_{ij}$ is the estimated genotypic value of the i variety in the j environment, μ is the overall mean, g_i is genotypic effect of the i variety, $B_i = 1 + b_i$ is the regression coefficient of the genotype-environment interaction and e_j is the environmental effect in the j environment considered as a fixed variable (Bucio, 1966). Marquez (1973) demonstrated that the model of equation of Bucio is the predicted value of the Eberhart and Russell (1966) model, therefor considering this last one, a variety is considered stable when $B_i = 1$ and the deviation sum of squares from regression $S^2_{di} = 0$. The test of hypothesis for this model is H_o: $B_i = 1$ vs. H_a: $B_i \neq 1$ made through the statistic $t = (\hat{B}_i - 1)/\sqrt{\hat{v}\mathrm{ar}(\hat{B}_i)}$ and the test of hypothesis H_o: $S_{2di} = 0$ vs. H_a: $S^2_{di} \neq 0$ with the statistic $F = MSDR_i/S^2 e$. where $MSDR_i$ is the mean square for deviations of regression and S^2e is the mean square of the error. According to Draper and Smith (1981) the first statistic correspond with the estimated standard deviation of the slope bi (ESDS) and the second one with the F test for the analysis of variance of linear regression $F = MS_{Reg}/S^2 e$.

The objective of this work was the study of stability parameters of morphophysiological traits related with drought resistance in sunflower drought resistance lines derived from interspecific crosses.

Materials and methods

The experiment was carried out in the "Centro per la Sperimentazione Agraria ERSA" at Pozzuolo del Friuli (UD). Italy., in deep medium clay loam soil. The sowing date was on may 28th 1994, in two experimental sites under irrigated-drought conditions. In each site was placed a plastic tunnel before plant anthesis, in both irrigated and drought treatments, in order to avoid rain and induce drought in the drought treatments. The irrigated treatments were sufficiently water supplied during all the biological cycle of the plants. During the vegetative phase both experiments were developed under the same mean temperature regime day/night 25/18 C°. After this, during the reproductive phase, due to the effect of plastic tunnels, each experiment was characterized by a mean temperature range regime day/night as follows: experiment one 38/26 C° and experiment two 33/23 C°. Each experiment was established in a bifactorial design with two replications where factor A was two water available levels 1) optimal water availability during all the biological cycle of the plant. also called "irrigation" and 2) optimal water availability until 10 days before anthesis and thereafter a progressive drought from anthesis to physiological maturity, also called "drought". Factor B were 21 lines. from these 20 experimental maintainer (mt) lines and one commercial cytoplasmic male sterile (cms) line as tester. From the experimental lines seventeen were derived from interspecific crosses: four lines derived from *H. annuus* x *H. argophyllus*, 11 lines derived from *H. annuus* x *H. debilis* and two lines derived from *H. annuus* x *H. bolanderi*. Three experimental lines were derived from a Mexican open pollinated variety of *H. annuus* cultivated (CIANOC-3).

The tester was the commercial cms line HA89 from ND-USDA derived from an interspecific cross between *H. annuus* x *H. petiolaris*. The experimental lines had an estimated inbreeding coefficient $F = 0.97$ (S_5) and the tester an estimated $F = 0.99$ (S_7).

The amount of water available in the soil during the biological cycle, expressed as v/v %, was measured using the TDR (Time Domain Reflectometry) equipment Tektronix 1502C in a soil depth of 0.6 m. In all treatments was applied a fertilization dose of 100-80-50. There were measured 7 phenological and morphophysiological traits. The measures were obtained during the reproductive cycle of the plants, from anthesis to harvest, on four plants by treatment, for a total of 336 plants by experiment. The measured traits were: upper leaves temperature (ULT) C° at 50 % of flowering measured with an infrared rays pistol Telatemp model AG42, reproductive index (RI) days, leaf area index (LAI) measured with a Delta-T area meter image analysis model AM-5414, total dry mater (TDM) g m^{-2} at physiological maturity, harvest index (HI), plant growing rate (PGR) cm day^{-1}, and seed yield (SY) g m^{-2}.

The statistical data analysis was made using a trifactorial analysis of variance for a randomized complete block design. With this purpose, each experiment was considered as an independent environment, so called factor **A** with two levels, E1 and E2; the water availability was then considered as factor **B** with two levels, irrigation (W1) and drought (W2): the lines were considered as factor **C** with 21 levels. The stability parameters were obtained using the genotypic model proposed by Bucio (1966) and Eberhart and Russell (1966). Other study made was the principal component analysis. The statistical analyses were made using a microcomputer statistical program (MSTAT-C Development Team, 1989).

Results and discussion

The soil water content (Figure 1) was maintained around the field capacity value during the complete biological cycle in the full irrigated treatments, environments E1W1 and E2W1. Whereas in the drought treatments, E1W2 and E2W2, the soil water content was optimal just during the plants' vegetative phase, decreased to the wilting point during the beginning of flowering, and remained at that level during all plants' reproductive phase, causing severe drougth stress in plants.

The analysis of variance (data not shown) revealed that most of traits were not affected significantly by the interaction water availability x genotypes (BC). It could be argued that these traits contribute to the general adaptation to any environment. While the traits that were affected significantly contribute to the specific adaptation for optimal water availability or drought. According with this, the traits directly related to any kind of water availability were: ULT, RI, TDM, HI and PGR. The traits directly related with optimal water availability or drought resistance were: LAI and SY. Only the factors (B) and (C) had a significant effect on all traits, except for HI the factor (B). It means that there is a significant genetical variability among genotypes for all traits and their expression depends basically on their genetical origin and regulated by the genotype-environment interaction.

To understand the relationships among traits in each genotype and their relative contribution to adaptation in irrigation or drought the principal components analysis was used.

Under irrigation the first three principal components explained 76.6 % of the total variation (Table 1). The first principal component explained 49.88 % of the total variation and the highest loadgings were assigned, in order of importance, to total dry matter, plant growing rate, leaf area index and seed yield; since these traits were highly positive correlated among them this component could be interpreted as biomass, photosynthetic capacity and yield (BPY). The second component which explained 15.8 % of the total variation, was composed by reproductive index, and harvest index; these traits were positive and significant correlated between them and negative correlated with leaf area index; this component could be interpreted as grain filling duration and photosinthates translocation intensity (GPTI). The third component explained 10.9 % of the total variation, it was represented by upper leaves temperature, this trait was positive and significantly associated to reproductive index but negative associated with harvest index, so this component could be interpreted as temperature-vegetative period duration (TVPD).

Under drought the first three principal components explained 77.05 % of the total variation (Table 1). The first principal component explained 54.4 % of the total variation, the main traits had the same order of importance as in irrigation: total dry matter, plant growing rate, leaf area index and seed yield; since these traits were highly positive correlated among them this component could get the same interpretation (BPY). The second component, which explained 12.3 % of the total variation, was composed different than in irrigation it is by reproductive index and upper leaves temperature, this component was interpreted as temperature-reproductive period duration and associated positive with harvest index (TRP). The third component explained 10.4 % of the total variation, it was represented by harvest index, because this trait was positive associated with seed yield this component could be interpreted as photosynthates translocation intensity (PTI).

The analysis of these results reveal that the principal component 1 (BPY), in both irrigation and drought, was composed first by traits with the greatest contribution (TDM and PGR) unaffected by the BC interaction and second by traits with the lesser contribution (LAI and SY), affected by the BC interaction. However the principal component two and three were composed different in irrigation and drought. This facts could be interpreted that depending of the irrigation or drought conditions, there were constituted specific relations among traits to adequate the adaptation of plants to water availability.

The lines' coordinates on the first three principal components are shown on Table 2. Under irrigation and drought all lines were positive associated with the principal component 1; among the *H. annuus x H. argophyllus* lines, GD-02-5 had the highest association, following in order of importance CIANOC-3-7 among the *H. annuus* lines; between the *H. annuus x H. bolanderi* lines, GD-42-4 had the highest value. Among the *H. annuus x H. debilis* lines, GD-23-6 had the highest association in irrigation and GD-23-10 under drought. In both irrigation and drought all the lines were negative associated with the principal component 2, except GD-42-4 under drought that was positive. In these same component all the GD-23 lines had the highest values and all the lines GD-42 had the lower ones in both irrigation and drought; but the line GD-02-3 had the lowermost value. All the lines were positive associated with the principal component 3 under irrigation and negative associated under drought (except GD-42-4). It could be stated that the adaptation of each genotype depends not only from the general contribution of traits non interacting and from the specific contribution of traits interacting with the environment, but also from the contribution of particular relations established among all kind of traits. This fact could be considered as an adaptative traits interaction system, that should be considered to understand the stability of genotypes in contrasting environments. It can be hypothesized that these inbreeding lines have the traits fixed and their adaptative traits interaction system too. Therefore in hybrid combinations can be excpected to find combinations that could be increase or diminish the effect of the adaptative traits interaction system. Can also be established that each group of lines have the tendency to manifest particular characteristics of similarity due to their common genetic origin, keeping at the same time variability. This variability is much evident among groups of lines due to their interspecific crosses origin.

The stability parameters were calculated including all genotypes, but considering that the genotypes: GD-02-5, GD-23-10, GD-42-5, CIANOC-3-7 and cms HA89 represent each group of genetical origin: the results and discussion were made in particular on these lines. Additionally to the stability parameters from Eberhart and Russell (1966) that a genotype is stable when $B_i = 1$ and $S^2_{di} = 0$, Carballo (1970) proposed that when $B_i < 1$ indicate a better response of genotypes in unfavorable environments, when $B_i > 1$ indicate that the genotypes react better in favorable environments, when $S^2_{di} = 0$ adopted the term consistent to indicate little fluctuations and when $S^2_{di} >$ or $\neq 0$ the term inconsistent to indicate greater fluctuations when change the environments. The stability parameters shown in Table 3 were classified in this way. From the six possible combinations of these five parameters were found four ones. The combination ESDS (B_i) = 1 and $S^2_{di} = 0$ was found just in the line GD-23-10 in two traits. The combination ESDS = 1 and $S^2_{di} \neq 0$ was found in lines GD-02-5, GD-23-10 and HA89 with one trait each one of them. When ESDS < 1 and $S^2_{di} = 0$ was the combination mostly found, the line GD-02-5 showed this combination in six traits, GD-23-10 in three, GD-42-5 in five, CIANOC-3-7 in five and cms HA89 in three traits. When ESDS > 1 and $S^2_{di} = 0$ there were found this combination in GD-23-10 in one trait, GD42-5 in two, CIANOC-3-7 in two and HA89 in three.

There seems to be that depends on the cumulative number of traits contributing with the combination ESDS < 1 and $S^2_{di} = 0$ to get genotypes with better response in unfavorable environments, as in GD-02-5 and CIANOC-3-7; and the combination ESDS= 1 and $S^2_{di} = 0$ to get genotypes with stability as in GD-23-10. But in any way the contribution of the genotypic component g_i, from the model $\hat{Y}_{ij} = \mu + g_i + B_i e_j$, determines greatly the response of genotypes for any trait in any kind of environment (Figure 2). This is the reason why GD-42-5 with the same accumulated traits as CIANOC-3-5, but with a g_i contribution for seed yield equals to -21.29 lesser than CIANOC-3-5 with a g_i of 27.88, had lesser seed yield than the last one. In comparison the genotype GD-23-10 with two traits in the combination ESDS= 1 and $S^2_{di} = 0$ and the genotype HA89 with one trait in the combination ESDS = 1 and $S^2_{di} \neq 0$, exhibited both good seed yield stability, but their g_i values for seed yield were low: 0.12 and -13.05, respectively, therefore their mean seed yields were low too. In contrast GD-02-5 that showed low seed yield stability, but with the greater g_i contribution, showed the greatest seed yield in all the environments.

Additionally, not only the cumulative number of traits for stability are important to increase seed yield in unfavorable environments, but also the kind of traits composing the combination of ESDS and S^2_{di} interacting among them. Perhaps if it is obtained a combination of traits for stability and for better response in unfavorable environments, it could be obtained genotypes with good stability and seed yield. For example in GD-02-5 the trait RI shows stability but at the same time inconsistency, therefore if selection will be made on this trait will maybe increased the yield in favorable and unfavorable environments. In the other genotypes to improve the yield response, it will be necessary to make selection for stability or better response in unfavorable environments making selection for the traits RI and TDM.

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Table 1. Latent vectors for traits, of sunflower lines derived from interspecific crosses, in descending order of importance at Prin 1 in both irrigation and drought.

	Irrigation			Drought		
Traits	Prin 1	Prin 2	Prin 3	Prin 1	Prin 2	Prin 3
TDM	0.318	0.101	0.125	0.316	0.019	-0.043
PGR	0.309	0.071	0.131	0.311	0.012	-0.067
LAI	0.300	-0.215	0.057	0.307	0.057	-0.173
SY	0.270	0.236	0.051	0.289	0.033	0.196
RI	0.064	0.463	0.355	0.078	0.563	-0.171
ULT	-0.126	0.179	0.419	-0.116	0.416	-0.039
HI	-0.252	0.261	-0.101	-0.113	0.121	0.485
L R †	8.480	2.690	1.847	9.240	2.085	1.775
V % ‡	49.88	15.83	10.86	54.35	12.26	10.44
C V % §	49.88	65.71	76.58	54.35	66.61	77.05

† Latent roots. ‡ Variance. § Cumulative variance

Table 2. Three main principal components calculated for sunflower lines derived from interspecific crosses and normal cultivated sunflower, growing in two environments.

		Irrigation			Drought		
Lines		Prin 1	Prin 2	Prin 3	Prin 1	Prin 2	Prin 3
GD-02-1	†	580.22	-29.66	288.82	540.20	-12.82	-54.15
GD-02-3	†	590.42	-61.66	311.06	473.19	-0.99	-13.13
GD-02-5	†	654.77	-136.80	389.88	587.77	-44.85	-121.59
GD-02-6	†	568.21	-75.83	320.21	517.52	-35.92	-71.40
GD-23-1	‡	470.27	-156.86	303.97	448.78	-37.26	-88.82
GD-23-2	‡	421.15	-108.09	249.62	377.37	-19.94	-44.82
GD-23-3	‡	463.66	-107.92	277.07	416.14	-47.64	-95.51
GD-23-4	‡	441.28	-146.94	280.15	439.12	-34.31	-78.65
GD-23-5	‡	458.22	-78.46	250.40	388.29	-33.50	-56.49
GD-23-6	‡	500.96	-157.37	316.05	457.30	-43.55	-83.85
GD-23-7	‡	458.95	-145.05	283.22	448.79	-35.40	-75.36
GD-23-8	‡	433.24	-93.74	243.97	363.90	-16.32	-27.65
GD-23-9	‡	469.97	-158.68	305.22	423.97	-33.68	-74.01
GD-23-10	‡	473.30	-149.51	296.71	478.40	-33.86	-81.03
GD-23-12	‡	440.01	-169.11	297.36	395.53	-33.15	-66.56
GD-42-4	§	267.69	-9.52	125.11	266.61	17.45	12.47
GD-42-5	§	382.14	-28.93	187.66	272.86	-7.86	-19.42
CIANOC-3-2	¶	484.31	-34.23	234.57	405.95	-10.06	-19.30
CIANOC-3-3	¶	370.46	-111.69	214.54	332.44	-15.39	-18.18
CIANOC-3-7	¶	561.10	-124.68	332.68	490.20	-35.13	-77.44
cms HA89 (T)	#	461.30	-109.63	273.58	380.02	-39.61	-69.77

† *H. annuus x H. argophyllus*, ‡ *H. annuus x H. debilis* , § *H. annuus x H. bolanderi*. ¶ *H. annuus*, # *H. annuus x H. petiolaris.*

Table 3. Estimated stability parameters of sunflower lines derived from interspecific crosses (*i*) growing in two irrigation and two drought environments.

Line	bi †	Bi ‡	ESDS §	t ¶	$H_o : H_a$	S^2_{di} #
Total dry matter						
GD-02-5 *i*	-0.384	0.616	0.428	0.898	< 1	= 0
GD-23-10 *i*	-1.738	-0.738	0.419	4.144 *	= 1	= 0
GD-42-5 *i*	1.239	2.239	0.795	1.559	> 1	= 0
CIANOC-3-7	1.516	2.516	1.882	0.805	> 1	= 0
HA89 *i*	1.292	2.292	1.191	1.095	> 1	= 0
Plant growing rate						
GD-02-5	0.013	1.013	0.617	0.002	< 1	= 0
GD-23-10	-0.481	0.519	0.135	3.561	< 1	= 0
GD-42-5	0.637	1.637	0.374	1.705	< 1	= 0
CIANOC-3-7	0.143	1.143	0.194	0.737	< 1	= 0
HA89	0.344	1.344	0.292	1.176	< 1	= 0
Leaf area index						
GD-02-5	-0.505	0.495	0.145	3.482	< 1	= 0
GD-23-10	-0.337	0.663	0.043	7.840 *	= 1	≠ 0
GD-42-5	-0.064	0.936	0.209	0.305	< 1	= 0
CIANOC-3-7	-0.313	0.687	1.681	0.186	< 1	= 0
HA89	-0.317	0.683	1.207	0.263	< 1	= 0
Seed yield						
GD-02-5	0.072	1.072	0.341	0.210	< 1	= 0
GD-23-10	-0.621	0.379	0.146	4.244 *	= 1	= 0
GD-42-5	0.986	1.986	0.294	3.359	< 1	= 0
CIANOC-3-7	0.072	1.072	0.026	2.746	< 1	= 0
HA89	-0.875	0.125	0.850	1.028	< 1	= 0
Reproductive index						
GD-02-5	-0.783	0.127	0.126	6.921 *	= 1	≠ 0
GD-23-10	-1.617	-0.617	0.637	2.538	> 1	= 0
GD-42-5	-1.548	-0.548	0.809	1.914	> 1	= 0
CIANOC-3-7	-1.337	-0.337	2.009	0.666	> 1	= 0
HA89	-2.481	-1.481	0.961	2.582	> 1	= 0
Upper leaves temperature						
GD-02-5	-0.090	0.910	0.089	1.008	< 1	= 0
GD-23-10	-0.211	0.789	0.151	1.396	< 1	= 0
GD-42-5	-0.240	0.760	0.402	0.598	< 1	= 0
CIANOC-3-7	0.123	1.123	0.233	0.528	< 1	= 0
HA89	0.504	1.504	0.026	19.532 **	= 1	≠ 0
Harvest index						
GD-02-5	-0.140	0.860	0.613	0.228	< 1	= 0
GD-23-10	0.251	1.250	0.391	0.640	< 1	= 0
GD-42-5	0.522	1.522	0.986	0.529	< 1	= 0
CIANOC-3-7	-0.564	0.436	0.412	1.367	< 1	= 0
HA89	-1.025	-0.025	0.731	1.403	> 1	= 0

* and ** are significant at t $p \leq 0.05$ and $p \leq 0.01$ respectively. † Slope; ‡ $B_i = 1 + b_i$; § the acceptance of hypotesis for Est. Stand. Dev. of the Slope is named β_i by Eberhart and Russell (1966) and B_i by Bucio (1966); ¶ t test; # deviation sum of squares from regression.

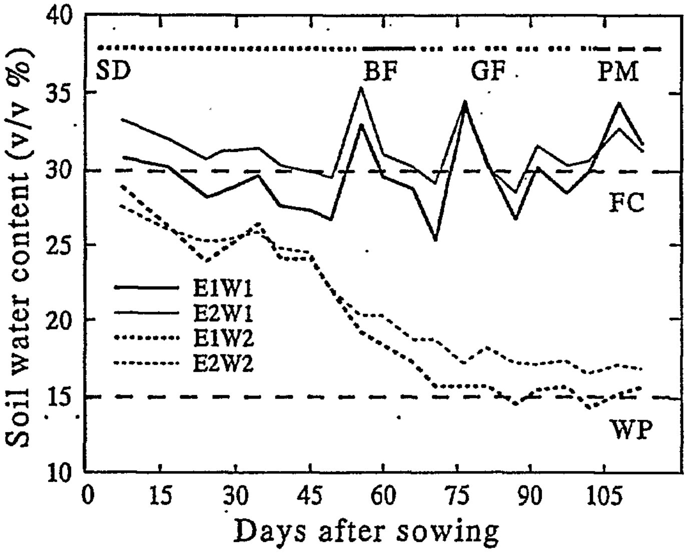

Fig.1 - Soil water content (v/v%) during the biological cycle for irrigated (W1) and drougth (W2) conditions in two environments (E1 and E2). FC is Field Capacity and WP is Wilting Point of soil water content. The Sowing Date (SD), Beginning of Flowering (BF), Grain Filling phase (GF) and Physiological Maturity (PM) are indicated.

Figure 2. Estimated stability parameters $\hat{Y}_{ij} = \mu + g_i + B_i e_j$ in sunflower mainteiner lines ● GD-02-5 (*H. annuus x H. argophyllus*), Δ GD-23-10 (*H. annuus x H. debilis*), ▲ GD-42-5 (*H. annuus x H. bolanderi*), ○ CIANOC-3-7 (*H. annuus*), and a cytoplasmic male sterile line * HA89 (*H. annuus x H. petiolaris*). The environmental index are Environments E1 and E2, W1 irrigation and W2 drought.