Genotype x environment interaction in new sunflower (*Helianthus annuus* L.) hybrids

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Summary
To evaluate the agronomic value of new experimental hybrids and their stability over environments ten trials: 2 locations (east-central and north-east Italy) for five years (1995-1999), were carried out.
In each year 9 experimental hybrids and 4 commercial controls with three replications were evaluated in field trials. Data were analysed for genotype environment interaction effect of each hybrid computing Shukla's stability variance statistic (σ^2_i) and Kang's yield stability statistic (YS_i) that combines yield and stability of performance into a single selection criterion.
The YS_i statistic penalised very few the genotypes on the basis of their unstability. The new hybrids selected in the environments of the experiment showed a better adaptability and consequently a better stability. The good value showed by the control cultivars, suggest that their stability should be analysed with other methods because the YS_i statistic, even if it selected two of them, did not explain the reasons for the choice. In fact on the basis of σ^2_i they would be discarded. On the basis of mean values of yield and YS_i Select, Isanthos, ISCI 9, ISCI 18, and Mito would be the hybrids to recommend to the growers. Adding σ^2_i the experimental hybrids were better than control cultivars.

Introduction
Genotype x environment interaction occurs in short term as long term crop performance trials. This is of interest both from the breeding as well as the cropping viewpoint. Some researchers ignore the GE interaction, especially in short-term trials, and select the suitable cultivar(s) considering only the mean performance across environments thinking that combining more criteria in choosing the best cultivar to be cropped could reduce it potential yield. However the main purpose of the cultivar trials is to estimate, with past (available) data, genotype performance in future cropping on growers' farms and a mistake in this aspect could lead to losing money. Many criteria have been proposed (Finley and Wilkinson, 1963; Eberhart and Russell, 1966; Shukla, 1972; and others) that use one or more statistical parameters to choose the best genotype to be cropped. Others combine yield and stability into a single selection criterion (Kang et al., 1990; Kang and Pham, 1991; Binns and Lin, 1993; Kang, 1993) without losing accuracy. Kang (1993) proposed a method designated as the yield- stability statistic (YS_i) which is based on Shukla's (1972) statistic (σ^2_i). It would be acceptable from an agronomic point of view because it provides the contribution of a genotype to the total GE interaction attributable to all genotypes in the test. Moreover, it would be considered similar to yield as genotype performance in any particular environment is also considered with respect to the yield of the other genotypes in the test.

Materials and Methods
The evaluation of the agronomic value of new experimental hybrids and their stability over environments was carried out in ten trials: 2 locations (east-central and north-east Italy) for five years (1995-1999). In each year nearly fifty experimental hybrids and 4 commercial controls, with three replications, were evaluated in the field trials and only those with a yield

statistically not different from the best were selected and cropped the following season. In the last year of evaluation only 13 cultivars remained from those at beginning (4 tests and 9 new hybrids). Every year yield, oil content, thousand seed weight (TSW), plant height and length of planting-maturity were recorded. From the first two oil yield was calculated.
Data of the 13 cultivars were analysed for genotype environment interaction effect computing a Shukla's stability variance statistic (σ^2_i) and Kang's yield stability statistic (YS_i).

Results

Analysis of variance (table 1) showed that there were differences among genotypes for all traits considered and that environments influenced their response. The magnitude of mean squares for GE, for all traits, was small compared to those of genotypes and consequently the average effect of genotypes was consistent over environments. Any way the sum of squares of GE was highly significant and this prompted us to investigate it further.
Isanthos showed the highest absolute yield, but according to student Newman Keul's test it was not significantly better than 11 other genotypes in the trials. This was probably due to the selection made in choosing tests as well as the new hybrids. The Kang's stability (YS_i) showed the best value in ISCI 14 followed by ISCI 18, Select, Isanthos and 5 other cultivars including the already marketed Mito and Gamma. YS_i penalised both Isanthos and Select a little but did not discard them as expected on the basis of σ^2_i (table 3). Surprisingly all test cultivars had significant σ^2_i and similar in amount, probably because it selected for environments different from those tested, so their value for YS_i was not understood. A similar response was also shown for oil content where Select had the highest mean value followed by Isanthos, Mito, Gamma, Gloriasol, etc. The YS_i statistic for this trait penalised the ranking of cultivars less compared to yield probably because with the exception of ISCI 12 and 19 all others had significant σ^2_i showing that oil content is actually very sensitive to the environment and the majority of genotypes are not buffered. A response similar to grain yield was also shown by oil yield for which Isanthos and Select had the best values followed by significant differences in the other genotypes. Anyway Isanthos and Select had significant σ^2_i and consequently were penalised by YS so the hybrid with the highest YS_i was ISCI 18 followed by Gamma and Select. Also in this trait, as for yield, the YS_i statistic tended to penalise the non stable genotypes but did not discard them. For the three traits considered until now only ISCI 19 had always σ^2_i not significant. Except for oil content, 7 new experimental cultivars had σ^2_i not significant showing that they were better buffered for the agronomic conditions of the experimentation, than the control cultivars, even if these continue to be competitive for absolute yield.
There was large variation in TSW, showing that a similar agronomic value can be obtained with big differences among yield components. Except for three new hybrids all others had significant σ^2_i indicating that trait is quite variable with respect to differences in environments.
There was a significant difference in plant height among hybrids (a variation within 25 cm) which was less variable among environments, than TSW. For planting maturity the cultivars could be classified as medium-early or medium-late, and with large variability among environments for many of them (large σ^2_i).

Conclusions

The YS_i statistic tended to be conservative and penalised very few of the genotypes on the basis of their unstability. The new hybrids selected in the environments of the experiment showed a better adaptability and consequently a better stability. The relative high mean values, over two locations for five years, showed by the control cultivars, suggest that their stability should be analysed with other methods because the YS_i statistic, even if it selected two of them, did not explain the reasons for the choice. In fact on the basis of σ^2_i they would be discarded. Moreover the differences of σ^2_i among testers, except Select, was very small and did not fully explain the differences of YS_i on the basis of mean values of yield and YS_i Select, Isanthos, ISCI 9, ISCI 18, and Mito would be the hybrids to recommend to the growers. Adding σ^2_i the experimental hybrids were better than control cultivars.

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Table 1. Mean squares in the analysis of variance for yield and other components.

Source of variation	d.f.	Yield t ha^{-1}	Oil content g kg^{-1}	Oil yield t ha^{-1}	TSW g	Plant height cm	Planting - maturity d
Genotypes	12	9,4 **	1210 **	3,7 **	967 **	2998 **	693 **
Environments	9	216,1 **	1940 **	54,4 **	2351 **	2284 **	1045 **
GE	108	3,6 **	76 **	08 **	44 **	231 **	40 **
Heterogeneity	12	0,2	0	0,6	0	4	0
Residual	96	4,0 **	85 **	0,9 **	50 **	260 **	45 **
Pooled error	240	1,8	12	0,4	14	84	15

In all tables *, ** significant rispectively at P ≤ 0.05 or 0.01

Table 2. Mean± of the agronomical traits and their stability statistic (YS_i)++.

Genotypes	Yield t ha^{-1}		Oil content g kg^{-1}		Oil yield t ha^{-1}		TSW g		Plant height cm		Planting - maturity d	
	mean	YS_i	mean	YS_i	mean	YS_i	mean	YS_i	mean	YS_i	mean	YS_i
Gloriasol	3,48 b	-7	505 f	5 +	1,60 b	1 +	44 a	-10	177 a	1	141 c	-8
Isanthos	3,80 b	7 +	511 fg	7 +	1,77 c	8 +	51 c	-5	201 e	8 +	149 df	4 +
Vidoc	3,63 b	1	462 b	-9	1,53 b	-7	51 c	-6	182 b	-5	139 b	-5
Select	3,71 b	8 +	516 g	8 +	1,76 c	11+	55 d	3 +	176 a	0	149 df	13+
Gamma	3,49 b	2	505 f	6 +	1,61 b	11+	47 b	0	197 e	5 +	142 c	-7
ISCI 9	3,62 b	8 +	484 e	1 +	1,60 b	8 +	63 f	8 +	197 e	11+	150 ef	7 +
Mito	3,58 b	4 +	489 e	7 +	1,59 b	7 +	53 c	6 +	190 cd	9 +	148 de	10+
ISCI 12	3,70 b	3	476 d	4 +	1,61 b	2	61 f	7 +	188 c	7 +	151 f	16+
ISCI 10	3,58 b	4 +	469 c	-6	1,54 b	3	53 c	5 +	189 c	0	142 c	-2
ISCI 14	3,74 b	13+	455 a	-10	1,56 b	4	56 d	12+	174 a	-5	148 de	5 +
ISCI 17	3,09 a	-10	467 bc	-8	1,32 a	-10	47 b	-5	172 a	-2	136 a	-10
ISCI 18	3,69 b	10+	484 e	-2	1,64 b	12+	51 c	0	195 de	3 +	147 d	0
ISCI 19	3,58 b	3	468 bc	1 +	1,53 b	2	58 e	14+	197 e	6 +	149 df	14+

+ Selected genotypes on the base of YS_i

++ Reference: Kang M.S., 1993. Simultaneous selection for yield and stability: consequences for growers. Agron. J.. 85: 754-757

± Means with the same letter are not significantly different according SNK test

Table 3. Shukla stability statistic σ^2_i

Genotypes	Yield t ha^{-1}	Oil content g kg^{-1}	Oil yield t ha^{-1}	TSW g	Plant height cm	Planting - maturity (d)
Gloriasol	5,0 **	86 **	1,2 **	45 **	29	60 **
Isanthos	4,9 **	78 **	1,1 **	40 **	265 **	83 **
Vidoc	5,2 **	101 **	1,2 **	153 **	229 **	28 *
Select	3,6 *	67 **	1,0 *	89 **	144	21
Gamma	2,6	65 **	0,5	15	911 **	39 **
ISCI 9	0,8	183 **	0,4	61 **	165 *	38 **
Mito	2,1	23 *	0,3	16	120	16
ISCI 12	6,2 **	13	1,3 **	44 **	56	26
ISCI 10	2,1	42 **	0,6	31 *	228 **	33 *
ISCI 14	1,8	103 **	0,4	16	169 *	29 *
ISCI 17	10,4 **	129 **	2,2 **	26 *	60	85 **
ISCI 18	1,3	81 **	0,4	27 *	375 **	38 **
ISCI 19	0,4	13	0,0	12	256 **	25