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Study the Seed and Oil Yield Stability of Sunflower Hybrids across Environments

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Authors' contributions

This work was carried out in collaboration among all authors. Author ZEG designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors MAA, KAM and MAA performed each experiment in each location and managed the analyses of the study. Author ZEG managed the correction of the manuscript. All authors managed the literature searches, read and approved the final manuscript.

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ABSTRACT

Aims: This study was conducted to investigate the nature of genotypes-environments interaction (GEI) and identify the most stable sunflower hybrids that can give high seed yield with high oil yield under a wide range of environmental conditions in Egypt.
Place and Duration of Study: Fifteen hybrids were evaluated across three years (2017 to 2019) and three locations (Giza, Ettay El-Barod and Shandaweel).
Study Design: The experiments were laid out in Randomized Complete Block Design (RCBD) with three replications.
Methodology: Analysis of variance, some stability methods as additive main effects and multiplicative interaction (AMMI) and genotype main effects and genotype-by-environment interaction effects (GGE-biplot) were conducted. Results of stability indices were ranked as AMMI Stability Value (ASV), yield stability (YSI) and rank-sum (RSI) and heritability was estimated.
Results: Combined analysis revealed that GEI was highly significant, indicating the possibility of selection for stable ones. AMMI analysis confirmed that the seed yield performance of sunflower

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hybrids was largely influenced by the environment. On the contrary, environments recorded less impact on oil yield as compared to the effect of hybrids (genetics). Then, heritability estimate of oil yield trait (93.86%) was higher than the seed yield one (31.10%). Indices of YSI and RSI presented that hybrids (H15, H7 and H11) and (H7, H8 and H15) were the best stable promising ones in seed and oil yield, respectively. GGE-biplot analysis indicated that hybrids (H15, H7, H4 and H11) and (H7, H15, H8 and H15) were considered as the most ideal for seed and oil yield, respectively whereas Shandweel was the ideal environment for both.

Conclusion: Therefore, all analyses agreed on hybrids H15, H7 and H11 were considered as the most desirable and stable ones. These hybrids can be recommended for wider cultivation due to better seed and oil yield with stable performance across the test environments.

Keywords: AMMI; GGE biplot; heritability; hybrids; oil; seed yield; stability index.

1. INTRODUCTION

Sunflower (*Helianthus annuus* L.) is an important oilseed crop of the world. This crop is grown under diverse agroclimatic regions which make its cultivation possible during any season of the year with adaptability to a wide range of soil and climatic conditions. Therefore, the production of sunflower hybrids and its development for increasing production is more availabile under diverse durations. This impact is mostly reflected through change performance of the most important yield traits as both seed and oil yield [1].

Breeding is an important aspect in the genetic improvement of crops to select the best hybrid combinations. It is desirable to study the impact of various environments to identify stable hybrids. Therefore, it is important to establish the responses of new sunflower genotypes (varieties, hybrid combinations, lines, populations, etc.) to different environmental conditions, and to study the genotype × environment interaction (GEI) [2] and [3]. Various statistical methods (parametric and non-parametric) have been proposed to study GEI [4] and [5].

The development and use of yield-stability statistic (YSi) have enabled the incorporation of stability in the selection process [6]. This statistic has been evaluated and found to be useful for recommending genotypes [7]. However, it was observed that the rank-sum method has an inherent weakness that it is weighing heavily towards yield performance, apart from the arbitrariness in the scoring procedure [8]. Therefore, this method is not fit for providing general conclusions. It was proposed that the selection index (I) consists of a yield component and a stability component [9].

In most cases, the applied different methods of statistical analysis to understand the genotype by environment interaction giving the stability indexes are usually univariate [10] and [11]. Regarding multivariate analysis using additive main effect and multiplicative interaction (AMMI) method, analysis of variance for basic genotype and environment effects with principal component analysis (PCA) of the genotype × environment interaction was combined in the same model [12,13,14,15 and 16]. AMMI stability value (ASV) based on the AMMI model's IPCA's scores for each genotype was developed [17]. Therefore, the AMMI model not only determines yield stability response of genotypes across environments or predicts the stable genotypes, but it is accurate estimate of the true performance of genotypes are evaluated to provide specific environments [18]. Using AMMI stability value and mean yield, GSI incorporates both mean yield and stability in a single criterion by genotype selection index (GSI) [19].

The GGE biplot method is based on data visualization and proved to be helpful in the detection of the genotype by environment interaction pattern, classification of mega environments, simultaneous selection of genotypes based on stability and mean yield and characterization of testing environments based on their discriminating ability and representativeness. GGE is a useful and popular tool for breeders; such a biplot presents a rank-two approximation of the sum of genotype effects and genotype x environment interaction effects [20].

This study aimed of this study was to compare seed and oil yield of 15 sunflower hybrids at three locations during three years to: (1) estimate the seed and oil yield of the newly developed sunflower hybrids (2) detect whether there is a link between the stability of new hybrids for seed and oil yield and (3) study adaptability of F_1 sunflower genotypes across different environments by using AMMI and GGE biplot

methods to identify and select the best promising hybrids across environments (ideal ones) to complete the breeding program with perfect condition.

2. MATERIALS AND METHODS

2.1 Field Experiments

The present experiments were carried out during three growing seasons from 2017 to 2019 at Giza Agricultural Research Station, Giza Governorate, Egypt (latitude 30° 0' 47" N with a longitude 31° 12' 32" E), Ettay Elbarod Agricultural Research Station, El Beheira Governorate, Egypt (30° 36′ 36″ N, 30° 25′ 48″ E) and Shandweel Agricultural Research Station, Sohag Governorate, Egypt (26° 32' 60" N, 31° 42' 0" E. The description of the Experimental locations is presented in Table (1).

This study was conducted using fifteen sunflower hybrids (15 F_1 obtained according to a breeding program of the Oil Crops Research Department, Field Crops Research Institute, Agricultural Research Center, Giza, Egypt). These fifteen sunflower hybrids (Table 2) were evaluated during three successive seasons (2017, 2018 and 2019) in a randomized complete block design with three replications at the three locations Giza, Ettay Elbarod and Shandaweel (combined as nine environments as shown in Table 2).

The experimental design in each location was arranged as randomized complete block design with three replications. Sowings were performed in July 2017, 2018 and 2019. The plot area was $15m^2$ (5rows, 5meters long). Each F_1 hybrid was sown without leaving separators via three seeds per hill with 5 m long, 60 cm broad and hill spaced 20 cm apart and later thinned to one plant per hill. All other agronomic practices for growing sunflower either soil preparation, soil fertilization or inter culture operations were applied as per recommended packages of Oil Crops Research Department, FCRI, ARC, Egypt.

Data were determined on a plot basis, using the three guarded inner rows for each hybrid. Experimental plot were harvested and evaluated for seed yield kg/plot. Seed oil content was determined, after drying at 70ºC for 48 h [21], by Soxhlet extraction technique, using diethyl ether, as reported by AOAC methods [22]. Then, data were converted to seed yield ton/hectare and oil yield content ton/hectare.

2.2 Statistical Analysis

2.2.1 Analysis of variance

Analysis of variance (ANOVA) for yield was carried out for individual locations, seasons and for combined analysis across them [23]. Homogeneity of residual variances was tested before a combined analysis using Levene test [24]. Analysis of variance for each environment, combined analysis of variance over locations and years was done on mean basis. Continued, combined analysis of variance from the pooled mean data over all environments was done to detect the presence of GE and to partition the variation due to genotype, environment and GE using GenStat 18th edition statistical software. Mean comparison using Duncan [25] was performed to explain the significant differences among pooled means of genotypes and locations (environments). Heritability estimates in broad sense h^2_b were calculated from the expected mean squares of the pooled ANOVA across years × locations as follows:

$\sigma^2E = M1$, $\sigma^2GLY = M2 – M1/r$, $\sigma^2GY = M3 – M2/rl$, $\sigma^2GL = M4 – M2/ry$, $\sigma^2G = M5 - (M4 + M3 – M2)/rly$ (as shown in Table 3).

Therefore, $h^2_b = \sigma^2G / [(\sigma^2G) + (\sigma^2GL/l) + (\sigma^2GY/y) + (\sigma^2GLY/ly) + (\sigma^2E /lry)]$

2.2.2 Stability analyses

Subsequently, the obtained data were subjected to parametric, non-parametric and graphical stability analyses to identify stable and high yielding hybrids.

2.2.3 Additive main effects and the multiplicative interaction (AMMI)

Approach fits the additive effects of genotypes and the environments by the usual analysis of variance and then describes the non-additive parts by principal component (PCA) analysis according to Zobel *et al* [12]. However, AMMI stability value of the genotypes (ASV_i) was calculated for each one and each environment proposed by Purchase *et al* [17]:

$ASV = [[(IPCA_1SS \div IPCA_2SS) * IPCA_1 \text{ score}]^2 + (IPCA_2 \text{ score})^2]^{1/2}$.

Where, $IPCA_1SS$ and $IPCA_2SS$ stand for the sum of squares of $IPCA_1$ and $IPCA_2$, respectively.

Table 1. Climatic and soils characteristics of the planting locations

Site	Year	Average annual temperature												Soil type
		Min.						Max.						
		Oct.	Sep.	Aug.	July	June	May	Oct.	Sep.	Aug.	July	June	May	
Giza	2017	21.0	23.8	25.2	24.9	23.9	20.7	29.9	34.7	35.5	36.5	35.4	33.0	clay
	2018	21.2	25.7	24.9	24.5	24.7	22.3	30.2	35.1	35.4	35.9	36.0	34.2	
	2019	22.1	24.6	24.6	24.5	23.8	20.1	30.8	33.8	35.2	35.9	35.4	34.6	
Ettay Elbarod	2017	19.6	23.7	23.5	24.2	22.6	19.2	27.5	30.7	31.4	31.6	29.8	27.6	clay
	2018	20.2	25.2	23.9	23.4	22.4	20.3	28.8	31.7	31.9	31.7	31.2	29.2	
	2019	20.6	23.8	23.7	23.9	23.0	17.9	28.5	30.8	31.5	31.8	30.0	28.8	
Shandweel	2017	18.6	24.6	25.3	26.1	25.8	21.8	31.9	37.9	39.0	40.3	40.2	37.9	clay loam
	2018	20.2	25.5	25.7	25.9	26.2	23.3	34.4	37.3	39.1	39.5	40.7	39.2	
	2019	20.8	24.7	24.6	25.5	25.8	22.7	35.1	37.8	39.4	39.9	40.2	39.2	

Table 2. Hybrids code, parents of the fifteen F_1 tested sunflower hybrids and environments

No.	Hybrids Code	Parents	Location	Season	Environment
1	H1	A1 * Line 2	Giza	2017	E1
2	H2	A6 * Line 2	Giza	2018	E4
3	H3	A15 * Line 2	Giza	2019	E7
4	H4	A1 * Giza 102	Ettay Elbarod	2017	E2
5	H5	A6 * Giza 102	Ettay Elbarod	2018	E5
6	H6	A15 * Giza 102	Ettay Elbarod	2019	E8
7	H7	A1 * Line 120	Shandweel	2017	E3
8	H8	A6 * Line 120	Shandweel	2018	E6
9	H9	A13 * Line 120	Shandweel	2019	E9
10	H10	A15 * Line 120			
11	H11	A1 * Sakha53			
12	H12	A6 * Sakha53			
13	H13	A12 * Sakha53			
14	H14	A15 * Sakha53			
15	H15	A9 * Sakha53			

2.2.4 Yield Stability Index (YSI) and Rank-Sum (RSI)

The approaches which incorporate both mean yield and stability in a single criterion were calculated according Farshadfar [19]. YSI_i = $RASV_i$ + RY_i, where $RASV_i$: is the rank of AMMI stability value and RY_i is the rank of mean yield of genotypes across environments. Rank sum (RSI_i) = Rank mean (R_i) + Standard deviation of rank (SDR).

2.2.5 Sustainability Index (SI)

The parameter was estimated according to Babarmanzoor *et al* [26] who suggested that values of sustainability index were divided arbitrarily into 5 groups viz. very low (up to 20%), low (21-40%), moderate (41-60%), high (61-80%) and very high (above 80%).

2.2.6 Stability index (I)

The non-parametric analysis was computed according to Rao *et al* [3]. Genotypes were ranked based on the (I) according to Bajpai and Prabhakaran [8]. Ranks were assigned in increasing order to the genotypes whose stability indices varied in decreasing order *i.e.*, the genotype which had the highest stability index (I) received first rank and the one with the lowest 'I'.

2.2.7 Genotype main effects and genotype-by-environment interaction effects (GGE-biplot)

This method was used to analyze the genotype by environment interaction of yield and generate the genotype and GEI. The GGE-biplot analysis was built according to Yan and Hunt [27] and Yan [28], which provides a clear insight into specific GEI combination and the general pattern of adaptation of genotypes.

3. RESULTS AND DISCUSSION

The combined analysis of variance for seed and oil yield (ton ha^{-1}) of fifteen sunflower genotypes (three locations and three years) is presented in Table (3). Results of partitioning sum of squares combined data indicated that, seed and oil yield was highly significant ($p<0.001$) influenced by years and locations accounted for (0.50% and 15.77%) and (41.59% and 0.91%), respectively of the total variation. It can be mentioned that, locations affected the seed yield larger than years; meanwhile oil yield was influenced by years with the largest degree [29]. Highly significant differences ($P<0.001$) were observed for seed and oil yield among the genotypes, showing the presence of genetic variability in yield performance among the studied genotypes (genotypes with high yielding and others with poor yielding). Genotypes contributed 14.28% and 45.43% of the total variation for seed and oil yield, respectively.

Both seed and oil yield explained significant for GEI (year * location, year * genotype, location * genotype and year * location * genotype) contributes to (1.07% and 1.60%), (3.03% and 6.08%), (20.64% and 3.48%) and (7.98% and 7.96%) of the total variation, respectively (Table 3). This indicates the big influence of the environment on the yield performance of sunflower genotypes. Similar findings were reported that GE interaction with location is more important than GE interaction with year, especially in seed yield [30]. As GE interaction was significant, therefore we can further proceed and estimate stability [31].

Table 3. Combined analysis of variance for seed and oil yield traits of 15 F_1 sunflower hybrids across 9 environments

Source of variation	DF	Mean squares	Seed yield Ton ha^{-1}		Oil yield ton ha^{-1}	
			Mean square (Ms)	Explained SS (%)	Mean square (Ms)	Explained SS (%)
Year (Y)	2		0.279**	0.50	0.935**	15.77
Rep* Y Error1	4		0.021	0.11	0.012	0.63
Location (L)	2		23.089**	41.59	0.054**	0.91
Y * L	4		0.298**	1.07	0.048**	1.60
Rep (Y * L) Error2	12		0.015	0.16	0.003	0.34
Genotype (G)	14	M5	1.132**	14.28	0.385**	45.43
Y * G	28	M4	0.120**	3.03	0.026**	6.08
L * G	28	M3	0.818**	20.64	0.015*	3.48
Y * L * G	56	M2	0.158**	7.98	0.017**	7.96
Error	252	M1	0.047	10.63	0.008	17.80
Heritability in broad sense (h^2_b)			31.10%		93.86%	

** and ** significant at 0.05 and 0.01 probability levels, respectively*

3.1 Heritability

Estimates of broad-sense heritability **(h^2_b)** on sunflower hybrids mean across three locations and three years were estimated for both seed and oil yield traits (Table 3). Looking seed yield was greatly influenced by the diversity in the locations more than oil yield and therefore, tested hybrids over a wide range of locations recorded broad sense heritability estimate (93.86%) for oil yield higher than seed yield heritability estimate (30.10%). This result was in agreement with Khan *et al* [32]. Then, heritability of a trait does not depend only on genetic factor; it also depends on the subjected environmental conditions [33] and [34] also found the same results.

3.2 Additive Main Effects and Multiple Interactions

AMMI model is an effective way to investigate significant GE interaction. This model combines a standard analysis of variance (ANOVA) with principal component analysis (PCA). The AMMI analysis of variance for both sunflower seed and oil yield traits (ton ha^{-1}) of fifteen genotypes (hybrids) tested over nine environments was presented in Table (4). Pooled analysis of variance illustrated the high significance ($P < 0.001$) of all the sources of variations (hybrids and environment as the main sources of variation and interaction hybrid x environment as the multivariate part). Environment contributed the highest total variation of sum of the square with 48.45% followed by interactions with 35.52% and genotypes with 16.02% of the whole effect of seed yield variation. Therefore, environments had the largest obvious impact and the most responsible for the variation in seed yield, which is in harmony with the findings of Cvejic *et al* [35] and [36]. A small portion ratio of hybrids in total sunflower seed yield variation may be due to the complex quantitative nature of the yield, which is controlled by a large number of components or the divergence of selected genotypes. Genotype-environment interaction (GEI) was highly significant; suggesting the existence of differential responses in hybrids to different environments and the need for extension of stability analysis. AMMI model partitioned interaction among the first two interaction principal component axis (IPCA) as they were significant in the assessment. The first principal component ($IPCA_1$) amounted to 50.04% of the variation caused by interaction, while ($IPCA_2$) accounted for 26.88% of the variation. These are in agreement with the recommendation of Gauch and Zobel [37] which recommended that the most accurate model for AMMI can be predicted using the first two IPCAs.

On the other side, the presents highly significant ($P < 0.001$) of all the sources of variation especially genotype-environment interaction (GEI) was demonstrated by the AMMI model for oil yield trait. Hybrids shared the highest total variation of sum of a square with 55.92% followed by environments with 22.51% and interactions with 21.57% of the whole effect of oil yield variation. Therefore, hybrids had the largest obvious effect and the most responsible for the variation in sunflower oil yield, indicating that the hybrids were diverse, with large differences among genotypic means causing most of the variation in oil yield. Similar outcomes have

reported by Akter *et al* [38] in rice yield. While the participation of GEI to the total variation revealed minimal role. A similar result was reported on most traits in sunflower by Bhoite *et al* [39]. The first principal component ($IPCA_1$ and $IPCA_2$) explained 41.79% and 23.25% of the interaction variation, respectively.

The magnitude of the environment was two times greater than the share hybrids, implying that most of the variation in seed yield was due to the environment. Meanwhile, in oil yield, hybrids were two times greater than the contribute environments. This indicated that the large influence of the environment causing most of the variation in seed yield performance of sunflower hybrids across all locations, contracting oil yield. While the contribution of GEI to the total variation demonstrated minimal role. A similar result was reported on sunflower by Cvejic *et al* [35] and [36] and Bhoite *et al* [39]. Regarding AMMI analysis, results confirmed that the most accurate model for AMMI can be predicted by using the first two PCAs [37] and [40], especially in oil yield whereas recorded no significant residual, indicating to success this model in clarifying and explanation most GEI. Meanwhile, seed yield recorded significant residual, suggesting the first two PCAs not concluded and explanation most GEI.

3.3 Mean Performance

The mean performance of sunflower hybrids in all environments for seed and oil yield is presented in Table (5). Both seed and oil yield explained wide variation by environments, indicating diverse the studied environments. Regarding seed yield, the 15 hybrids average ranged from (2.47) to (3.15 ton ha^{-1}) for hybrids (H13 – H7 and H15), respectively with a grand mean of 2.84 ton ha^{-1}. Meanwhile, nine of the hybrids (H4, H6, H7, H8, H10, H11, H12, H14 and H15) gave seed yield above the grand mean (2.84 ton ha^{-1}). On the other side, the other six hybrids have seed yield below the grand mean. The performance of hybrids at Giza in three years was below the overall performance of the environments (2.56, 2.50 and 2.54 ton ha^{-1}) while at Shandweel it was the highest in three years (3.29, 3.33 and 3.31 ton ha^{-1}).

Concerning oil yield, the sunflower is mostly grown for improving oil content is one of the main goal of sunflower breeding [41]. Table (5) revealed the differences in oil yield mean performance in all hybrids, indicating a high genetic potential of oil yield. The average oil yield of all hybrids and all environments was (0.98 ton ha^{-1}), varied from (0.74 to 1.19 ton ha^{-1}) for hybrids (H5 and H7), respectively. Eight of the hybrids (H7, H8, H9, H10, H11, H12, H14 and H15) recorded higher values above the grand mean (0.98 ton ha^{-1}). Among all hybrids, H7 and H8 had the highest average (1.19 and 1.10 ton ha^{-1}), respectively. Across environments, there was high variability of oil yield among the studied environments. Hybrids demonstrated the highest average oil yield in Ettay El-Barod (1.10 ton ha^{-1}) in the 3rd year while the lowest was in Shandweel in the 2nd year (0.90 ton ha^{-1}).

The results exhibited differential performance of hybrids for seed and oil yield across the tested environments, indicating the existence of hybrid-environment interaction. Since all the locations are sunflower growing regions, further stability analysis was carried out to identify a hybrid which is stable and had high mean yield across environments.

Table 4. Additive main effects and multiplicative interaction (AMMI) analysis of variance for seed and oil yield trait of 15 F_1 sunflower hybrids across 9 environments

Source of variance	df	Seed yield (ton ha^{-1})			Oil yield (ton ha^{-1})		
		SS	MS	SS (%)	SS	MS	SS (%)
Block	18	0.31	0.017	0.276	0.115	0.006	0.97
Treatments	134	98.92	0.738**	89.09	9.631	0.072**	81.23
Genotype (G)	14	15.85	1.132**	16.02	5.386	0.385**	55.92
Environment (E)	8	47.93	5.991**	48.45	2.168	0.271**	22.51
G x E	112	35.14	0.314**	35.52	2.077	0.019**	21.57
IPCA1	21	17.58	0.837**	50.04	0.868	0.041**	41.79
IPCA2	19	9.44	0.497**	26.88	0.483	0.025**	23.25
Residual	72	8.11	0.113**	23.08	0.726	0.010ns	34.95
Error	252	11.8	0.047	10.63	2.111	0.008	17.81
Total	404	111.04	0.275	100 %	11.86	0.029	100%

*ns and ** means insignificant and significant at P<0.05, respectively*

Table 5. Mean performance of seed and oil yield (ton ha^{-1}) of 15 F_1 sunflower hybrids across 9 environments and their combined means

Genotype	Seed yield (ton ha^{-1})									Combined
	E1	E2	E3	E4	E5	E6	E7	E8	E9	mean
H1	2.77	2.25	3.71	2.41	1.95	3.41	2.72	1.99	3.56	2.75^{de}
H2	2.41	3.16	2.47	2.54	2.18	2.65	2.45	2.20	2.56	2.52^{f}
H3	2.19	3.31	3.15	2.16	2.51	2.91	2.19	2.52	3.03	2.66^{e}
H4	2.42	2.29	3.40	2.56	3.27	3.36	2.49	3.25	3.38	2.94^{bc}
H5	2.47	2.71	3.04	2.30	2.71	2.81	2.47	2.68	2.92	2.68^{e}
H6	2.38	2.27	3.79	2.39	2.38	3.95	2.48	2.41	3.87	2.88^{bc}
H7	2.85	2.65	3.44	2.92	3.26	3.57	2.85	3.26	3.51	3.15^{a}
H8	3.00	2.64	2.99	2.94	2.76	2.78	2.85	2.70	2.89	2.84^{cd}
H9	2.60	2.80	2.87	2.55	2.28	3.20	2.73	2.29	3.03	2.71^{e}
H10	2.38	3.15	3.49	2.38	2.49	3.77	2.79	2.50	3.63	2.95^{bc}
H11	2.66	3.15	3.28	2.97	2.82	3.36	2.46	2.83	3.32	2.98^{b}
H12	2.44	3.45	3.42	2.27	2.46	3.86	2.71	2.48	3.64	2.97^{bc}
H13	2.32	3.03	2.57	2.00	2.37	2.89	1.95	2.38	2.73	2.47^{f}
H14	2.38	2.70	3.92	2.36	2.34	3.93	2.29	2.46	3.92	2.92^{bc}
H15	3.09	2.82	3.78	2.80	3.01	3.50	2.72	3.02	3.65	3.15^{a}
Mean	2.56^{c}	2.83^{b}	3.29^{a}	2.50^{c}	2.59^{c}	3.33^{a}	2.54^{c}	2.60^{c}	3.31^{a}	2.84
	Oil yield (ton ha^{-1})									
H1	1.04	0.90	1.01	0.84	0.73	0.78	1.12	1.12	1.08	0.96^{efg}
H2	0.95	0.97	0.95	1.17	0.83	0.85	1.00	1.01	1.00	0.97^{ef}
H3	0.83	0.82	0.83	1.00	0.82	0.84	0.99	1.01	0.98	0.90^{h}
H4	0.91	0.90	0.84	0.86	1.02	1.06	0.89	0.98	1.00	0.94^{fgh}
H5	0.84	0.67	0.67	0.62	0.67	0.66	0.94	0.80	0.81	0.74^{i}
H6	0.87	0.84	0.87	0.89	0.83	0.88	0.91	1.07	1.06	0.91^{gh}
H7	1.08	1.11	1.20	1.03	1.22	1.21	1.32	1.27	1.30	1.19^{a}
H8	1.16	1.07	1.04	1.05	1.11	1.04	1.17	1.17	1.10	1.10^{b}
H9	0.93	0.89	1.03	1.04	0.90	0.88	1.04	1.11	1.11	0.99^{def}
H10	0.95	0.91	1.17	1.14	0.91	0.91	1.14	1.32	1.25	1.08^{bc}
H11	1.05	1.09	0.98	1.14	1.06	0.98	1.13	1.07	1.07	1.06^{bc}
H12	0.89	0.85	0.96	1.13	0.85	0.86	1.03	1.30	1.14	1.00^{de}
H13	0.77	0.67	0.65	0.83	0.75	0.68	0.99	0.92	0.78	0.78^{i}
H14	1.00	1.02	0.97	1.05	0.90	0.89	1.17	1.21	1.17	1.04^{cd}
H15	1.14	1.01	1.00	1.05	1.00	1.00	1.22	1.14	1.18	1.08^{bc}
Mean	0.96^{bc}	0.91^{c}	0.94^{bc}	0.99^{b}	0.91^{c}	0.90^{c}	1.07^{a}	1.10^{a}	1.07^{a}	0.984

Means of the same row or column followed by the same letter (s) are not significantly different

3.4 Yield-stability Statistics

There are several methods of simultaneous selection for yield and stability. AMMI model Interaction Principal Component Axes (IPCAs), seed and oil yield mean and estimates of some investigated yield-stability statistics in 15 sunflower hybrids among studied environments are presented in Table (6). IPCA scores of a hybrid in the AMMI analysis indicate the stability of a hybrid across environments. Whereas, the closer IPCAs score to zero was the more stable hybrids across their testing environments [4] and [19]. Considering, hybrids H15, H4 and H7 that recorded the highest seed yield means with relatively IPCA1 values close to zero indicated to small interaction effects and was considered as stable across environments. However, H15, H9 and H14 recorded the best values for both mean performance and IPCA1 in oil yield trait. Meanwhile, hybrids with high mean and large PCAs scores were considered as specific adaptability to favorable environments. AMMI stability value (ASV) parameter exhibited hybrids measure across environments that referred to the existence of crossover GE interaction [42]. ASV measure aids screening of relatively stable hybrids. Hybrids H9, H15 and H11 recorded the least ASV score for both seed and oil yield traits.

Table 6. IPCAs, seed and oil yield mean and estimates of some investigated yield-stability statistics in sunflower hybrids among studied environments

Genotypes	$IPCA_1$	$IPCA_2$	Yield mean	ASV	YSI	SI (%)	I	RSI
				Seed yield (ton ha^{-1})				
H1	-0.54	0.03	2.75	0.74	21	30.20	0.58	15.58
H2	0.58	-0.40	2.52	0.89	27	59.74	1.10	19.58
H3	0.21	-0.35	2.66	0.46	18	49.14	0.72	18.58
H4	0.05	0.70	2.94	0.70	16	55.84	0.73	11.58
H5	0.31	0.15	2.68	0.45	16	71.11	1.50	17.58
H6	-0.73	0.17	2.88	1.01	23	27.34	0.58	13.58
H7	0.13	0.50	3.15	0.54	9	77.40	1.03	7.58
H8	0.52	0.30	2.84	0.77	21	87.28	4.01	14.58
H9	0.16	-0.16	2.71	0.26	12	64.43	1.04	16.58
H10	-0.28	-0.33	2.96	0.50	11	47.70	0.66	10.58
H11	0.22	-0.02	2.98	0.30	5	73.51	1.06	8.58
H12	-0.24	-0.55	2.97	0.64	13	43.38	0.64	9.58
H13	0.35	-0.28	2.47	0.55	23	50.24	0.83	20.58
H14	-0.70	-0.08	2.92	0.96	21	27.26	0.58	12.58
H15	-0.03	0.30	3.16	0.30	4	72.14	0.89	6.58
				Oil yield (ton ha^{-1})				
H1	0.14	-0.37	0.96	0.42	22	54.27	0.25	15.58
H2	0.09	0.27	0.97	0.29	19	69.72	0.52	14.58
H3	0.04	0.14	0.90	0.14	16	66.48	0.65	18.58
H4	-0.35	0.16	0.94	0.49	26	73.39	0.84	16.58
H5	-0.16	-0.25	0.74	0.33	26	44.95	0.45	20.58
H6	0.01	0.03	0.91	0.03	13	67.34	0.65	17.58
H7	-0.18	-0.13	1.19	0.28	9	92.34	0.52	6.58
H8	-0.20	-0.01	1.10	0.27	9	96.67	1.74	7.58
H9	0.11	0.05	0.99	0.15	12	73.94	0.59	13.58
H10	0.36	-0.02	1.08	0.48	18	62.92	0.22	9.58
H11	-0.15	0.18	1.06	0.28	14	91.50	1.47	10.58
H12	0.33	0.12	1.00	0.45	20	55.90	0.23	12.58
H13	-0.04	0.00	0.78	0.05	16	46.55	0.40	19.58
H14	0.12	-0.06	1.04	0.17	12	71.87	0.38	11.58
H15	-0.09	-0.10	1.08	0.16	8	84.79	0.66	8.58

IPCA1 and 2= interaction principal component axis 1 and 2, ASV= AMMI stability value, YSI= Yield stability index (yield rank + ASV rank), SI= Sustainability index, I= Stability index and RSI= Rank sum (yield rank + Standard deviation of rank)

Yield stability index (YSI) is essential to rank hybrids stability according to their yield and ASV rank. The least YSI value is considered as the most desirable hybrids for the selection of both stability and high seed and oil yield [19]. Based on the YSI, the best hybrids were H15 followed by H7 and H11 with the best yield mean performance (3.16, 3.15 and 2.98 ton ha^{-1}) and attained an IPCA-1 value relatively close to zero (-0.03, 0.13 and 0.22) and also its ASV ranking, indicating that it was a stable and widely adaptable hybrids for seed yield. On the other side, the best hybrids for oil yield were H15 followed by H7 and H8 for oil yield with the best average (1.19, 1.10 and 1.08 ton ha^{-1}) and fulfilled an IPCA-1 value (-0.18, -0.19 and -0.09) and also its ASV ranking. Therefore, the (H15, H7 and H11) hybrids and (H15, H7 and H8) hybrids were stable and widely adaptable hybrids for seed and oil yield, respectively. Whereas, H15, H11 and H7 in seed yield and H15, H7 and H8 in oil yield had the closer IPCAs score to zero with the largest mean and low (ASV) were the more stable hybrids across their testing environments.

Sustainability index (SI) values were divided into five groups explaining, very low (below 20%), low (21- 40%), moderate (41- 60%), high (61-80%) and very high (above 80%) [26]. Results in Table (6) revealed that hybrid H8 had a very high sustainability index (87.28%), while the group of (H7, H11, H15, H5 and H9) hybrids showed high sustainability index (ranged from 77.40 to 64.43%). These results confirmed that the sustainability index was a partially fit as stability

index for screening stable hybrids with high seed yield. Meanwhile, some hybrid (H8, H7, H11 and H15) recorded very high sustainability index (96.67, 92.34, 91.5 and 84.79%), while the group of (H9, H4, H14, H2, H6 and H10) hybrids showed high sustainability index (ranged from 73.94 to 62.92%) for oil yield. These results prove that the sustainability index was completely suitable as a stability index for screening stable hybrids with high oil yield.

Regarding, stability index (I) for evaluated hybrids order was determined in Table (6). In case of decreasing order the hybrids which had the highest stability index (I) received the first rank and the one with the lowest (I) value in the presently studied hybrids. Results of stability index (I) indicated that the ranking of studied hybrids was partially similar based on hybrids mean. However, the same stability index (I) was concerning most mean performance for both seed and oil yield. Further, the hybrids, which showed high mean performance (H15, H7 and H11) were stable across environments as indicated by high magnitudes of (I) for seed yield [3], while (H7 and H11) were high magnitudes of (I) for oil yield. Concerning, rank-sum (RS) was conclusion yield mean rank and its standard deviation. In general, Rank-sum (RS) presented hybrid H15 with (RS=6.58) followed by hybrids H7, H11, H12 and H10 with (RS=7.58, 8.58, 9.58 and 10.58) as the most stable hybrids with high seed yield. Meanwhile, hybrids H7, H8, H15, H10 and H11 recorded 6.58, 7.58, 8.58, 9.58 and 10.58 RS for oil yield. Both YSI and RS introduced the same hybrids (H15, H7 and H11) and (H7, H8 and H15) as stable with high seed and oil yield, respectively.

3.5 GGE Biplot Graphs

The first two principal components (PC1 and PC2) derived from seed or oil yield data were used to construct GGE biplot and subject environment effects [43] and [20]. Figures of seed yield trait showed that GGE was partitioned through the site regression model into PC1 and PC2 accounted for 47.97 and 26.82% of GGE sum squares, respectively with totally explained 74.79% of the variation. Meanwhile, figures of oil yield trait revealed that PC1 and PC2 explained 73.74% and 11.60% of GGE sum squares, respectively with a totally 84.84% of the variation. Generally, hybrid with large PC1 scores (high mean yield) and near zero PC2 scores (high stability) is considered as the most desirable and stable ones.

3.5.1 Mega-environment identification by 'Which-Won-Where' pattern

The 'which-won-where' pattern view of the GGE biplot helps us to identify which hybrids performed the best in each environment and each mega-environment. Mega-environment is defined as a group of environments that consistently participate in the best set of hybrids [40], as well as test environments with different winning hybrids located at the vertex of the GGE polygon and situated in different sectors [44]. Results of the test three locations (Giza, G-Ettay, E- Shandweel, Sh) and three seasons (1, 2, 3) was identified as (locations by seasons) all environments (G1, E1, Sh1, G2, E2, Sh2, G3, E3, Sh3) and were located in sectors. In the seed yield trait, the GGE biplot polygon view sides in Fig. (2) facilitate a comparison between neighboring vertex hybrids. Based on vertex corner hybrids located at the extreme point of the polygon in a sector, hybrids no. H7, H15, H6, H14, H13, H2 and H8 were the most responsive ones across all environments. Whereas, hybrids on the right side were the highest positively means converse on the right side with negative response. The polygon showed that all studied environments were divided into 3 mega-environments. Hybrids no. H7 and H15 were the most positive response in mega-environment 1 which contains (G1, G2, G3, E2 and E3) locations, therefore was the highest seed yield at the vertex. Meanwhile, hybrids no. H6, H14 and H1 presented the most positively highest seed yield at the vertex in mega-environment 2 which includes (Sh1, Sh2 and Sh3) locations. However, mega-environment 3 containing (E1) had negative response and the poorest yielding by hybrids no. H13 and H2.

Regarding oil yield, the GGE biplot polygon view sides in Fig. (3) showed that hybrids no. H7, H10, H12, H4, H5 and H13 were the most responsive ones. This polygon was divided into two mega-environments. For the 1st mega-environment (containing G1, E1, Sh1, E2, Sh2, G3 and Sh3 locations), H7 was the most positively responsive at the vertex, while, 2nd mega-environment (containing G2 and E3 locations), H10 and H7 were the most positively responsive ones at the vertex and therefore were the highest oil yield. Hybrids within the polygon were less responsive to location than the vertex hybrids for all seed and oil yield [29]. Then, the polygon view of a GGE biplot displayed the which-won-where pattern [43] since each sector showed the vertex with the indicative hybrid and

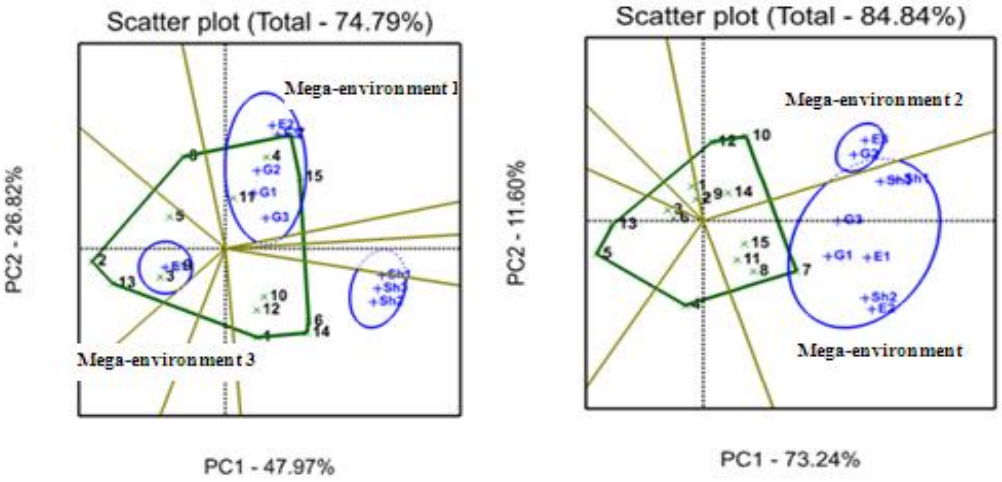

Fig. 1. Polygon of GGE biplot showing the mega-environments and their respective high seed and oil yielding sunflower hybrids for 'which-won-where' pattern

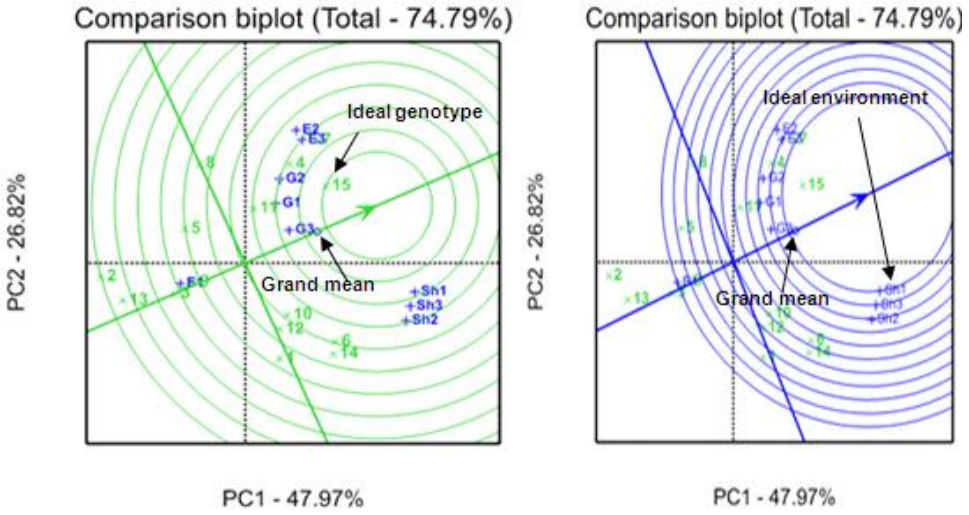

Fig. 2. Seed yield GGE-biplot showing the comparison hybrids and environments with the 'ideal' ones

the positions of all other hybrids showing their responsiveness to the environment under study.

3.5.2 Evaluation of hybrids and environments based on the ideal ones

Compare the performance of the hybrids and environments with that of an ideal hybrid and environment, respectively can be used to evaluate both hybrids and environments [28]. Whereas, an ideal hybrid and environment had high yield performance and stable across environments, as well as the ideal one, was located in the first or the nearest concentric circle in the biplot. The closer to the ideal hybrid and environment were the stable ones. The comparisons of both hybrids and environments with the ideal one for seed yield trait was shown in Fig. (2). GGE-biplot for comparisons of the hybrids with the ideal hybrid illustrated that hybrid H15 was situated in the central circle (in the middle circle) which was considered as an ideal hybrid with high seed yield potential and relative stability compared to the rest of evaluated hybrids. As well as, hybrids (H7, H4, H11, H10 and H6) were considered as desirable hybrids because they are the closest to the ideal hybrid or around the center of a concentric circle. Meanwhile, the farthest hybrids from the ideal were considered as the poorest yielding ones.

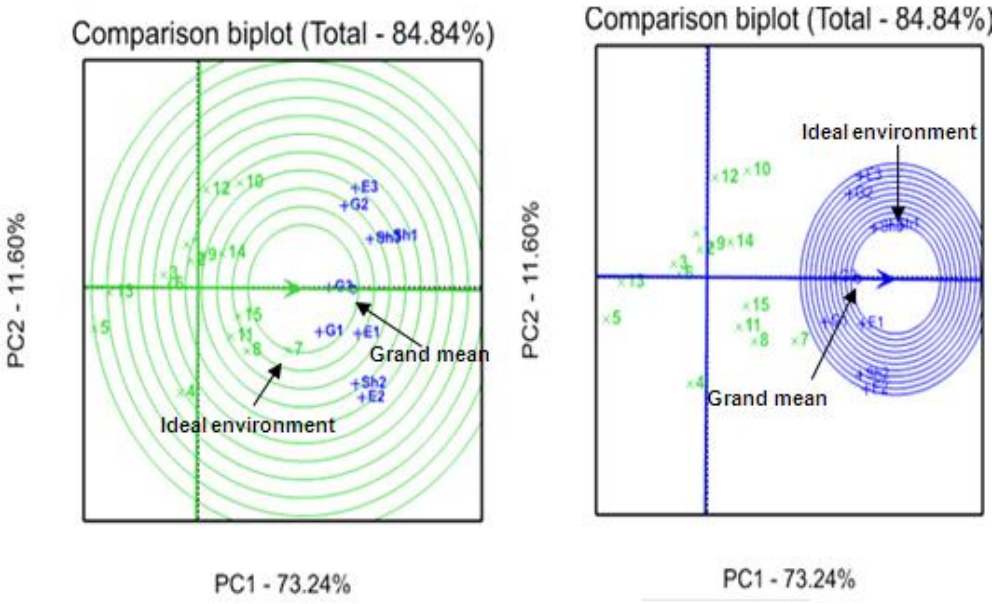

Fig. 3. Oil yield GGE-biplot showing the comparison hybrids and environments with the 'ideal' ones

Alike the ideal environment locating in the first concentric circle in the environment focused biplot was Sh1 (Shandweel, season1) to select widely adapted sunflower seed yield. Environments Sh3 (Shandweel, season3) and E3 (Ettay El-baroad, season3) was the nearest to the ideal environment followed by G3 (Giza, season3). This implied that, stability diversity may due to the change in the tested location not only, but also due to the change in the growing season per location. This result was in line with Branković *et al* [29], [35] and Cvejic *et al* [36].

Seed yield (ton ha^{-1}) GGE biplot based analysis on tested hybrids comparison demonstrated that (H15, H7, H4, H11, H10 and H6) were considered as desirable hybrids. The environments-focused comparison revealed that, except at Shandweel (season1and 3), the tested environments were inconsistent for mean seed yield and IPCA scores during 2017 and 2019. This observed instability might have been due to variation in weather conditions, soil and other uncontrolled factors.

For oil yield (ton ha^{-1}) GGE biplot analysis for comparisons of the hybrids and environments with the ideal ones was carried out (Fig. 3). Starting from the middle circle, hybrid H7 which was plotted on the concentric circle considered as an ideal hybrid. The closest hybrids to the ideal hybrid (H15, H8 and H11) were considered as desirable ones with most yielding and stable. While hybrids (H5, H13 and H4) were situated far from the ideal with low yielding associated with instability.

Accordingly to the ideal hybrid, the ideal environment was situated in the middle concentric circle in the environment-focused biplot as shown in Fig. (3). The environment Sh1 (Shandweel, season1) was the ideal environment followed by environments Sh3 (Shandweel, season3) as the nearest to the first concentric circle. Meanwhile, E2 (Ettay El-baroad, season2) was far from the ideal environment and considered as unstable.

4. CONCLUSION

Studied hybrids performed significantly in different environments (seasons and locations). Based on the highly significant of genotype-environment interaction (GEI), it was suggested the extension of stability analyses. Both yield traits and performance stability should be considered, simultaneously to reduce the impact of GEI and make selection of promising hybrids. The results of stability parameters demonstrated that SI% and I had a relative agreement (not identical) in discriminating stable hybrids with high yield (seed or oil). Meanwhile, non-parametric indices, YSI (based on AMMI stability value ASV which is multivariate) and RSI (as univariate statistics) were the most desirable ones for discriminating the most stable hybrids

with high yield. The best stable promising hybrids were H15, H7 and H11 in seed yield and H7, H8 and H15 in oil yield. The results of AMMI analysis indicated that the first two IPCA's were highly significant and explained (50.04% and 41.79%) followed by GE interaction (26.88% and 23.25%) of total sum of squares for seed and oil yield, respectively. The magnitude of the environment effects was three times greater than the hybrids, implying that most of the variation in seed yield was due to the environment. On the contrary oil yield, hybrids were two times greater than the contribute environments. This indicated that the large influence of the environment causing most of the variation in seed yield performance of sunflower hybrids across all locations, contracting oil yield. The genotype main effect plus genotype x environment interaction (GGE) biplot was applied to analyze. The first two principal components PC1 and PC2 for seed and oil yield stability caused by G+GE were accounted for 74.79 and 84.84% of the total variation, respectively. The GGE biplot analysis examined the nature of sunflower yield GEI and identifying the best sunflower hybrids. Shandweel was considered as the ideal of the tested locations for future sunflower breeding activities. Hybrids H15 was close to the ideal hybrid and can thus be used as a standard for the evaluation of sunflower followed by hybrids H7, H4, H11, H10 and H6 in seed yield. While, hybrid H7 was considered as the ideal one followed by H15, H8 and H11 in oil yield. Generally, GGE biplot analysis indicates that hybrids H15, H7 and H11 were considered as the most desirable and stable ones, therefore can be recommended for wider cultivation due to better seed yield and stability performance across the test environments.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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