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PRODUCTIVITY AND STABILITY ANALYSES TO CHARACTERIZE SESAME GENOTYPES UNDER NORMAL AND DROUGHT CONDITIONS IN SANDY AND CLAY SOILS

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SUMMARY

Sesame (*Sesamum indicum* L.) is an oilseed crop flourishing in marginal lands. It has a high nutritional value because it is rich in protein and fat and has many health benefits. However, the varieties of this crop available in Egypt are very few. Seventeen new sesame lines incurred evaluation in two crop seasons, 2021–2022, for seed yield under eight environments comprising normal and drought conditions in sandy and clay soils. Applying 16 parameters and non-parameters of stability helped select stable and adaptive sesame lines under ideal and drought conditions, with the genotypes arranged in a randomized complete block design with three replicates. Line C5.8 achieved the highest relative productivity in sandy and clay soils and exhibited a good source for breeding programs under drought conditions. Four lines, C1.3, C9.15, C9.6, and C9.20, under eight different environments had higher seed yield than the control. A genetic-environment interaction (GEI) effect on seed productivity occurred in all sources of the combined analysis. The association between seed yield and stability parameters showed the possibility of using a selection index that included some of them to identify sesame genotypes with higher yield and genetic stability.

Keywords: sesame (*S. indicum* L.), parametric and non-parametric stability, drought, water productivity, seed yield

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Key findings: According to parametric and non-parametric statistics, sesame lines C9.3, C9.7, C6.7, C2.2, C5.8, C9.6, C9.15, and C6.12 were more stable for seed production under different conditions. Lines C9.20, C9.6, and C9.15 showed higher water productivity than the control and showed a slight variation in yield under diverse environmental conditions, with these lines classified as biologically stable.

INTRODUCTION

The sesame crop has a great future as an oil crop since it possesses many advantages over other oil crops, for example, more resilience to climatic changes, drought tolerance, and higher income for farmers when selling oil and meal instead of whole seeds. Sesame protein has many essential amino acids such as cysteine, methionine, and tryptophan; therefore, sesame protein can raise some foods' nutritional value (Fasuan *et al*., 2018). Sesame seeds are rich in unsaturated fatty acids and antioxidant lignans, such as sesamin. Thus, sesame seeds are widely used in the food and pharmaceutical industries (Zhang *et al*., 2019). The sesame seed meal is a one-feed ingredient that might replace conventional feed ingredients like soybean meal and sunflower cake (Şahin and Elhussein, 2018). Sesame produces bioactive chemical compounds that are resistant to *Fusarium wilt*. These compounds can aid in generating antimicrobial formulations on a large scale (Sahab *et al*., 2021). As the season of this crop is short, it allows for fast cultivation, intensification, and diversification of agricultural systems (Oyeogbe *et al*., 2015). Sesame is an appealing crop tailored for challenging climatic changes, especially in arid and semi-arid areas (Li *et al*., 2018).

Despite its many advantages, it lags in genetic improvement due to its narrow genetic base, lack of interest in genetic improvement, and poor management practices. Moreover, climate change significantly negatively impacts arid and semi-arid countries experiencing rapid population growth and limited freshwater resources. Water scarcity and shortage are among Egypt's most crucial issues affecting crop cultivation and production. Drought stress hinders sesame crop production during the flowering phase (Kermani *et al*., 2019; Abdelraouf *et al*., 2020; Wang *et al*., 2023). Developing new high-yielding varieties with high resistance to biotic and abiotic stresses and fewer water requirements is an essential option for increasing the sesame cultivated area in Egypt (Shabana *et al*., 2014; Abdelraouf and Anter, 2020; Azzam *et al*., 2021, 2022; Khondoker *et al*., 2023). Also, it is necessary to reduce irrigation water consumption by raising the water productivity of field crops to meet future food needs with limited water supplies (Letseku and Grové, 2022).

Plant breeding is one of the most effective ways to keep crop production stable under drought conditions posed by climatic changes by developing more adaptable crops to their environmental stress conditions (Gupta *et al*., 2022; Li *et al*., 2022). The main goal of breeding for drought tolerance is to develop cultivars that produce 80% of the potential yield when the available water is less than the amount needed to complete the life cycle and obtain a high yield (Messina *et al*., 2022; Khaled *et al*., 2023). However, selecting crop varieties in target environments is an essential goal for crop breeders and poses a significant challenge due to the genotype-by-environment interaction. Meanwhile, no generally accepted guidelines exist for assessing yield stability (Reckling *et al*., 2021).

Several statistical methods have become proposed tools for stability analytics to interpret the interactions, which depend on univariate and multivariate models (Flores *et al*., 1998). Two main statistical groups are available for interpreting interactions through numerical analysis: parametric and non-parametric methods (Mircioiu and Atkinson, 2017). However, parametric stability statistics need certain assumptions, including homogeneity of variance of the errors and a normal distribution and their interaction effects. In contrast, non-parametric statistics need no assumptions and are more easily comparable with parametric statistics based on the ranks of genotypes in each environment. Each method has advantages and disadvantages; hence, it is preferable to mix them, and this study used the STABILITYSOFT program (Pour-Aboughadareh *et al*., 2019) to calculate several parametric and non-parametric statistics. The presented research sought to select stable and adaptive sesame lines under normal and drought conditions.

MATERIALS AND METHODS

The breeding materials comprised the investigation of 17 sesame lines along with a commercial cultivar Shandweel (C) to select stable lines under normal and drought conditions. The sesame lines were C1.3, C1.9, C2.2, C2.6, C5.8, C6.2, C6.4, C6.7, C6.9, C6.11, C6.12, C8.8, C9.3, C9.6, C9.7, C9.15 and C9.20 according to Saber (2015). Genotypes' evaluation transpired to select stable lines under normal and drought conditions at two governorates during two main cropping seasons (2021–2022), one in clay soil at the Agricultural Experiments and Research Station, Cairo University, Faculty of Agriculture in Giza, Egypt (South: 27° 40′ 6″ N; North: 30° 18′ 20″ N, West: 27° 22′ 44″ E; East: 31° 57′ 34″ E), and the other in sandy soil at the Agricultural Production and Research Station at the National Research Centre, El-Nubaria district, El-Behera, Egypt (South: 29° 52′ 31″ N; North: 31° 30′ 35″ N, West: 29° 37′ 34″ E; East: 30° 50′ 39″ E). The physical and chemical properties of the soils at the two sites are available in Table 1. Genotype sowing occurred on May 15 each year.

In each site, genotypes evaluation had two experiments under normal and drought conditions. In the first, genotypes were well-watered throughout the growing period to allow the genotypes to affect production (YP). In the second, genotypes received adequate watering from germination to the boot stage (just before the flowering stage), after which no additional watering followed (YS). The arrangement of genotypes appeared in a randomized complete block design (RCBD) with three replications. The plot had three rows of 3 m in length, 50 cm between rows, and 10 cm between plants within the row. The Ministry of Agriculture's guidelines for sesame cultivation were applied. Seed yield attained assessment after harvest from the central row.

Statistical analysis

The stability analysis for the seed yield of genotypes evaluated across environments used the STABILITYSOFT program to calculate several parametric and non-parametric statistics (Pour-Aboughadareh *et al*., 2019). These are Plaisted and Peterson's mean Plaisted's variance component (θ_i), GE variance component ($\theta_{(i)}$), regression coefficient (b_i), deviation from regression (S^2_{di}), Shukla's stability variance (σ^2_i), and environmental coefficient of variance (CV_i), Nassar and Huhn's statistics ($S^{(1,2)}$), Huhn's equation ($S^{(3,6)}$), Thennarasu's non-parametric statistics ($NP^{(1-4)}$), and Kang's rank-sum (*KR*). The water productivity computation of sesame used the following formula:

$$WP_{Sesame} = Ey/IRg$$

Where WP_{Sesame} is water productivity ($kg_{Sesame}\ m^{-3}{}_{water}$), Ey is the economic/marketable yield (kg_{Sesame}/ha), and IRg is the amount of irrigation water applied ($m^3{}_{water}$/ha/season) (Table 2).

Table 1. Physical and chemical properties of soil in the experimental sites.

Properties	Soil layer depth (cm)	Texture	Silt + clay (%)	Organic matter	EC (dSm^{-1})	pH	Total $CaCO_3$ (%)
Clay soil	0-25	Clay	86.0%	1.85	1.28	8.03	28.3
Sandy soil	0-25	Sandy	2.51%	0.55	0.44	8.60	7.0

EC = Electrical conductivity.

The crop coefficient (Kc) and Penman-Monteith equation helped compute the daily irrigation water requirements. The volume of irrigation water calculation used the formula:

$$IRg = (ETO \times Kc) / Ei - R + LR$$

Where IRg represents the daily gross irrigation needs (mm), ETO is reference evapotranspiration (mm/day) (estimated from the Central Laboratory for Climate - Agricultural Research Centre, Egyptian Ministry of Agriculture at El-Nubaryia farm and according to Penman-Monteith Equation), Kc is the crop factor, Ei is the irrigation efficiency (%), R is the rainfall (mm), and LR is the amount of water required for salt leaching (mm).

The yield data under different conditions were subjected to the analysis of variance (ANOVA). The combined variance analysis of the two seasons was conducted using the computer-based statistical package MSTATC. Means were separated using the least significant differences (LSD) at a probability level of 5%.

Table 2. The values of added water volumes for irrigating sesame for two irrigation systems and for two sites.

	Sandy soil (Sprinkler Irrigation System)				Clay soil (Gated Pipes System)				X: Average Overall IRg (m^3/ha)
	2021		2022		2021		2022		
	Yp, (100%FI)	Ys, (50%FI)	Yp, (100%FI)	Ys, (50%FI)	Yp, (100%FI)	Ys, (50%FI)	Yp, (100%FI)	Ys, (50%FI)	
IRg (m^3/ha)	6200	3100	6160	3075	7400	3700	7350	3675	5082.5

X = mean performance, Yp = yield under normal conditions, Ys = yield under drought conditions, FI= Full Irrigation.

RESULTS

Seed yield of sesame genotypes under normal and drought conditions

The genotypes were significantly different ($P < 0.05$) for seed yield when assessed under normal and drought conditions (Table 3). The CV% values were less than 20% in different environments. Also, the $LSD_{0.05}$ values indicated significant differences between the average yield of the lines and the control (C).

In sandy soils, the average seed production of the five lines (C9.3, C1.3, C9.6, C9.15, and C9.20) was higher than the control seeds by 4.0%, 9.5%, 14.0%, 28.7%, and 47.8%, respectively. Meanwhile, they were excellent under drought conditions, except for line C9.3. Line C5.8 achieved 82.0% of the seed yield (R1) compared with the optimal conditions, followed by lines C8.8 and C2.2, which reached 74.0%, while the C9.15 and C1.3 lines achieved 66.0%, and the control achieved 62.0%.

In clay soil, the average seed yield of the eight lines (C1.3, C6.2, C5.8, C6.7, C9.6, C9.20, C9.7, and C9.15) was higher than the control seeds by 5.5%, 5.7%, 8.2%, 8.6%, 30.9%, 30.4%, 32.5%, and 37.5%, sequentially. Meanwhile, they were excellent under drought conditions, except for line C1.3. Three lines named C5.8, C6.7, and C6.9 achieved 66.0% (R2) of the seed yield compared with the optimal conditions. Under eight different environments, the mean performance of four lines, C1.3, C9.15, C9.6, and C9.20, had higher seed yields than C by 1.6%, 20.5%, 22.8%, and 30.6%, respectively.

Table 3 shows that the yield in clay soil was better than in sandy soil. It has become clear that the genotypes change their seed yield from one environment to another due to apparent variation; thus, a combined variance analysis proceeded (Table 4). It was evident that significant differences ($P < 0.05$) occurred between genotypes regarding seed yield for main effects, which included environments (E),

Table 3. Seed yield, variance of sesame genotypes under normal and stress conditions.

Soil	Sandy soil				Clay soil				R1%	R2%	yields (kg/ha)
Season	2021		2022		2021		2022				
Environments	E1	E2	E3	E4	E5	E6	E7	E8			
Genotypes	Yp	Ys	Yp	Ys	Yp	Ys	Yp	Ys			
C1.3	553.0	365.0	603.0	395.0	765.0	400.0	815.0	430.0	66.0	53.0	*1201.6*
C1.9	180.0	50.0	230.0	80.0	650.0	403.0	700.0	433.0	31.0	62.0	*757.1*
C2.2	185.0	140.0	235.0	170.0	601.0	378.0	651.0	408.0	74.0	63.0	*768.9*
C2.6	210.0	90.0	260.0	120.0	384.0	238.0	434.0	268.0	45.0	62.0	*556.7*
C5.8	225.0	190.0	275.0	220.0	720.0	476.0	770.0	506.0	82.0	66.0	*939.3*
C6.2	290.0	135.0	340.0	165.0	721.0	447.0	771.0	477.0	48.0	62.0	*929.3*
C6.4	310.0	165.0	360.0	195.0	587.0	357.0	627.0	387.0	54.0	61.0	*830.0*
C6.7	425.0	225.0	475.0	255.0	719.0	476.0	779.0	506.0	53.0	66.0	*1072.2*
C6.9	500.0	165.0	550.0	195.0	601.0	396.0	651.0	426.0	34.0	66.0	*967.8*
C6.11	192.0	121.0	242.0	151.0	510.0	200.0	560.0	230.0	63.0	40.0	*612.7*
C6.12	288.0	181.0	338.0	211.0	510.0	250.0	560.0	280.0	63.0	50.0	*727.1*
C8.8	336.0	253.0	386.0	283.0	550.0	285.0	600.0	315.0	74.0	52.0	*835.6*
C9.3	650.0	220.0	700.0	250.0	673.0	417.0	723.0	447.0	35.0	62.0	*1133.3*
C9.6	700.0	386.0	750.0	416.0	950.0	500.0	1000.0	530.0	55.0	53.0	*1453.3*
C9.7	336.0	208.0	386.0	238.0	975.0	499.0	1025.0	529.0	62.0	51.0	*1165.6*
C9.15	577.0	380.0	627.0	410.0	1050.0	490.0	1080.0	520.0	66.0	47.0	*1426.0*
C9.20	769.0	484.0	819.0	514.0	1000.0	450.0	1050.0	480.0	63.0	45.0	*1546.0*
C	577.0	357.0	500.0	315.0	900.0	420.0	800.0	390.0	62.0	48.0	*1182.9*
X	405.7	228.6	448.7	254.6	714.8	393.4	755.3	420.1			
SL $_{0.05}$	2181.0**	831.4**	2083.2**	784.3**	2153.2**	513.5**	1998.0**	514.2			
CV%	13.2	14.5	15.3	15.7	15.5	17	16.4	13.4			-
LSD $_{0.05}$	43.3	25.1	45.4	47.5	36.2	30.2	85.2	37.1			-

Yp = Yield under normal conditions, Ys = yield under drought conditions, R1= ([Ys/Yp]*100) in sandy soil, R2 = ([Ys/Yp]*100) in clay soil, X= Mean performance, C= Control, SL$_{0.05}$ = Significant level at 5%, CV= Coefficient of variability, LSD= least significant different, **= Significant level at 0.05.

Table 4. Combined variance analysis for seed yield of 17 sesame genotypes across eight environments.

Source of variation	DF	SS	MS
Environments (E)	7	5348315.947	764045.1**
Error	8	190000.0	23750.0
Genotypes (G)	18	6141902.6	341216.8 **
G×E	126	6458115.0	51254.8 **
Error	144	57000.0	395.8
Total	303	18195333.6	
CV: 4.1%			

DF= Degree of freedom, SS =Sum of squares, MS= Mean square, **= Significant level at 0.05, CV= Coefficient of variability.

contributing 29.3%, genotypes (G), supplying 29.3%, and GEI interactions, providing 34.74%, which makes it difficult for the breeder to select the most stable genotypes.

Parametric and non-parametric seed yield stability analyses

The study ranked sesame genotypes based on 16 parametric and non-parametric statistics for seed yield under normal and drought conditions for identifying the most stable lines. According to the results in Table 5, line C1.3, which ranked fourth for yield, became selected as a stable genotype based on three non-parameters named NP$^{(1)}$, NP$^{(2)}$, and NP$^{(3)}$, and five parameters of stability called W_i^2, σ^2_i, CV_i, *KR*, and $\theta_{(i)}$.

Line C9.15, which ranked third in terms of yield, bore selection as a stable genotype due to eight non-parameters (S$^{[1-4,6]}$ and NP$^{[1, 3, 4]}$). Line C9.6, which ranked second in terms of yield, was classified as a stable genotype based on six non-parameters ($S^{[1-3,6]}$ and $NP^{[3-4]}$). Line C9.20, which ranked first for yield, was a choice for a stable genotype based on five non-parameters ($S^{[3]}$, $S^{[6]}$, and $NP^{[2-4]}$) and two parameters of stability (CV_i and θ_i). It was evident that the two lines, C6.7 and C6.4, were more stable in yield through different stability parameters. The control (C) has recorded the best (b_i) value and the lowest SD value (Figure 1). At the same time, lines C1.3, C9.6, and C9.20 appeared (b_i) closer to 1 with less deviation from seed yield across environments.

Table 5. Rank of sesame genotypes based on seed yield, non-parametric and parametric stability analyses across eight environments.

Genotype	Y	$S^{(1)}$	$S^{(2)}$	$S^{(3)}$	$S^{(6)}$	$NP^{(1)}$	$NP^{(2)}$	$NP^{(3)}$	$NP^{(4)}$	W_i^2	σ^2_i	S^2_{di}	CV_i	*KR*	$\theta_{(i)}$	θ_i	b_i	SD
C1.3	4	10	10	7	6	5	3	3	6	5	5	8	1	1	5	14	0.9	3.4
C1.9	15	18	18	18	18	18	14	16	18	14	14	15	18	17	14	5	1.2	3.3
C2.2	14	7	7	11	12	5	16	15	12	10	10	13	15	14	10	9	1.0	3.2
C2.6	18	2	2	8	15	8	18	18	15	11	11	2	12	17	11	8	0.6	5.7
C5.8	10	14	14	14	10	13	4	11	11	15	15	16	13	16	15	4	1.1	3.7
C6.2	11	14	15	16	14	15	6	10	14	7	7	9	14	7	7	12	1.2	3.5
C6.4	13	4	4	4	7	2	13	7	7	2	2	3	11	5	2	17	0.9	4.7
C6.7	8	6	6	3	3	1	1	1	3	1	1	6	7	1	1	18	1.0	4.5
C6.9	9	12	13	12	11	10	5	12	10	12	12	12	8	12	12	7	0.8	2.3
C6.11	17	1	1	6	13	3	17	17	13	3	3	5	17	10	3	16	0.8	6.5
C6.12	16	11	9	15	17	8	15	14	17	4	4	1	9	10	4	15	0.7	5.3
C8.8	12	17	17	17	16	12	10	13	16	6	6	4	2	7	6	13	0.7	5.1
C9.3	7	13	12	10	8	13	12	9	8	16	16	17	5	13	16	3	0.9	4.2
C9.6	2	2	2	1	1	10	8	2	1	9	9	10	4	3	9	10	1.2	3.8
C9.7	6	16	16	13	9	17	9	8	9	18	18	14	16	14	18	1	1.6	5.1
C9.15	3	5	5	2	2	4	11	4	2	13	13	7	10	6	13	6	1.4	4.1
C9.20	1	8	8	5	4	16	2	5	4	17	17	18	3	7	17	2	1.1	6.3
C	5	9	11	9	5	7	7	6	5	8	8	11	6	4	8	11	1.0	2.3

$S^{(1,2)}$ =Nassar and Huhn's statistics, $S^{(3,6)}$ = Huhn's equation, $NP^{(1-4)}$ = Thennarasu's non-parametric statistics. W_i^2= Wricke's ecovalence stability index, σ^2_i = Shukla's stability variance, S^2_{di} = Deviation from regression, CV_i = Environmental coefficient of variance, *KR* = Kang's rank-sum, $\theta_{(i)}$ = GE variance component, θi =Mean variance component, b_i = Regression coefficient, SD= Stander deviation.

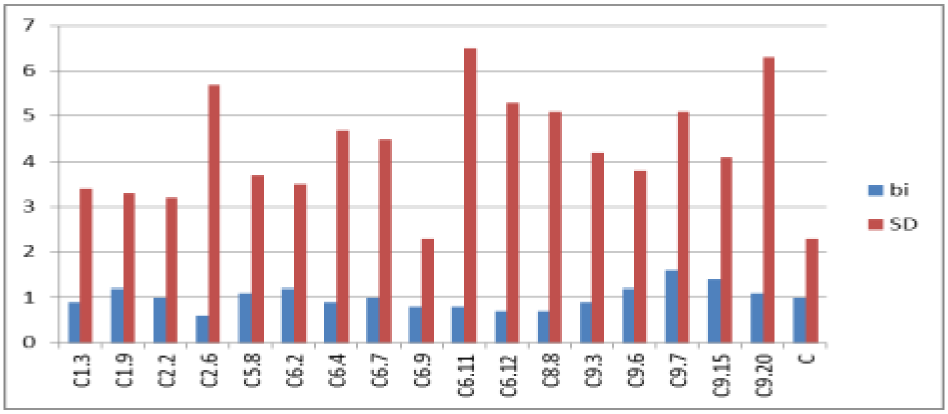

Figure 1. Regression coefficient (b_i) and standard deviation (SD) values of seed yield for sesame genotypes across eight environments**.**

Correlation among the stability parameters

Data in Table 6 showed that seed productivity mean under different conditions (Y) was positively and significantly associated with $S^{(3)}$, $S^{(6)}$, $NP^{(2)}$, $NP^{(3)}$, $NP^{(4)}$, CV_i, and *K*R. In contrast, it gave a negative and significant linkage with S^2_{di} and b_i. The rest of the parameters did not record a significant positive or negative correlation with seed productivity.

Water productivity of sesame genotypes

The water productivity of new sesame lines under different conditions reached estimation to identify the best genetic sources for providing irrigation water and maintaining productivity (Figure 2 and Table 7). The data confirmed that lines C9.20, C9.6, and C9.15 had higher water productivity than the control and other lines.

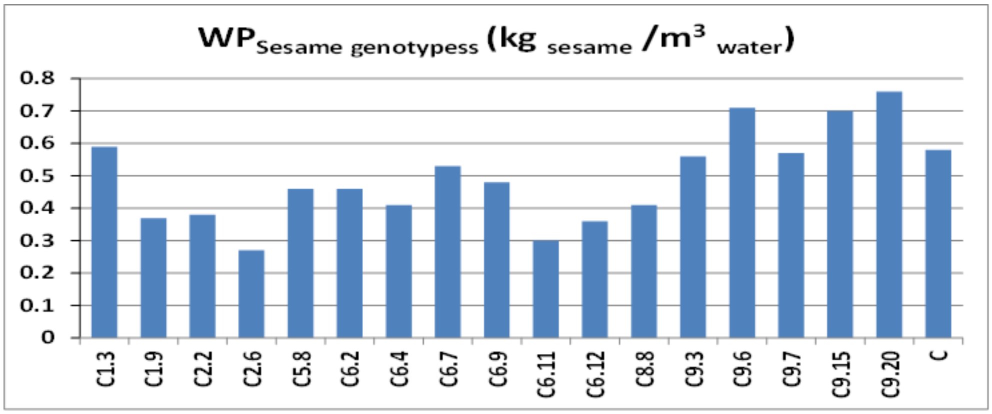

Figure 2. Water productivity of sesame genotypes (kg $_{\text{sesame}}$ /m^3 $_{\text{water}}$) under non-stress and stress conditions.

Table 6. Simple correlation between seed yield and parametric and non-parametric statistics for sesame genotypes under different conditions.

	$S^{(1)}$	$S^{(2)}$	$S^{(3)}$	$S^{(6)}$	$NP^{(1)}$	$NP^{(2)}$	$NP^{(3)}$	$NP^{(4)}$	W_i^2	σ^2_i	S^2_{di}	CV_i	*K*R	$\theta_{(i)}$	θ_i	b_i
Y	-0.01	-0.04	0.46**	0.84**	-0.13	0.72**	0.87**	0.84**	-0.34	-0.34	-0.47	0.60**	0.54**	-0.34	0.34	-0.55**
$S^{(1)}$		0.99**	0.84**	0.44	0.72**	-0.24	0.17	0.45	0.39	0.39	0.43	0.05	0.33	0.39	-0.39	0.22
$S^{(2)}$			0.83**	0.40	0.71**	-0.29	0.14	0.41	0.39	0.39	0.45	0.05	0.30	0.39	-0.39	0.25
$S^{(3)}$				0.82**	0.62**	0.15	0.62**	0.83**	0.21	0.21	0.17	0.32	0.57**	0.21	-0.21	-0.08
$S^{(6)}$					0.32	0.55**	0.90**	0.99**	-0.05	-0.05	-0.22	0.48**	0.64**	-0.05	0.05	-0.41
$NP^{(1)}$						-0.15	0.19	0.33	0.72**	0.72**	0.62**	0.11	0.49**	0.72**	-0.72**	0.37
$NP^{(2)}$							0.72**	0.55**	-0.08	-0.08	-0.38	0.52**	0.52**	-0.08	0.08	-0.30
$NP^{(3)}$								0.90**	0.07	0.07	-0.15	0.59**	0.78**	0.07	-0.07	-0.45
$NP^{(4)}$									-0.04	-0.04	-0.21	0.49**	0.65**	-0.04	0.04	-0.40
W_i^2										0.99**	0.78**	0.13	0.59**	0.99**	-0.99**	0.50**
σ^2_i											0.78**	0.13	0.59**	0.99**	-0.99**	0.50**
S^2_{di}												0.04	0.32	0.78**	-0.78**	0.52**
CV_i													0.64**	0.13	-0.13	0.29
*K*R														0.59**	-0.59**	-0.03
$\theta_{(i)}$															-0.99**	0.50**
θ_i																-0.50**

$S^{(1,2)}$ = Nassar and Huhn's statistics, $S^{(3,6)}$ = Huhn's equation, $NP^{(1-4)}$ = Thennarasu's non-parametric statistics. W_i^2= Wricke's ecovalence stability index, σ^2_i = Shukla's stability variance, S^2_{di} = Deviation from regression, CV_i = Environmental coefficient of variance, *KR* = Kang's rank-sum, $\theta_{(i)}$ = GE variance component, θi = Mean variance component, b_i = Regression coefficient, SD = Stander deviation, **= significant level at 0.05.

Table 7. Water productivity of sesame genotypes (kg $_{sesame}$ /m^{3} $_{water}$) under non-stress and stress conditions.

Genotypes	Overall Seed yields (X) for eight environments (g /4.5 m^{2})	Overall Seed yields (X) for eight environments (kg /ha)	WP $_{Sesame\ genotypes}$ (kg $_{sesame}$ /m^{3} $_{water}$)
C1.3	540.7	1201.6	0.59
C1.9	340.7	757.1	0.37
C2.2	346.0	768.9	0.38
C2.6	250.5	556.7	0.27
C5.8	422.7	939.3	0.46
C6.2	418.2	929.3	0.46
C6.4	373.5	830.0	0.41
C6.7	482.5	1072.2	0.53
C6.9	435.5	967.8	0.48
C6.11	275.7	612.7	0.30
C6.12	327.2	727.1	0.36
C8.8	376.0	835.6	0.41
C9.3	510.0	1133.3	0.56
C9.6	654.0	1453.3	0.71
C9.7	524.5	1165.6	0.57
C9.15	641.7	1426.0	0.70
C9.20	695.7	1546.0	0.76
C	532.3	1182.9	0.58
LSD $_{0.05}$	29.5	187.7	0.14

LSD= least significant different.

DISCUSSION

The success of crop improvement activities depends on creating variation and identifying which varieties are superior in productivity (Aboelnaga *et al*., 2020; Martínez-Fortún *et al*., 2022). A genotype can be considerably superior if it has the potential for high productivity in a favorable environment and, at the same time, has immense phenotypic stability (Al-Ashkar *et al*., 2023). The results indicated a wide variability of genotypes concerning seed productivity under different better, as Langham (2007) indicated. These lines were superior in plant height, which led to an increase in the number of capsules per plant, as reflected in the final seed yield (not shown in the Tables), similar to those observed by Miao *et al*. (2020) and Wang *et al*. (2023). The high yield was mainly due to maintaining high photosynthetic capacity during growth stages (Li *et al*., 2022). Thus, these lines can be suggestions for yield trials. The recent results showed that line C5.8 achieved a relative yield exceeding 80.0% (R1) of the seed yield under drought conditions in sandy conditions (Table 3). Hence, this variation can effectively improve seed yield by selecting and estimating genetic stability. This variation was due to the genetic divergence between the parents that make up the lines, as well as the interaction with environmental conditions, as the sesame crop has a great deal of variability (Agrawal *et al*., 2017; Anter and Ghada, 2021; Samaha *et al*., 2023).

Four lines (C1.3, C9.15, C9.6, and C9.20) showed a clear advantage in seed yield compared with the control because these lines have high input architectures and perform

lands. It also achieved the highest relative yield (R2) under clay soil compared with the control; hence, it is a good source for breeding programs under drought conditions (Fazal *et al*., 2022; Messina *et al*., 2022). Noticeably, the performance of genotypes for seed production varies according to environmental conditions (Table 3), as also reported by Oladosu *et al*. (2017). In conjunction with that, lines C9.6, C9.20, and C9.15 showed minimal change in seed yield under different conditions. Table 4 showed that genotypes (G), environments (E), and genotypes ×

environment interaction (G×E) were statistically significant ($P < 0.05$) for seed yield, indicating that the sesame genotypes were significantly different in their genetic potential under diverse conditions (Anter, 2019; Anter and El-Sayed, 2020; Nehra *et al*., 2023). The value of the coefficient of variation (4.1%) was low, implying the quality of the implementation of the experiments (Lopes *et al*., 2021).

Interpreting the effect of GEI in multiple environments, trials helped select the most stable lines when assessed in various environments (Vaezi *et al*., 2018; Pour-Aboughadareh *et al*., 2022; Abobata *et al*., 2023). However, the effect of GEI reduced the correlation between genetic and phenotypic values, making it challenging to select the best cultivar (Boureima and Yaou, 2019). Therefore, this study used parametric and non-parametric methods (Table 5) to solve this problem (Pour-Aboughadareh *et al*., 2019). The outstanding lines' classification in the seed yield based on parametric and non-parametric methods were as follows: Line C1.3 as a stable genotype based on three non-parameters: $NP^{(1)}$, $NP^{(2)}$, and $NP^{(3)}$. The low values of these statistics indicated high stability with five parameters: W_i^2, σ^2_i, CV_i, *KR*, and $\theta_{(i)}$. This line showed low deviations from the mean across environments, as shown by a low value of W_i^2.

After removing the main effects of environmental means, this line showed a low value of σ^2_i, and at the same time, recorded the lowest value of CV_i. Also, this line achieved a lower *KR* value than the control. The value of *KR* was 1, indicating that line C1.3 combined high yield and genetic stability. Line C9.15 was classified as a stable genotype based on seven non-parameters: $S^{(1\text{-}4,6)}$ and $NP^{(1,3,4)}$, as low values of these stats reflected stability and had support from a low value for θi compared with the control. Line C9.6 ranked as a stable genotype due to the low value of six non-parameters $S^{(1\text{-}3,6)}$ and $NP^{(3\text{-}4)}$. This line has a low CV_i value, with a high average yield being the most favorable. Line C9.20 classification was a stable genotype based on the low value of five non-parameters ($S^{[3,6]}$ and $NP^{[2\text{-}4]}$) and the low value of two parameters stability (CV_i and θ_i). The low value of CV_i with the highest seed yield reflected the stability of this line. It was evident that the two lines, C6.7 and C6.4, were more stable in yield through different parameters, but they were not distinct in yield, and therefore, one can say that they are a good source of yield stability for breeding programs.

Notably, the average performance of C, C9.20, C2.2, C5.8, and C6.7 across environments was less deviation for seed yield across environments, indicated by b_i values, and does not significantly differ from 1 (Table 5 and Figure 1). The control (C) recorded the best value of b_i and the lowest value of SD, which indicated high stability and a lack of vulnerability to environmental conditions, and this is predictable because it is a commercial variety. At the same time, lines C1.3, C5.8, and C9.20 had a regression coefficient closer to 1 with less deviation from seed yield across environments and high productivity. Thus, they were classified as highly adaptable in broader seed production environments. In supporting these results, this study conducted correlation coefficients between seed yield and parametric and non-parametric methods (Table 6).

The results further revealed that the direct selection based on the selection index, which included seed yield + W_i2 + σ^2_i + S2di + $\theta_{(i)}$ and indirect selection based on the selection index, which included *KR* + b_i + CV_i + $S^{(1,2,3,6)}$ + $NP^{(1\text{-}4)}$, could lead to the isolation of genotypes that combine genetic stability and high productivity. Fortunately, the lines that excelled in seed yield achieved the highest average of water productivity compared with other genotypes (Table 7 and Figure 2). These lines were distinct because they had longer roots than other genotypes (Abdelraouf and Anter, 2020), in addition to the possibility that the accumulation of biomass after flowering plays a pivotal role in achieving high productivity under the conditions of water stress, as indicated by Yang *et al*. (2021). Based on the above, it is now possible to classify these lines as genetically stable with a high seed yield.

CONCLUSION

This study evaluated 17 new sesame lines for seed yield under normal and drought conditions in sandy and clay soils. The results showed an apparent variation between the lines for seed yield under the different conditions. Additionally, the lines C5.8, C9.15, C9.6, and C9.20 could be suggestions for production trials under normal and drought conditions and could serve as a parent in sesame breeding programs.

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