Assessment of Sudanese sunflower hybrids for yield, yield components and stability

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ABSTRACT

Development of local sunflower hybrids with superior yields and stable across different environments is the main objective in our breeding program. For this purpose, ten local Sudanese sunflower hybrids designated as SFH32, SFH36, SFH37, SFH310, SFH313, SFH314, SFH341, SFH345, SFH302, and SFH325 were evaluated against Hysun-33 for yield potential and its components at Sennar, Wad Medani, Rahad, New Halfa and Suki. The experiment over all irrigated environments was laid out in RCBD with three replicates during the winter season of 2008. There was considerable variation for yield and its components among hybrids and locations. Genotype-environment interactions through different parameters and the performance of six traits of hybrids were studied. The six traits were plant height (cm), number of seeds per head, percentage of empty seeds, 100-seed weight (g),seed yield (kg ha^{-1}) and oil yield (kg ha^{-1}).Significant differences were observed for hybrids (G), locations (E) and G xE interaction for these six traits. Stability analysis after Eberhart and Russell's model suggested that the hybrids used in this study were all, more or less, responsive to environmental changes. Most of the hybrids performed better in E4 (New Halfa). Stability analysis identified SFH37 and SFH310 as stable hybrids for plant height, SFH345 and SFH302 were identified as stable for number of seeds per head, whereas, Hysun-33, SFH310 and SFH341 were found stable for low percentage of empty seeds and heavy seed weight, respectively. Three hybrids; SFH310, SFH313 and SFH341 performed better than Hysun-33 and other hybrids across five environments and were considered as most stable hybrids for seed and oil yields. In contrast, hybrids such as SFH32 and SFH37 with regression coefficients greater than one were regarded as sensitive to environmental changes for seed and oil yields. The hybrid SFH310 was identified as stable hybrid for various yield components. The three promising local hybrids were released in June 2009 for commercial production and the local seed production of the hybrid SFH310 (Bohooth-1) was adopted by some seed producers in the country.

INTRODUCTION

Sunflower (*Helianthus annuus* L.) is one of the four most important oil crops globally and is grown on over 22 million hectares worldwide and is produced mainly in Argentina, Russia, France, Ukraine, Spain, India, USA, China, Turkey, Romania and Hungary (FAO, 2010). However, sunflower is a temperate zone crop, but it can perform well under a variety of climatic and soil conditions. It is grown in a number of countries on marginal soils, generally in semi-arid conditions acting as a limiting factor in crop production. The sunflower cultivated area in Sudan had shown an increasing trend in the last ten years. This is because sunflower is one of the crops which attracted the interest of both farmers and private companies. Also, the area under sunflower is increasing because of its wide adaptability, suitability to mechanization, low labor needs, short duration, high yield potential and good quality. Moreover, the increase in the areas under sunflower both in developed and in developing countries, depends primarily on the development of new hybrids. One of the most effective ways of increasing the yield of sunflower per unit area is the use of heterosis through two line hybrids (Skoric, 1992). The practical use of heterosis in sunflower became possible after a source of cytoplasmic male sterility was identified by Leclercq (1966) in France and fertility restoration was discovered in the USA (Kinman,1970). In the Sudan, virtually 98% of oilseed sunflower production is with hybrid cultivars, which necessitate the need for the development and release of more hybrids that can meet farmers' standards. In spite of having high yield potential, the production of sunflower in Sudan is very low. One of the reasons for this is the cultivation of exotic hybrids, which are not well adapted to the agro-climatic conditions of the country.

On the other hand, successful oilseed-sunflower cropping depends on the yielding ability of genotypes (hybrids), as well as on the reliability of production systems. Also, according to Becker and Leon (1988), successful new hybrids must show good performance for yield and other essential agronomic traits and their superiority should rely over a wide range of environmental conditions. Therefore, in a plant breeding program, potential genotypes are usually evaluated in different environments before selecting desirable ones that show stability across environments. For stabilizing yield it is necessary to identify the stable genotypes suitable for wide range of environments. Also, to identify such genotypes, G×E interactions are of major concern for the breeder, because such interactions confound the selection of superior cultivars by altering their relative productivity in different environments (Eagles and Frey, 1977). Use of stability is a good technique for measuring the adaptability of different crop varieties to varying environments. The most widely used way to biometrically assess stability is the regression method, which is based on regression of the mean value of each genotype on the environmental index. The technique to measure stability was previously proposed by Finlay and Wilkinson (1963) and was later improved by Eberhart and Russell (1966). The stability of a variety or hybrid was defined by a high mean yield and regression coefficient (b_i=1) and deviations from regression as small as possible (S^2_{di}=0). Thus, to make sunflower a successful crop in the Sudan, we need to develop our own hybrids which are well adapted to our agro-climatic conditions. The objectives of the present study were to determine the yield performance and stability of ten local sunflower hybrids across five environments, and select the best hybrid(s) for irrigated conditions in the Sudan.

MATERIALS AND METHODS

The development of single-cross sunflower hybrids involves the crossing of a cytoplasmic male sterile line as the female parent (A-line) to a fertility restorer line as the male parent (R-line). Ten local Sudanese sunflower hybrids were produced from one A-line (SA3) and ten R-lines (SR2, SR6, SR7, SR10, SR13, SR14, SR41, SR45, SR02, and SR25Br). The ten local Sudanese sunflower hybrids designated as SFH32, SFH36, SFH37, SFH310, SFH313, SFH314, SFH341, SFH345, SFH302, and SFH325 were evaluated against Hysun-33 at Sennar, Wad Medani, Rahad, New Halfa and Suki. The eleven sunflower hybrids were evaluated for their uniformity, adaptability and yield potential during the winter season of 2008 at five irrigated locations (Table 1).

At each environment, sunflower hybrids were arranged in a randomized complete block design with three replicates. The plot size was 4 rows and 8m long ridges spaced 0.80 m apart. The effective sowing date was during the first week of November for winter planting. Seeds were sown in hills spaced 0.30 m apart within ridges and thinned to one plant per hill two weeks after planting. Irrigation was applied at intervals of 12 to 14 days

depending on weather conditions. Plots were kept weed-free through frequent hand weeding. Nitrogen was applied at irrigated sites at 80 kg urea (46% N) per hectare. All recommended agronomic practices were followed throughout the season.

Data were collected from the middle two rows on days to 50% flowering, plant height (cm), head diameter (cm), number of seeds per head, percentage of empty seeds, 100-seed weight (g), seed yield per plant (g), seed yield (kg/ha) and seed oil content. Analysis of variance was performed on individual trials (each environment) and the F-test was made. Combined analysis was performed separately for each environment and pooled over five environments, assuming random environment and fixed hybrid (Gomez and Gomez, 1984). Stability performance of each hybrid over five environments was determined following the model of Eberhart and Russell (1966). IRRISTAT statistical analysis package for windows (2006) was used for the data analysis.

Table 1: Locations and soil properties under which sunflower hybrids were evaluated.

Location	Sennar	Medani	Rahad	Halfa	Suki
Envr. no.	E1	E2	E3	E4	E5
Latitude	13° 33' N	14° 23' N	13° 28' N	15° 19' N	13° 25' N
Longitude	33° 34' E	33° 29' E	33° 31' E	35° 36' E	33° 51' E
Altitude (m. a. s. l.)	416	405	421	450	430
Clay content (%)	58	54	60	65	68
pH	8.2	8.0	8.1	7.9	7.8
Available P (mg kg $^{-1}$)	2.8	3.0	1.8	2.0	3.0
O.C (%)	0.50	0.36	0.60	0.40	0.60
N (%)	0.05	0.03	0.05	0.03	0.03

Source: Soil Survey Department, ARC, Sudan

RESULTS AND DISCUSION

The ultimate goal of sunflower breeding programs around the world is the development of hybrids with high seed yield, high oil content and high stability to different agro-ecological zones. In this study, and for easy reference, the combination of irrigated locations were considered as an environment and given a number as E1 (Sennar), E2 (Wad Medani), E3 (Rahad), E4 (New Halfa), and E5 (Suki). The combined analysis of variance across environments revealed highly significant differences (P≤0.01) among the hybrids for all traits. Also, the pooled analysis of variance for hybrids showed significant differences (P≤0.01) among most of the traits except head diameter and number of seeds per head. However, the highly significant differences observed among environments indicated that the hybrids under study were evaluated under diverse locations, while significant hybrids variance components indicated that hybrids differed in their genetic potential for seed and oil yields and its components (Table 2). Moreover, the hybrid x environment (GxE) interaction was significant for six traits *viz*, plant height, number of seeds per head, percentage of empty seeds, 100-seed weight, seed yield and oil yield and non-significant for days to 50% flowering, head diameter and seed yield per plant (Table 3).

Table 2. Pooled analysis of variance of yield and yield components in 11 sunflower hybrids evaluated at five locations.

Character	Source of variation				
	Environments (E) d.f = 4	Hybrids (G) d.f= 10	G x E interaction d.f=40	Error d.f= 100	C.V. (%)
Days to 50% flowering	260.56**	73.90**	6.51ns	4.99	3.46
Plant height (cm)	1577.17**	739.64**	86.35*	52.69	5.30
Head diameter (cm)	895.48**	3.43ns	2.02ns	2.61	9.5
No. of seeds per head	2307115.16**	48603.7ns	47772.9*	28341.7	14.7
Empty seeds (%)	724.05**	47.68**	10.85**	5.77	16.6
100- seed weight (g)	154.84**	1.61**	0.87**	0.37	10.3
Seed yield per head (g)	6957.39**	257.79**	105.72ns	90.76	17.3
Oil content (%)	205.28*	16.72**	18.77ns	-	-
Seed yield (kg ha^{-1})	10640923.7**	320483**	122816.**	62232.73	14.8
Oil yield (kg ha^{-1})	2482023.2**	79853.8**	27425.7**	10853.77	14.7

*,** and ns significant at 0.05 and 0.01 probability levels, respectively and ns not-significant.

Table 3. Analysis of variance for stability for some quantitative traits in 11 sunflower hybrids across five environments.

Source of variation	d.f	PH[1]	NSH	ES	SW	SY	OY
Hybrid (G)	10	246.54**	16198.4ns	15.89**	0.54 ns	106827.2**	26618.2**
Enviro. (E)	4	525.67**	769034.0**	241.4**	51.61**	3546980.0**	827343.5**
G x E	40	28.78 **	15924.40**	3.62 **	0.29	40938.0**	9141.65**
E +(G x E)	44	73.96	84388.91	25.23	4.96	359669.1	83523.63
E (Linear)	1	2102.9**	3076154.5**	965.4**	206.5**	14187899**	3309364.8**
GxE (Linear)	10	35.02 *	15879.30 *	3.57*	0.43*	56999.6*	9895.88*
Pooled dev.	33	24.28 ns	14490.22 ns	3.30 **	0.22**	32350.18*	8082.32**
Pooled error	100	52.69	28341.38	5.77	0.37	62232.52	10851.71

Where, PH[1] = Plant height (cm), NSH = Number of seeds per head, ES = Percentage of empty seeds, SW = 100-seed weight (g), SY = Seed yield (kg ha^{-1}) and OY = Oil yield (kg ha^{-1}). *,** and ns significant at0.05 and 0.01 probability level, respectively and ns not-significant.

These results revealed that hybrids reacted differently at different environments for the six traits mentioned including seed and oil yields. The (GxE) interactions was further portioned into linear and non-linear (pooled deviation) components. Thus, the combined analysis of variance and hybrid by environment interaction were only carried out for those six characters in which homogonous error variance were obtained *via*: plant height (cm), number of seeds per head, percentage of empty seeds, 100-seed weight (g), and seed and oil yields (kg ha^{-1}). The results of the analysis for each of these characters were presented in Table 3. The analysis of variance for GxE interaction revealed highly significant ($P \leq 0.01$) difference among the hybrids (G), environment (E) and E+(GxE) for the six characters. Also, non-linear (unpredictable) components of (GxE) interactions were found to be highly significant ($P \leq 0.01$) with respect to these traits (Table 3). Hence, the environments of study showed highly significant difference for these six characters.

Similarly, the GxE non-linear interaction (unpredictable factors) was also highly significant for the above traits, which indicated that the unpredictable factors were predominant and the breeders would search for a hybrid that has general adaptability and good performance over a range of environments. On the other hand, these significant levels of interactions suggest that, the breeding program should encourage the development of a number of hybrids each adapted to a specific kind of environment with respect to these six characters. Becker and Leon (1988) stated that successful new hybrids must show good performance for yield and other essential agronomic traits and their superiority should be reliable over a wide range of environmental conditions.

In this study, stability of performance for the tested local sunflower hybrids against the introduced hybrid (Hysun-33) was carried out following Eberhart and Russell (1966) procedure. Thus, from the results of the combined analysis, only six characters that showed significant hybrid x environment (GxE) interaction were further analyzed for estimating stability parameters as follows:

Plant height

The means, regression coefficients (b_i) and deviation from regression (S^2_{di}) for plant height (cm) of the 11 evaluated hybrids are displayed in Table 4. The overall mean for this character was 137 cm. The tallest hybrid was Hysun-33 (156 cm) and the shortest one was SFH 37 (129 cm). Three hybrids and the commercial check had above average plant height. The hybrids SFH 345, SFH 32, Hysun-33, and SFH 314 had high regression values (1.37 to 1.48) and almost zero deviation, indicating the sensitivity of this trait to changing environments. However, hybrids SFH 37 and SFH 310 had regression values (1.09 and 1.20) closer to unity and deviation approaching zero, indicating that they had better stability for plant height. On the other hand, other hybrids were shorter and had low regression values, indicating that these hybrids have greater resistance to changing environment and have better adaptability in poor environments only.

Number of seeds per head

The mean performance of the individual hybrid along with their stability parameters (b^i and S^2_{di}) for number of seeds per head are presented in Table 5. From the environmental mean it was observed that E4 (New Halfa) was the most favorable environment. Analysis of the stability parameters of individual hybrids indicated that five hybrids (SFH 341, SFH 310, SFH 36, Hysun-33 and SFH 37) had higher mean performance, b_i>1 and S^2_{di}=0, indicating their stability for favorable environment. However, only two hybrids (SFH 345 and SFH 302) had higher mean performance associated with b_i=1 and S^2_{di}=0 showing stability over a wider range of environments for this character. Also, two hybrids *viz.*, SFH 313 and SFH 325 had higher mean performance, b_i<1 and S^2_{di}=0, indicating their adaptability in poor environmental conditions with respect to number of seeds per head.

Table 4. Estimates of stability and adaptability parameters of plant height of 11 sunflower hybrids evaluated at five environments.

Hybrids	Environments (E)							
(G)	E1	E2	E3	E4	E5	(x_i)	(b_i)	(S^2_{di})
SFH 32	133.00	127.67	127.33	151.67	144.67	136.87	1.44	0.40
SFH 36	135.33	134.67	136.67	139.33	141.33	137.47	0.24*	0.11
SFH 37	127.67	124.33	124.33	143.00	127.67	129.40	1.09	0.07
SFH 310	129.67	142.67	136.00	155.33	140.00	140.73	1.20	0.47
SFH 313	130.67	135.33	126.33	142.00	135.00	133.87	0.73	0.18
SFH 314	132.00	122.33	127.00	150.67	136.33	133.67	1.48	0.27
SFH 341	130.33	136.33	127.00	140.00	132.33	133.20	0.57	0.22
SFH 345	132.00	132.33	130.67	153.33	141.00	137.87	1.37*	0.04
SFH 302	131.33	139.67	130.33	146.67	127.33	135.07	0.80	0.69
SFH 325	126.00	127.33	128.67	137.00	138.33	131.47	0.62	0.31
Hysun-33	156.67	141.33	157.00	176.00	147.67	155.73	1.46	0.46
Env. Mean	133.5	133.09	131.94	148.64	137.42	136.80		

Where, E1 = Sennar, E2 = Wad Medani, E3 = Rahad, E4 = New Halfa and E5 = Suki
(x_i)= Mean, (b_i) = Regression coefficient and (S^2_{di}) = Deviation from regression

Table 5. Estimates of stability and adaptability parameters for number of seeds per head of 11 sunflower hybrids evaluated at five environments.

Hybrids	Environments (E)							
(G)	E1	E2	E3	E4	E5	(x_i)	(b_i)	(S^2_{di})
SFH 32	1035.00	1039.0	613.00	1452.67	836.00	995.13	1.11	0.15
SFH 36	1602.67	1056.3	784.33	1471.00	992.33	1181.33	1.20	0.25
SFH 37	1467.00	1009.0	629.67	1456.00	1171.00	1146.53	1.24	0.21
SFH 310	1228.33	1134.6	679.67	1588.00	1166.33	1159.40	1.17	0.14
SFH 313	1199.33	1147.0	850.33	1400.33	1172.00	1153.80	0.70	0.06
SFH 314	1249.67	1042.3	842.00	1321.00	1008.33	1092.67	0.73	0.01
SFH 341	1601.67	1243.6	704.33	1357.67	967.00	1174.87	1.14	0.43
SFH 345	1217.67	1021.0	879.00	1641.00	1050.67	1161.87	1.03	0.17
SFH 302	1380.00	1129.0	890.33	1453.67	975.67	1165.73	0.90	0.06

SFH 325	1074.67	1154.6	989.00	1485.67	1129.00	1166.60	0.57	0.19
Hysun-33	1428.67	1102.0	836.00	1649.67	1005.67	1204.40	1.23	0.05
Env.Mean	1316.79	1098.0	790.70	1479.70	1043.09	1146.00		

Where, E1 = Sennar, E2 = Wad Medani, E3 = Rahad, E4 = New Halfa and E5 = Suki
(x_i)= Mean, (b_i) = Regression coefficient and (S^2_{di}) = Deviation from regression

Percentage of empty seeds

The mean percentage of empty seeds of the individual hybrids and their stability parameters b_i and S^2_{di} are presented in Table 6. The environmental mean showed that E4 (New Halfa) had the lowest mean percentage of empty seeds (8.85%) and the highest in E2 (Wad Medani, 19.18%) and E1 (Sennar, 19.15%). This indicated that E4 was the most favorable and the majority of the hybrids had the capacity to exploit that environment by attaining high self-compatibility and low percentage of empty seeds. Over all environments, four hybrids (Hysun-33, SFH 313, SFH 341 and SFH 310) had the lowest mean percentage of empty seeds of less than 13.50%. The lowest percentage of empty seeds (12.33%) was given by Hysun-33 and the highest (18.07%) by SFH 36. However, according to regression coefficient and deviation from regression values, it is clear that hybrids; Hysun-33 and SFH 341 had a slope close to 1.00 with deviation around zero. On this basis these hybrids can be recommended as most stable hybrids with respect to percentage of empty seeds over 5 environments represented in this trial.

Table 6. Estimates of stability and adaptability parameters of percentage of empty seeds of 11 sunflower hybrids evaluated at five environments.

Hybrids	Environments (E)							
(G)	E1	E2	E3	E4	E5	(x_i)	(b_i)	(S^2_{di})
SFH 32	21.00	16.67	7.00	9.67	16.00	14.07	1.07	0.32
SFH 36	22.33	25.00	17.33	9.33	16.33	18.07	1.19	0.25
SFH 37	21.33	21.67	14.33	8.67	16.67	16.53	1.12	0.06
SFH 310	15.33	16.67	12.67	8.33	13.67	13.33	0.63	0.06
SFH 313	15.33	15.67	8.00	10.33	13.00	12.47	0.64	0.09
SFH 314	20.67	19.67	12.00	7.33	15.33	15.00	1.16	0.04
SFH 341	15.67	17.67	10.00	6.00	14.00	12.67	0.96	0.08
SFH 345	21.33	19.00	11.67	9.67	13.67	15.07	1.03	0.05
SFH 302	19.67	21.67	9.33	11.67	13.67	15.20	1.05	0.17
SFH 325	22.33	19.67	10.67	8.67	13.00	14.87	1.22	0.09
Hysun-33	15.67	17.67	8.00	7.67	12.67	12.33	0.93	0.04
Env. Mean	19.15	19.18	11.00	8.85	14.36	14.51		

Where, E1 = Sennar, E2 = Wad Medani, E3 = Rahad, E4 = New Halfa and E5 = Suki
(x_i)= Mean, (b_i) = Regression coefficient and (S^2_{di}) = Deviation from regression

One hundred seed weight

The average percentage of 100-seed weight of the individual hybrids over five environments with their regression coefficients and deviations from regression are presented in Table 7. From the environmental mean, it was observed that most of the hybrids produced maximum 100-seed weight when sown in E4 (New Halfa) (9.62). The highest 100-seed weight (6.29 g) was produced by the hybrid Hysun-33 followed by SFH 341 (6.28 g) and SFH 313 (6.20 g), and the lowest (5.45 g) by the hybrid SFH 302. Six hybrids showed means above the average 100-seed weight (5.90 g). Considering the stability parameters along with mean 100-seed weight, it is clear that two hybrids (Hysun-33 and SFH 310) recorded mean 100-seed weight above the average with a regression value of 0.93 for both closer to unity and deviation zero, indicating that they were the most stable hybrids for this character. The hybrids SFH 341, SFH 313 and SFH 314 showed higher b_i values (1.26, 1.17 and 1.13, respectively) indicating their stability only for highly favorable environments for 100-seed weight.

Table 7. Estimates of stability and adaptability parameters of 100-seed weight of 11 sunflower hybrids evaluated at five environments.

Hybrids	Environments (E)							
(G)	E1	E2	E3	E4	E5	(x_i)	(b_i)	(S^2_{di})
SFH 32	4.33	5.03	4.33	9.23	6.63	5.91	0.91	0.10
SFH 36	4.10	5.77	4.10	8.87	5.00	5.57	0.91	0.01
SFH 37	3.70	5.73	4.03	9.50	5.33	5.66	1.06	0.01
SFH 310	4.60	6.27	5.13	9.67	4.97	6.13	0.93	0.04
SFH 313	3.87	5.77	4.70	10.50	6.17	6.20	1.17	0.04
SFH 314	4.13	6.10	4.33	10.27	6.00	6.17	1.13	0.02
SFH 341	4.93	6.20	3.80	10.93	5.53	6.28	1.26	0.03
SFH 345	5.23	5.70	3.87	8.23	4.67	5.54	0.72	0.07
SFH 302	4.00	4.90	4.37	9.10	4.87	5.45	0.95	0.02
SFH 325	4.30	5.17	3.93	9.60	5.27	5.65	1.05	0.01
Hysun-33	5.10	6.00	5.30	9.90	5.13	6.29	0.93	0.04
Env. Mean	4.39	5.69	4.35	9.62	5.42	5.90		

Where, E1 = Sennar, E2 = Wad Medani, E3 = Rahad, E4 = New Halfa and E5 = Suki
(x_i)= Mean, (b_i) = Regression coefficient and (S^2_{di}) = Deviation from regression

Seed and oil production

The ultimate goal of sunflower breeding program is the development of hybrids with high seed yield, high oil content and high stability to environmental changes. The average seed and oil yields of the individual hybrids coupled with b_i and S^2_{di} are presented in Tables 8 and 9, respectively. From the environmental means it was observed that E4 (New Halfa) had the highest mean of seed yield (2402 kg ha^{-1}) and oil yield (1077.87 kg ha^{-1}). However, the lowest f seed (1168 kg ha^{-1}) and oil yields (476.57 kg ha^{-1}) were produced in E3 (Rahad). This indicated that New Halfa had the most favorable environment and the majority of hybrids had the capacity to exploit that environment to confer the highest seed and oil yields. Over all environments, three local hybrids, SFH313, SFH310 and SFH341 gave the highest seed yield and out-yielded the introduced hybrid Hysun-33.

Also, for oil yield, the three hybrids had the highest oil yield compared to the grand mean, and two of them (SFH313 and SFH310) out-yielded Hysun-33 in terms of oil yield (Table 9). It was emphasized that both linear (b_i) and non-linear (S^2_{di}) components of GxE interactions are necessary for judging the stability of a hybrid. A regression coefficient (b_i) approximating 1.0 coupled with an S^2_{di} of zero indicate average stability (Eberhart and Russell, 1966). Regression values above 1.0 describe genotypes with higher sensitivity to environmental changes (below average stability) and greater specificity of adaptability to high yielding environments. A regression coefficient below 1.0 provides a measurement of greater resistance to environmental change (above average stability), and thus increases the specificity of adaptability to low yielding environments (Wachira *et al.*, 2002). Also, Zubair *et al.* (2002) suggested that if regression coefficients of the genotypes are not significantly different from 1.0, the stability of these genotypes should be judged upon other two parameters i.e., average mean (x^-) and deviation from regression (S^2_{di}).

In the present study, the regression coefficients for seed yield ranged from 0.72 to 1.38 and for oil yield from 0.77 to 1.31, Tables 8 and 9, respectively. These large variations in regression coefficients (b_i values) give the breeder an advantage to select hybrids for both adverse and favorable environments. Therefore, the resultant regression coefficient (b_i) and deviation from regression (S^2_{di}) and mean yield for each hybrid are parameters for estimating the stability of yield over the environments. For seed yield,
SFH313, SFH310 and SFH341 gave the highest seed yield over the grand mean with the regression coefficients of 1.06, 0.79 and 1.05, respectively that were not significantly different from regression (Table 8). Thus, these three local hybrids proved to be stable for seed yield, adapted to a wide range of environments, and suitable for general cultivation. Yield and stability of Hysun-33 was improved only under optimal growing conditions. In contrast, SFH37 and SFH32 are expected to give good seed yield under favorable environmental conditions due to their greater values of regression coefficient (b_i<1.0), i.e. 1.38 and 1.20, respectively.

Table 8. Estimates of stability and adaptability parameters of seed yield (kg ha^{-1}) of 11 sunflower hybrids evaluated at five environments

Hybrids	Environments (E)							
(G)	(E1)	(E2)	(E3)	(E4)	(E5)	(x_i)	(b_i)	(S^2_{di})
SFH 32	1044	1307	967	2540	2530	1677	1.38	0.04
SFH 36	1041	1432	1008	2247	1673	1480	0.87	0.08
SFH 37	1062	1372	816	2396	2137	1556	1.20	0.02
SFH 310	1451	1859	1399	2432	2223	1872	0.79	0.02
SFH 313	1369	1633	1426	2569	2585	1916	1.06	0.03
SFH 314	1087	957	1210	2353	2343	1590	1.15	0.19
SFH 341	1538	1957	888	2575	2279	1847	1.05	0.25
SFH 345	1120	1238	1138	2385	2370	1650	1.15	0.05
SFH 302	1110	1405	1392	2286	2015	1641	0.83	0.05

SFH 325	1050	1566	1250	2144	1796	1561	0.72	0.06
Hysun-33	1535	1533	1361	2501	2065	1798	0.81	0.04
En. Mean	1218	1478	1168	2402	2183	1690	1.00	
Env. Index	471.46	212.13	521.67	712.33	492.93			

Where, E1 = Sennar, E2 = Wad Medani, E3 = Rahad, E4 = New Halfa and E5 = Suki
(x_i)= Mean, (b_i) = Regression coefficient and (S^2_{di}) = Deviation from regression

Regarding oil yield and the three stability parameters for the individual hybrid, SFH313, SFH310, Hysun-33 and SFH341 gave the highest oil yield of 831.84, 791.19, 785.80 and 775.91 kg ha^{-1} over the grand mean of oil yield with regression coefficients of 1.11, 0.85, 0.83 and 0.97, respectively, that are not significantly different from regression (Table 9). Hybrid SFH310 and SFH313 had above average oil yield, regression coefficient approximately close to one and low deviation from regression (0.03 and 0.003, respectively) indicating wide adaptation and stability for oil yield across the tested environments. Also, Hysun-33 and SFH341 had above average oil yield and regression coefficients close to one (0.83 and 0.97) but they had high values of S^2_{di} (0.14 and 0.25) showing sensitivity to environmental changes. The rest of hybrids under study had average oil yield below the grand mean. Therefore, the need to improve the oil content in hybrid seeds in developing sunflower hybrid oil types is crucial, because oil yield depends upon oil content in the seeds and seed yield of the hybrids.

Table 9. Estimates of stability and adaptability parameters of oil yield (kg ha^{-1}) of 11 sunflower hybrids evaluated at five environments.

Hybrids	Environments (E)							
(G)	(E1)	(E2)	(E3)	(E4)	(E5)	(x_i)	(b_i)	(S^2_{di})
SFH 32	417.60	522.93	367.46	1092.34	961.27	672.32	1.21	0.01
SFH 36	458.04	529.96	363.00	1011.00	669.33	606.27	0.87	0.09
SFH 37	424.80	466.59	318.37	1150.24	918.77	655.75	1.31	0.01
SFH 310	580.53	743.60	559.47	1094.25	978.12	791.19	0.85	0.03
SFH 313	602.21	653.20	584.80	1233.38	1085.70	831.84	1.11	0.002
SFH 314	412.93	363.53	520.44	941.33	1054.50	658.55	1.05	0.24
SFH 341	615.33	822.08	355.20	1107.11	979.83	775.91	0.97	0.25
SFH 345	448.00	445.68	477.82	1097.25	1019.10	697.57	1.18	0.05
SFH 302	466.20	519.85	584.64	1028.70	866.59	693.20	0.86	0.05
SFH 325	430.50	548.22	512.36	900.62	862.08	650.76	0.77	0.03
Hysun-33	690.90	613.07	598.69	1200.48	825.87	785.80	0.83	0.14
En. Mean	504.28	566.25	476.57	1077.87	929.20	710.80	1.00	
En. Index	929.2	0.11	476.60	566.20	504.30			

Where, E1 = Sennar, E2 = Wad Medani, E3 = Rahad, E4 = New Halfa and E5 = Suki
(x_i)= Mean, (b_i) = Regression coefficient and (S^2_{di}) = Deviation from regression

CONCLUSION

Based on the results, the SFH37 and SFH310 were identified as stable hybrids for plant height, SFH345 and SFH302 were identified as stable for number of seeds per head, whereas, Hysun-33, SFH310 and SFH341 were found stable for low percentage of empty seeds and one hundred seed weight, respectively. Three hybrids, SFH310, SFH313 and SFH341 performed better than Hysun-33 and other genotypes across five environments and were considered as the most stable hybrids for seed and oil yields. In contrast, hybrids such as SFH32 and SFH37 with regression coefficients greater than one were regarded as sensitive to environmental changes for seed and oil yields. Therefore, the hybrid SFH310 was identified as stable hybrid for various yield components and their parents (female and male) can be used for developing future hybrids that could show wider adaptability and stability under diverse environments. Also, this information could be exploited in breeding programs for the development of hybrids with combinations of stable traits. The three promising local hybrids (SFH 310,SFH 313 and SFH 341)
were released in June 2009 for commercial production under irrigated conditions in the central clay plains of the Sudan. The local seed production of these hybrids (based on availability of three parental lines; A, B and R-lines) will be a safeguard for sunflower production against foreign political constraints concerning seed importation of introduced hybrids like Hysun-33.

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تقويم هجن محصول زهرة الشمس السودانية للقدرة الإنتاجية ومكونات الإنتاجية وثبات الإنتاجية

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الخلاصة

تطوير هجن محلية من محصول زهرة الشمس ذات إنتاجية عالية وثابته في مختلف البيئات ، يعتبر من أهم أهداف برنامج التربية. أجريت هذه التجربة للتقييم عشرة هجن محلية بالرموز SFH32 ، SFH36، SFH37، SFH310، SFH313، SFH314، SFH341، SFH345، SFH3302، و SFH325 واختبارها مع الشاهد Hysun-33 في خمسة بيئات مروية هي سنار ، واد مدني، الرهد، حلفا الجديدة، والسوكي لمعرفة مقدرتها الإنتاجية الكامنة. أستخدم تصميم القطاعات العشوائية الكاملة بثلاثة مكررات لتنفيذ التجربة في كل موقع خلال الموسم الشتوي 2009/2008. أوضحت النتائج وجود فروقات كبيرة في الإنتاجية و مكوناتها بين الهجن والمواقع. كما أوضح تفاعل الطرز الوراثية مع البيئة (genotype x environment interactions وجود فروقات معنوية عالية لسته صفات تمت دراستها وهى أطوال النباتات (سنتمترات) وعدد البذور بالقرص والنسبة المئوية للبذور الفارغة ووزن المائة بذرة (جرامات) وإنتاجية البذور(كيلوجرامات/هكتار) وإنتاجية الزيت (كيلوجرامات/هكتار).أوضح تحليل ثبات الإنتاجية stability analysis بإسـتخدام نموذج Eberhart and Russell's model بان جميع الهجن لها استجابات متباينة مع المتغيرات البيئية فى المواقع الخمسة وكان أفضل الأداء فى حلفا الجديدة (E4). كما أوضح التحليل بان الهجينين SFH37 و SFH310 هما من الهجن المستقرة و الثابتة الأداء لصفة أطوال النباتات و الهجينين SFH345 و SFH302 لصفة عدد البذور بالقرص ، بينما الهجن Hysun-33 ، SFH310، وSFH341 لصفتي النسبة المنخفضة من البذور الفارغة والوزن المرتفع للمائة بذرة علي التوالي. أوضحت الدراسة ان ثلاثة هجن محلية (SFH310، SFH313 و SFH341) وخاصة الهجين SFH310 ، لها مقدرة إنتاجية عالية من البذور والزيت وثبات الإنتاجية فى البيئات الخمسة مقارنة مع الشاهد Hysun-33 وباقي الهجن ، بينما هجن اخرى مثل الهجينين SFH32 و SFH37 تعتبر حساسة للتغيرات البيئة فى إنتاجيتها من البذور والزيت. تم التعرف على الهجين SFH310 بأنه أكثر ثباتاً للإنتاجية ومكوناتها. الهجن السودانية الثلاثة الواعدة تمت إجازتها في يونيو 2009 للإنتاج التجاري والأنتاج المحلي لبذور الهجين SFH310 (بحوث-1= Bohooth-1) تم تبنيه من بعض منتجي البذور فى السودان.