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STABILITY AND COMBINING ABILITY ANALYSIS FOR GRAIN SORGHUM HYBRIDS AND THEIR PARENTAL LINES

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ABSTRACT

This investigation aimed to study the stability and performance across 8 environments of twenty-eight genotypes of grain sorghum and two commercial hybrids as checks (Sh.1 and Sh.2). A model for partitioning genotype X environment effect of the hybrids was suggested. Combined analysis of variance across environments indicated that the mean squares due to environments (E), (G) and G x E were highly significant for all the studied traits. The estimates of coefficient of variation (C.V) suggested that the stability of grain yield must be considered in studying G X E effects. Yield performance of each hybrid showed different ranking across the studied environments, three hybrids surpassed the check (Sh.1). Mean squares due to parental lines, crosses and lines versus crosses were highly significant. The data indicated that the non-additive genetic effects were twice bigger than the additive effects. Also, the variances due to the interaction between environment and genetic effects of males, females and males versus females, were highly significant indicating the additive and non-additive effect respond differently to environmental factors. The combining ability over several environments was also studied to obtain unbiased estimates of genetic parameters. The female parent ICSA- 88004 was a good general combiner for yield and nine hybrids were the best with regard to specific combining ability. The results showed that the participation of deviations from the linear responses (S^2_{di}) in the variance due to GE is more important than that due to linear regression (b_i). W_i values revealed that crossing between two stable lines may not produce the most stable hybrid, in other words, the heterosis and other effects may have a role in the final stability of any hybrid. The hybrid ICSA88004XICSR92003 was the most stable, ICSA14XICSR93004 was moderately stable and ICSA14XICSR89037 was the most unstable. Variances and covariances of these hybrids revealed that the difference in direction (sign) of the interaction between GCAX.E(F) and GCAX.E(M) led to diminish the GE effect of the hybrids and consequently decreased W_i values or increased stability. These results aid the breeder to predict the most stable hybrid that could be recommended for growing across different environments.

***Key words**: combining ability , grain sorghum , hybrids , stability parameters.*

1. INTRODUCTION

New hybrids to be released must show high performance for yield over a wide range of environmental conditions. In other words, the superior hybrids have to be highly stable and possess a great yield potential. The instability of genotypeX productivity under different environments is due to high genotype environmental interactions (GE-(Interaction). This phenomenon attracts the attention of several workers and breeders hence, numerous investigations were conducted to elucidate it. The most common definition of stability in crop plants is the repeatability or consistency of performance in different environments.

To pave the way for a greater understanding of this phenomenon, several parameters and methods were postulated to define and estimate stability. The variance of a genotype across environments was used by Roemer (1917), this variance considers all deviations from the genotype mean and is known as environmental variance. Wricke (1962) developed this statistic of stability, which squared and summed GE-interaction effects across all environments and termed it as ecovalence (Wi). Shukla (1972) discussed this parameter and developed an unbiased estimate of this variance.

A linear relationship between GE-interaction and environmental effects was observed so that several researchers suggested models to calculate a linear regression coefficient in order to characterize the specific response of genotypes to varying environmental conditions (Finlay and Wilkinson, 1963, Eberhart and Russell, 1966, Perkins and Jinks, 1968 and Tai, 1971). The GE-interaction splits into two parts, i.e. the first part due to the linear relationship between GE-interaction effects and environment effects, (bi) estimated as a linear regression coefficient while the second part is a deviation from the regression line (di). In these methods, the physical environmental factors are not regarded but a biological value for each environment is used that called environmental index.

According to genotype ranks in different environments, Haldane (1946) suggested other methods to study stability. Other methods depending on multivariate analysis were used (Calinski *et al.*, 1987 a and b).

On the other hand, the effects of genetic components received limited attention. Patanothai and Atkins (1974 a and b) compared the response of 16 F_1 hybrids and 48 related three-way crosses along with their parental lines to a range of environmental conditions. Three-way crosses as a group were slightly more stable for grain yield than F_1 hybrids. Moreover, Becker and Leon (1988) stated that the homozygous genotypes show larger GE-interactions than the heterozygous ones and they summarized many investigations on the effect of genetic heterogeneity compared with homogeneity that revealed that heterogeneous populations show small GE-interactions.

Bains (1976) crossed wheat lines, which were known to differ widely in their values of bi and S^2d_i, and developed unselected F_4-lines. Yield and stability of parents and F_4 lines were estimated in independent trials. The bi values clearly reflected the parental values.

In the present study, the role of GE-interaction effects on different agronomic characters will be compared. At the same time, the genetic variability and yield productivity of 28 grain sorghum hybrids and their parental lines grown across diverse environments will be evaluated with the genetic system controlling grain yield. Finally, the possibility of selecting certain parents for hybrid constitution to be stable over different environments will be investigated.

2. MATERIALS AND METHODS

Twenty-eight grain sorghum crosses were made at Giza Agricultural Research Station, ARC during 2000 growing season. Theses crosses were produced by crossing four male sterile (A) lines, viz., ICSA-1, ICSA-14, ICSA-88004 and ICSA-88006 and seven restorer (R) lines, viz., ICSR 89016, ICSR-89022, ICSR-89037, ICSR-89053, ICSR-91022, ICSR-92003 and ICSR-93004. The crosses and their parental lines as well as the two commercial hybrids (checks) viz., Shandaweel-1 and Shandaweel-2 were evaluated in four yield trials at Giza, Nubaria, Sids and Shandaweel Agricultural Research Stations and repeated during two seasons (2001 and 2002). A randomized complete block design with three replications was used in each trial.

Each experimental plot was four rows, 4 meters long, 60 cm apart. Planting was carried in hills spaced 20 cm apart within rows and seedlings were thinned to two plants per hill. All the agronomic practices were followed whenever needed as recommended for grain sorghum. Data were recorded for days to 50% flowering, plant height, leaf area, panicle length, panicle width, 1000 kernel weight and grain yield/plant. Data collected from each trial were subjected to the standard analysis of variance and the combined analysis was also performed.

2.1. Statistical analysis

The model used

$X_{lk} = \mu + G_l + E_k + (GE)_{lk} + (e_{lk})$ (1)

Where X_{lk} is the observed phenotypic mean value of genotype l ($l=1, 2 \ldots G$) in the environment k ($k=1, 2 \ldots E$), μ is the overall mean, G_l is the effect of the l^{th} genotype, E_k is the effect of kth environment, the $(GE)_{lk}$ is the interaction effect of the l^{th} genotype and the k^{th} environment and (e_{lk}) is the error attached to the l^{th} genotype in the k^{th} environment.

The stability parameter postulated by Wricke (1962) depends on the $(GE)_{lk}$ effects squared and summed across all environments that was denoted as ecovalence (W_i). It may be estimated as follows:

$$\text{Ecovalence: } W_i = \sum (X_{lk} - X_{l.} - X_{.k} + X_{..})^2 / (E-1) \qquad (2)$$

Where $X_{..}$ is the general overall mean, X_l is the genotype mean for l genotype across used environments and $X_{.k}$ is the environmental mean for k environment or genotypes mean in this environment.

Concerning the genetic effects of a genotype and using general and specific combining ability terms to partition the genetic effect to its components, the following formula was used

$G_{ij} = g_i + g_j + s_{ij}$ (3)

Where G_{ij} is the genetic effect of the cross between the i and j parents, g_i is the general combining ability (denoted gca) of ith parent, and S_{ij} is the specific combining ability (denoted sca) for the cross between ith and jth parents.

In the same way the Gekl can be partitioned to their components, so that

$GE_{kl} = gE_{il} + gE_{jl} + sE_{ijl}$ (4)

Where the Ge_{kl} is the interaction effect of the cross l between i and j parents with the environment k, gE_{ik} is the interaction between gca of the ith parent and sE_{ijk} is the interaction effect due to the kth environment and sca of the cross between the ith and jth parents. When the gca and sca effects estimates in different environments separately, each component will be attached with its counterpart interaction effect with an environment. Therefore, the latter interaction effect can be calculated using the following formula:

$gE_{ik} = g_{ik} - g_{ic}$ (5)

Where g_{ik} is the general combining ability effect of ith parent in the kth environment and g_{ic} is the general combining ability effect overall environments used in the study. Similarly, the interaction between specific combining ability with an environment can be calculated using the following formula:

$sE_{ijk} = s_{ijk} - s_{ijc}$ (6)

Where s_{ijk} is the specific combining ability effect of the ith parent and the jth parent when their cross-grown in environment kth and s_{ijc} is the specific combining ability effect overall environments used in the study.

Considering the variance of GE_{kl} across environments termed as ecovalence (Wricke, 1962), it can be divided also as follows

$V(GE_{kl}) = V(gE_{ik}) + V(gE_{jk}) + V(sE_{ijk}) + 2COV(gE_{ik}.sE_{ijk}) +$
$2COV(gE_{jlk}.sE_{ijk}) + 2COV(gE_{ik}.gE_{jk})$ (7)

In contrast with diallel designs, independent female and male sets of parents are usually used in North Carolina Design II (Comstock and Robinson, 1948) and Line x Tester so that the latter term $COV(gE_{il}.gE_{jl})$ might be minute and insignificant so that it will be neglected.

The variance of gE_{ik} $V(GE_{kl})$ is the sum of squared gE_{ik} divided by (E-1) and the variance of sE_{ijk} $V(sE_{ijk})$ is the sum squared sE_{ijk} divided by (E-1) while the covariance COV ($gE_{ik}.sE_{ijk}$) is sum of products of gE_{il} times sE_{ijl} divided by (E-1).

Aiming to compare between variances of different studied characters that can be due to the genotypeX environment interaction (GE), the variances due to GE interactions were calculated from the expectations of the mean squares presented in Table (1). To compare variances of different trait variances were divided by their corresponding means to calculate the coefficient of variations (C.V.)

Combining ability analysis estimates were calculated according to Hallauer and Miranda (1981). Other parameters were calculated according to the above model.

Table (1): A portion of the combined ANOVA showing the partitioning of sum squares for F_1 hybrids and expectations of mean squares.

Source of variation	df	Mean square	Expectation of mean squares
Genotypes (G)	G-1	M3	$\sigma^2 + r\sigma^2_{Gl} + rL\sigma^2_g$
Genotypes X locations (GxL)	(G-1) (L-1)	M2	$\sigma^2 + r\sigma^2_{Gl}$
Error	L(r-1) (g-1)	M1	σ^2

3. RESULTS AND DISCUSSION

Combined analysis of variance for all studied traits across environments revealed highly significant mean squares due to environments (E), genotypes (G) and genotypes X environments for all studied characters (Table 2). These results clarify the great variation among the tested genotypes and environments. The highly significant GE interactions indicate that different genotypes respond differently to effective environmental factors for all studied characters. Eskridge (1990) and Kang (1993) attracted attention to the GE interaction in selecting the high yielding and stable cultivars.

The estimates of coefficient of variations (C.V.) shown in Table (2) revealed that the GE-interactions affecting 1000 kernel weight and leaf area are considerable. On the other hand, the days to 50% flowering, plant height and panicle length were more stable and had lower C.V. estimates due to GE-interaction. Nevertheless, grain yield per plant, which is the final expression of plant performance displayed medium effect of GE-interaction.

Table (2) Combined analysis of variance for evaluating 41 genotypes for characters studied across diverse environments .

	df	Mean squares							
		50% flowering	Plant height	Leaf area	Panicle length	Panicle width	1000 kernel weight	Grain yield/plant	Kernel number
Environments (E)	7	627.9	12088.91**	105593.35*	569.14**	70.25**	2522.24**	7637.86*	5831456.69**
Error a	16	5.00	145.15	3869.29	19.64**	10.42	10.087	34.95	87252.46
Genotypes (G)	40	59.11**	10451.83**	159367.45*	168.17**	17.10**	125.47**	2525.83**	1816443.89**
G.E.	280	32.59**	597.52**	59559.93**	22.36**	10.16*	32.65**	366.61**	520715.79**
Error b	640	5.05	94.59	38593.57	4.79	7.04	5.09	25.10	62254.70
C.V		4.23	7.9	15.52	8.07	14.26	16.12	12.23	9.02

+ C. V due to GE-interaction

* and ** indicate significance at 0.05 and 0.01 level of probability, respectively.

3.1. Average performance

Average productivity of the tested genotypes including checks in the eight environments is presented in Table (3). All the evaluated hybrids produced grain yield significantly less than the check hybrid Sh-2 (100.86 g/plant),. However, the three hybrids ICSA 14 x ICSR 92003, ICSA 88006 x ICSR 92003 and ICSA 88004 x ICSR 89053 produced grain yield statistically equal to the other check Sh-1; their average yields were 93.36, 92.12, 90.50 and 90.42 g/plant, respectively. The least yielding hybrids were ICSA 1 x ICSR 89022, ICSA 14 x ICSR 89037 and ICSA 88006 x ICSR 93004 that produced 74.12, 73.90 and 70.11 g/plant, respectively.

Comparing hybrids with their parental lines over all environments, showed that the hybrids produced 82.85 g/plant that exceeded the parental lines by (67.79 g/plant) by 22.22% so that the advantage of hybrids over inbred lines is proved. The cytoplasmic male sterile lines were the least yielding genotypes, their grain yield were 50.20, 53.75, 63.85 and 58.24 g/plant for ICSA-1, ICSA-14, ICSA-88004 and ICSA-88006, respectively. Nevertheless, there were significant differences between these lines.

The best environment was Nubaria in 2001 season in which each plant produced 94.22 g of grain on the average, while the productivity was 68.54 g/plant at Shandaweel, in 2001 season. So the latter environment was considered the least productive one in the present investigation.

The genotypes showed different performance in different environments so that the grain yield differed significantly from one environment to another when tested by the least significant difference due to GE (6.33). As an example, the hybrid ICSA-1 x ICSR-89022 produced 65.70, 119.67, 55.53, 74.50, 69.17, 73.27, 59.33 and 75.80 g/plant in the environments E1,E2, E3, E4, E5, E6, E7 and E8, respectively. The averages significantly differed from one environment to another. This result may be attributed to GE interactions. Consequently, ranks of this genotype differed in environments that were 36, 5,38, 15, 32, 34, 38, 16, and 32 in the same order of the E1 to E8 environments. In contrast, the hybrid ICSA-1 x ICSR-89016 produced 74.23, 89.57, 85.6, 62.67, 75.57, 84.6 and 83.33 and 68.33 g/plant in environments E1,E2, E3, E4, E5, E6, E7 and E8, respectively. The averages showed less significant differences from one environment to another than the above case . This result may be due to less GE

Table (3): Average grain yield/plant, g of 28 sorghum hybrids and their parental lines (four A lines and seven R lines) and two checks evaluated in eight environments.

	Giza 2001		Nubaria 2001		Sids 2001		Shandaweel 2001		Giza 2002		Nubaria 2002		Sids 2002		Shandaweel 2002		Combined	
GENOTYPE	Yield	Rank	Yield	Ran	Yield	Rank	Yield	Rank	Yield	Rank	Yield	Rank	Yield	Rank	Yield	Rank	Yield	Rank
ICSA 1 x ICSR 89016	74.23	27	89.57	28	85.60	19	62.67	30	75.57	25	84.60	25	83.33	21	68.33	27	77.99	27
ICSA 1 x ICSR 89022	65.70	36	119.6	5	55.53	38	74.50	15	69.17	32	73.27	34	59.33	38	75.80	16	74.12	32
ICSA 1 x ICSR 89037	88.03	12	97.87	17	85.50	20	79.07	11	80.50	22	92.10	16	97.00	1	74.47	20	86.82	9
ICSA 1 x ICSR 89053	69.03	32	95.23	24	94.53	10	83.43	5	66.20	35	95.90	5	93.33	4	81.83	10	84.94	13
ICSA 1 x ICSR 91022	78.30	23	109.9	9	108.30	1	64.33	28	82.73	16	85.80	22	93.33	5	58.80	34	85.20	11
ICSA 1 x ICSR 92003	83.40	15	103.4	13	105.77	3	70.37	20	81.47	19	83.00	26	85.17	18	62.73	31	84.42	16
ICSA 1 x ICSR 93004	92.23	10	96.57	19	53.40	40	68.03	23	91.43	8	88.87	18	72.33	32	66.53	28	78.67	26
ICSA 14 x ICSR 89016	80.80	20	98.97	16	100.57	7	63.73	29	81.33	20	84.97	24	94.37	2	69.93	26	84.33	17
ICSA 14 x ICSR 89022	88.77	11	104.1	12	93.03	11	76.47	12	85.50	12	76.77	31	92.67	8	79.07	12	87.05	8
ICSA 14 x ICSR 89037	66.13	35	65.00	37	98.27	8	47.87	38	64.57	36	66.30	39	92.00	9	91.07	4	73.90	34
ICSA 14 x ICSR 89053	84.37	13	97.77	18	106.67	2	70.93	18	89.67	9	98.23	1	89.67	13	75.17	18	89.06	6
ICSA 14 x ICSR 91022	76.33	25	65.40	36	88.97	15	68.20	22	74.83	27	63.67	41	87.67	16	94.47	2	77.44	28
ICSA 14 x ICSR 92003	96.87	4	107.2	10	101.70	5	70.50	19	94.57	6	88.03	19	93.67	3	94.33	3	93.36	2
ICSA 14 x ICSR 93004	60.80	39	90.50	27	100.87	6	44.70	40	74.00	29	79.90	29	74.80	30	78.70	13	75.53	30
ICSA 88004 x ICSR 89016	81.73	18	92.50	26	83.40	25	55.30	35	86.63	11	94.07	9	89.33	14	90.87	5	84.23	18
ICSA 88004 x ICSR 89022	78.67	22	101.1	14	90.37	13	84.97	2	78.13	23	94.17	8	86.33	17	72.87	24	85.84	10
ICSA 88004 x ICSR 89037	75.27	26	99.50	15	86.33	18	71.77	17	85.27	14	94.57	6	82.00	24	86.77	6	85.19	12
ICSA 88004 x ICSR 89053	93.03	8	127.4	2	91.53	12	58.23	33	95.23	5	94.27	7	91.00	10	73.30	22	90.50	4
ICSA 88004 x ICSR 91022	95.70	6	113.0	8	80.00	27	69.53	21	89.17	10	73.73	33	82.00	25	73.00	23	84.53	15
ICSA 88004 x ICSR 92003	84.23	14	95.80	21	87.50	16	75.93	13	82.23	17	90.00	17	88.83	15	73.80	21	84.79	14
ICSA 88004 x ICSR 93004	96.03	5	94.60	25	81.47	26	66.50	25	96.20	2	86.80	21	84.00	19	63.40	30	83.63	19
ICSA 88006 x ICSR 89016	70.10	30	115.5	7	85.30	22	66.17	26	68.60	34	96.67	2	82.33	23	62.20	32	80.86	24
ICSA 88006 x ICSR 89022	81.27	19	80.10	31	79.00	28	84.97	3	85.33	13	80.13	28	72.00	33	77.40	14	80.03	25
ICSA 88006 x ICSR 89037	67.30	34	96.47	20	89.63	14	67.00	24	76.33	24	94.03	10	79.33	26	80.93	11	81.38	22
ICSA 88006 x ICSR 89053	72.37	28	78.37	33	75.83	30	79.77	10	68.70	33	78.27	30	76.97	28	74.87	19	75.64	29
ICSA 88006 x ICSR 91022	69.97	31	82.00	30	71.27	32	55.33	34	71.27	31	81.63	27	76.57	29	52.87	37	70.11	37
ICSA 88006 x ICSR 92003	97.27	2	105.2	11	94.67	9	73.07	16	97.40	1	93.40	11	92.87	7	83.07	9	92.12	3
ICSA 88006 x ICSR 93004	79.03	21	95.30	23	85.40	21	96.03	1	75.00	26	96.03	4	93.10	6	85.27	7	88.15	7
ICSR 89016	65.20	37	116.2	6	77.47	29	83.13	6	64.43	37	85.60	23	73.27	31	85.27	8	81.32	23
ICSR 89022	97.10	3	58.03	41	66.60	35	51.87	36	93.63	7	69.20	36	72.00	34	54.73	36	70.40	36
ICSR 89037	82.13	17	79.00	32	56.27	37	81.03	8	84.63	15	74.93	32	90.07	12	43.70	40	73.97	33
ICSR 89053	70.73	29	121.5	4	84.10	24	64.37	27	80.83	21	93.33	12	71.23	35	66.27	29	81.55	21
ICSR 91022	93.10	7	63.00	39	60.47	36	80.37	9	74.40	28	87.83	20	64.83	37	56.27	35	72.53	35
ICSR 92003	76.40	24	95.43	22	84.40	23	82.87	7	72.43	30	93.13	14	82.70	22	75.67	17	82.88	20
ICSR 93004	82.40	16	82.00	29	54.37	39	46.77	39	82.17	18	93.27	13	83.80	20	71.93	25	74.59	31
ICSA 1	49.40	41	63.33	38	37.23	41	38.80	41	44.70	39	66.90	38	53.87	40	47.33	38	50.20	41
ICSA 14	50.20	40	62.70	40	73.60	31	61.00	32	38.60	40	65.13	40	35.47	41	43.27	41	53.75	40
ICSA 88004	67.40	33	67.70	35	68.30	34	61.67	31	62.20	38	69.60	35	54.63	39	59.33	33	63.85	38
ICSA 88006	61.43	38	69.37	34	70.63	33	49.43	37	35.33	41	68.07	37	67.63	36	44.00	39	58.24	39
Sh-1	92.47	9	127.0	3	87.10	17	75.13	14	95.67	3	92.50	15	77.17	27	76.27	15	90.42	5
Sh-2	102.3	1	139.1	1	103.57	4	84.13	4	95.33	4	96.57	3	90.53	11	95.27	1	100.86	1
Mean	78.96		94.22		82.55		68.54		77.84		84.52		80.55		71.74		79.86	

L.S.D.$_{0.05}$ between environments is 3.22, L.S.D. $_{0.05}$ between genotypes is 3.43 and L.S.D. $_{0.05}$ due to interaction is 6.33

interactions. Thus the different ranks of this genotype in the E1-E8 environments were 27,28,19,30,25,25,21and27 respectively, that showed confined range from the 19th to the 30th. Similar results were reported by Eweis 1998 and Mostafa 2001.

3.1.1. Genetic analysis

Data in Table (4) present the combined analysis of variance for grain yield of four male sterile lines (females), seven restorer lines (males) and their 28 hybrids evaluated over eight environments. The mean squares due to environmental effects was highly significant reflecting the varied edaphic and climatic factors influencing sorghum plants. Highly significant mean squares due to the tested genotypes suggested the presence of important genetic variation among these genotypes. However, partitioning the latter mean squares to parental lines, crosses, and lines versus crosses resulted in three highly significant components of mea n squares. The lines were too diverse to produce significantly different crosses. The highly significant mean squares due to lines vs. hybrids is a confirmation of the presence of heterosis. The mean squares attributed to crosses were subjected to more partitioning aiming at studying the genetic variance affecting the crosses. Both effects of male and female parents were highly significant indicating the important role of additive genetic variance controlling grain yield of sorghum. On the other hand, the highly significant effect of interaction between genetic systems of male and female lines in the crosses I ndicated the major role of non-additive genetic effects controlling grain yield. The proportional participation of males, females and the interaction effects in the crosses variance were 25, 8.7 and 66.3%, respectively. These results clarify that the participation of the non-additive genetic effect is twice that of the additive effects.

Mean squares due to genotype x environment interactions were highly significant (Table, 4). This result suggests that the genotypes used responded differently to effective environmental factors. However, the partitioning of mean squares due to the interaction between crosses and environments resulted in three highly significant components that were mean squares accounted to interactions between environments and genetic effects of males, females and males X females. So, genetic systems controlling additive and non-additive effects responded differently to environmental factors. Patil and Ghopde (1981) stated the necessity to conduct studies on combining ability over as many environments as possible for obtaining unbiased estimates of genetic parameters.

Table (4) Analysis of variance for grain yield of four male sterile lines (females), seven restorer lines (males) and their 28 hybrids across environments.

Source of Variance	d.f	MS.
Environment (E)	7	6700.39**
Error	16	42.31
Genotypes (G)	38	2293.81**
Crosses Vs parents	1	34346.51**
Parents (P)	10	3118.42**
Crosses C	27	801.27**
Female effects (F)	3	627.12**
Male effects (M)	6	89984**
Female x Male effects	18	797.43**
GXE	266	366.13**
Gx P x E	7	767.02**
P x E	70	483.49**
C X E	189	307.81**
F x E	21	571.76**
M x E	42	240.94**
F. M x E	126	289.11**
Pooled error	608	24.83

3.2. Combining ability

3.2.1. General combining ability (GCA)

Estimates of general combining ability (GCA) effects for grain yield at each environment and combined over all environments are presented in Table (5).

Combined over all environments, the female parent ICSA 88004 proved to be the best general combiner as its significant GCA effect (2.68) surpassed those of the other female parents. On the other hand, the A lines ICSA 88006 and ICSA-1 displayed lower GCA effects that were -1.67 and -1.11, respectively. Unfortunately, the estimates of (GCA) effect were greatly changed from one environment to another. The GCA effects for ICSA 88004 were (+6.13**, +6.35**, -2.07**, -0.73*, +6.59**, +3.62**, +1.02 and +0.51) and for ICSA 88006 were (-3.49**, -3.80**, -4.86**, +5.00**, -3.45**, +0.55**, -3.31** and -1.98*) in environments E1, E2, E3, E4, E5, E6, E7 and E8, respectively.

Table (5) Estimates of general combining ability effects for yield at eight environments.

Entries	E1	E2	E3	E4	E5	E6	E7	E8	Comb.
1- Females (A-lines)									
ICSA-1	-1.54*	+4.67**	-3.78**	+2.15**	-2.81**	+0.18	-1.79**	-5.99**	-1.11**
ICSA-14	-1.10*	-7.23**	10.71**	-6.42**	+0.33	-6.35**	+4.07**	+7.47**	+0.10
ICSA 88004	+6.13**	+6.35**	-2.07**	-0.73*	+6.59**	+3.62**	+1.02	+0.51	+2.68**
ICSA88006	-3.49**	-3.80**	-4.86**	+5.00**	-3.45**	+0.55**	-3.31**	-1.98*	-1.67*
S.E. of gi	-0.62	+0.79	2.04	0.76	0.55	1.027	0.97	1.20	0.99
SE of gi-gj	0.87	1.12	2.98	1.07	0.77	1.45	1.37	1.69	1.04
2- Restorer lines									
ICSR89016	-3.53**	2.05**	0.85	-7.65**	-2.93**	4.03**	2.15**	-2.95**	-1.00*
ICSR89022	-1.65*	4.18**	-8.39**	10.60**	-1.43*	-4.96**	-7.61**	0.50	-1.09*
ICSR89037	-6.07**	-7.38**	2.06**	-3.20**	-4.30**	0.71**	2.39**	7.53**	-1.03
ICSR89053	-0.55	2.62**	4.27**	3.47**	-1.02	5.62**	2.55**	0.51	2.19**
ICSR91022	-0.17	-4.48**	-0.74	-5.27**	-1.47	-9.83**	-0.30	-6.00**	-3.53**
ICSR92003	10.19**	5.84**	9.54**	2.85*	7.95**	2.57**	4.94**	2.70**	+5.82**
ICSR93004	1.78*	-2.84**	-7.59**	-0.80	3.19**	1.86	-4.13**	-2.30**	-1.36*
S.E. of gi	0.81	1.05	2.70	1.00	0.72	1.36	1.28	1.58	1.30
S.E. of gi-gj	1.15	1.48	3.81	1.41	1.02	1.92	1.82	2.24	1.86

Table (6): Estimates of specific combining ability effects for grain yield at eight environments.

Crosses	E1	E2	E3	E4	E5	E6	E7	E8	Comb.
ICSA-1 x ICSR89016	0.94	14.27	0.66	-1.45	0.35	-5.65	-2.22	1.48	-2.75
ICSA-1 x ICSR89022	-11.36	13.73	-20.17	-7.88	-7.55	-7.99	-16.46	5.51	-6.52
ICSA-1 x ICSR89037	15.39	3.48	-0.65	10.49	6.65	5.17	11.20	-2.85	6.11
ICSA-1 x ICSR89053	-9.12	-9.14	6.17	8.19	-10.94	4.06	7.38	11.54	1.02
ICSA-1 x ICSR91022	-0.23	12.68	24.95	-2.17	6.05	-9.41	10.23	-4.99	6.99
ICSA-1 x ICSR92003	-0.25	-4.17	12.14	-4.15	-4.64	-5.79	-3.18	-9.76	-3.14
ICSA-1 x ICSR93004	11.75	-2.53	-23.10	-2.93	10.09	0.79	-6.94	-0.95	-1.71
ICSA-14 x ICSR89016	5.18	7.06	1.14	8.19	3.26	1.24	2.95	-10.37	2.38
ICSA-14 x ICSR89022	11.26	10.09	2.84	2.66	6.29	20.3	11.01	-4.68	5.19
ICSA-14 x ICSR89037	-6.95	-17.48	-2.38	-12.14	-11.77	-14.10	0.35	0.29	-8.02
ICSA-14 x ICSR89053	5.76	5.29	3.82	4.26	10.04	12.91	-2.15	-8.59	3.92
ICSA-14 x ICSR91022	-2.65	19.98	-8.88	10.27	-4.33	-6.20	-1.30	17.22	-1.98
ICSA-14 x ICSR92003	7.52	11.53	-6.41	4.45	5.98	5.77	-0.54	8.38	4.59
ICSA-14 x ICSR93004	-20.13	3.48	9.87	-17.70	-9.83	-1.65	-10.33	-2.24	-6.07
ICSA-88004 x ICSR89016	-1.11	-12.99	-3.25	-5.94	2.01	0.38	0.97	17.52	-0.30
ICSA-88004 x ICSR89022	-6.07	-6.45	12.95	5.47	-7.99	9.47	7.73	-3.92	1.40
ICSA-88004 x ICSR89037	-5.05	3.44	-1.53	6.07	2.01	4.20	6.61	2.95	0.69
ICSA-88004 x ICSR89053	7.20	21.38	1.46	-14.12	8.70	-1.01	2.23	-3.50	2.79
ICSA-88004 x ICSR91022	9.49	14.10	-5.06	5.91	3.08	-6.09	-3.92	2.71	2.53
ICSA-88004 x ICSR92003	-5.78	-6.91	1.28	10.75	-6.71	4.33	4.24	1.37	-6.56
ICSA-88004 x ICSR93004	7.88	-6.0	3.25	-1.59	5.45	-4.27	1.92	-10.58	-0.54
ICSA-88006 x ICSR89016	-3.13	20.17	1.44	-0.80	-5.99	4.04	-1.70	-8.65	0.67
ICSA-88006 x ICSR89022	6.15	17.36	4.37	-0.26	9.25	-3.50	-2.27	3.10	-0.07
ICSA-88006 x ICSR89037	-3.39	10.56	4.56	-4.42	3.11	4.73	-4.94	-0.40	1.23
ICSA-88006 x ICSR89053	-3.84	-17.53	-11.45	1.68	-7.80	-15.95	-7.47	6.55	-7.73
ICSA-88006 x ICSR91022	-6.61	-6.80	-11.0	-14.0	-4.79	2.87	-5.02	14.94	-7.54
ICSA-88006 x ICSR92003	10.3	6.11	2.12	4.40	11.93	2.24	6.04	6.56	5.11
ICSA 88006 x ICSR93004	0.5	4.68	9.97	22.22	-5.7	5.58	15.35	13.77	8.32
S.E (Sij).	1.627	2.08	5.39	2.01	1.45	2.95	2.56	3.17	2.62
S.E(Sij-S_{kl})	2.30	2.96	7.62	2.84	2.05	4.44	3.63	4.48	3.70

The reason for that might be due to GE interaction. This deduction is assured by highly significant mean squares due to interactions between environment and genetic effects, (Table 4). These results are in the same line with those obtained by El-Menshawi (1996) and Mostafa and El-Menshawi (2001).

3.2.2. Specific combining ability ((sca)

Estimates of specific combining ability (SCA) effects for grain yield at each environment and combined over all environments are presented in Table (6). The hybrids ICSA-IXICSR89037, ICSA14xICSR 89016, ICSA-1XICSR 91022, ICSA 88004 X ICSR 91022, ICSA-14 XICSR89053, ICSA 14 x ICSR92003, ICSA88006 x ICSR92003, ICSA88004xICSR89053 and ICSA88006 x ICSR93004 had significant positive (SCA) effects for grain yield in most environments. But the individual estimates indicated that non-additive genetic (SCA) effects were greatly changing from one environment to another. It is similar in trend as the additive genetic (GCA) effects. Hence, the stability parameters have to be calculated.

3.3. Stability parameters

Combined analysis of variance for grain yield/plant according to Eberhart and Russell (1966) is presented in Table (7). Highly significant mean squares due to genotypes revealed the presence of variability among them. Genotype-environment interaction and environment effects were highly significant which encouraged estimating stability parameters. The mean squares due to different linear responses of genotypes to environmental changes were highly significant indicating that genotypes may genetically differ in their response to environmental fluctuations. The deviations from the lines of the response of genotypes were large enough to cause highly significant mean squares. The relative participations of linear response and deviation sum of squares in the total sums of squares due to genotype x environment interaction were 21 and 79%, respectively, indicating that the deviation from the linear responses is more important. These results are in the same line with those obtained by Vasil and Milas (1984).

The ideal hybrid as proposed by Eberhart and Russell (1966) would be the most productive one over a range of environments, that has a linear regression coefficient (b_i) statistically equal to one and deviation mean squares from this linear regression (S^2d_i) that does not statistically differ from zero. The data presented in Table (8) indicate that 12 hybrids have linear regression coefficients across all environments equal to unity. These hybrids are H2, H4, H7, H10, H12, H13, H14, H15, H21, H23, H25 and H28. Two of them H25 and H28 fulfilled, most of Eberhart and Russell's (1966) requirements to be stable hybrids. They are moderately productive hybrids as their grain yields were 77.64 and 88.15 g/plant, respectively.

Table (7) Analysis of variance according to Eberhart and Russell (1966).

Source of variance	DF.	M.S
Genotypes (G)	40	2525.87^{**}
(G X E)	280	543.97^{**}
Environments (E)	7	53465.18^{**}
GXE (linear)	40	559.56^{**}
Pooled deviation	246	326.31^{**}
Error.	640	25.01

The other hybrids H1, H3, H5, H6, H8, H9, H11, H16, H17, H18, H19, H20, H22, H24, H26, and H27 had (bi) estimates more than unity. According to Breese (1969) these hybrids would be adapted to more favorable environments and respond to ever y environmental improvement. Among them four hybrids showed insignificant S^2di *i.e.*, H1, H20, H22 and H27, they would be more responsive to favorable environments and gave grain yields of 77.98, 87.79, 80.86 and 92.12 g/plant, respectively. Nevertheless, the most productive hybrid was ICSA88006 x ICSR91022 that had bi value of 1.24 and S^2d_i that significantly differs from zero.

The last column in Table (8) presents the ecovalence (W_i) estimates calculated according to Wricke (1962). As it is the sum of squares of genotype environment interaction effects of a particular genotype divided by the degree of freedom (the number of environments minus 1), it can be considered as a whole estimate for stability. The correlation coefficients between W_i with b_i and S^2d_i were ($r=-0.24$, $P=0.14$) and ($r=0.91$, $P<0.01$), respectively, indicating high important role of S^2d_i in the genotype x environment interaction and coincides with the previous deduction from the analysis of variance (Table, 7). Similar results were obtained by Vasil and Milas (1984) who illustrated the strong correlation due to the relatively large variability of S^2d_i as compared to the variability due to the b_i values.

Table (8): Mean grain yield and estimates of stability parameters of 41 genotypes across 8 environments.

No	Genotypes	Mean	b_i	S^2d_i	Wi
H_1	ICSA-1 x ICSR89016	77.99	1.11^*	1.58	12.01
H_2	ICSA-1 x ICSR89022	74.12	1.36	38.77^{**}	284.82
H_3	ICSA-1 x ICSR89037	86.82	0.89^*	3.31^*	24.44
H_4	ICSA-1 x ICSR89053	84.94	0.75	15.23^{**}	112.76
H_5	ICSA-1 x ICSR91022	85.20	2.04^{**}	11.70^{**}	151.19
H_6	ICSA-1 x ICSR92003	84.42	1.53^*	9.51^*	85.61
H_7	ICSA-1 x ICSR93004	78.67	0.95	26.34^{**}	188.37
H_8	ICSA14 x ICSR89016	84.33	1.43^{**}	6.77^*	60.10
H_9	ICSA14 x ICSR89022	87.05	0.93^*	5.42^*	39.05
H_{10}	ICSA14 x ICSR89037	73.90	0.22	43.13^{**}	345.87
H_{11}	ICSA14 x ICSR89053	89.06	1.24^*	7.03^*	53.69
H_{12}	ICSA14 x ICSR91022	77.44	-0.52	16.75^{**}	263.29
H_{13}	ICSA14 x ICSR92003	93.36	1.02	7.55^*	53.97
H_{14}	ICSA14 x ICSR93004	75.53	1.48	22.30^{**}	173.59
H_{15}	ICSA88004 x ICSR89016	84.23	1.01	12.91^{**}	92.26
H_{16}	ICSA88004 x ICSR89022	85.84	0.94^*	4.41^*	31.75
H_{17}	ICSA88004 x ICSR89037	85.19	0.92^*	4.42^*	32.00
H_{18}	ICSA88004 x ICSR89053	90.50	2.40^{**}	4.74^*	155.95
H_{19}	ICSA88004 x ICSR91022	84.53	1.36^*	13.25^{**}	102.54
H_{20}	ICSA88004 x ICSR92003	87.79	0.89^*	0.65	5.35
H_{21}	ICSA88004 x ICSR93004	83.63	1.12	12.01^{**}	86.79
H_{22}	ICSA88006 x ICSR89016	80.86	2.15^{**}	5.69	123.40
H_{23}	ICSA88006 x ICSR89022	80.03	-0.12	2.40^{**}	95.37
H_{24}	ICSA88006 x ICSR 89037	81.38	1.12^{**}	6.96^*	50.55
H_{25}	ICSA88006 x ICSR89053	75.64	0.07	1.81	66.94
H_{26}	ICSA88006 x ICSR91022	70.11	1.24^{**}	3.41^*	27.80
H_{27}	ICSA88006 x ICSR 92003	92.12	1.09^{**}	3.19	23.36
H_{28}	ICSA88006 x ICSR93004	88.15	0.24	8.93	99.66
H_{29}	ICSR89016	81.32	1.15^{**}	26.02^{**}	187.32
H_{30}	ICSR89022	70.40	0.17	40.0^{**}	328.58
H_{31}	ICSR89037	73.97	0.41	33.45^{**}	260.75
H_{32}	ICSR89053	81.55	2.21^{**}	7.67^*	145.15
H_{33}	ICSR91022	72.53	0.19	25.32^{**}	268.77
H_{34}	ICSR92003	82.88	0.73	4.72^*	38.23
H_{35}	ICSR93004	74.59	1.06^*	26.21^{**}	187.49
H_{36}	ICSA-1	50.20	0.92	8.74^*	62.90
H_{37}	ICSA-14	53.75	0.6	23.75^{**}	179.80
H_{38}	ICSA 88004	63.85	0.34	2.84^*	47.06
H_{39}	ICSA88006	58.24	1.16^*	13.85^{**}	100.55
H_{40}	Sh-1	90.42	1.83^{**}	11.03^*	121.09
H_{41}	Sh-2	100.86	1.78^{**}	11.23^*	118.12

* and ** significant at 0.05 probability levels

The estimates of W_i revealed that the most stable hybrid was ICSA-88004 x ICSR-92003 followed by the hybrids ICSA-1 x ICSR-89016, ICSA-88006 x ICSR-92003 and ICSA-1 x ICSR-89037 in a descending order. Among these four hybrids two lines were common in two hybrids, viz., the A-line ICSA-1 and the R-line ICSR-92003 that showed Wi estimates of 62.90 and 38.23, respectively. They were the most stable lines. Unfortunately, the hybrid between these two lines ICSA-1 x ICSR-92003 showed W_i value of 85.61 that indicates a moderate stability. This result suggests that crossing two stable lines may not produce the most stable hybrid, in other words, heterosis or other effects may interfere in the final stability of any hybrid.

On the other side, the most unstable R-line was ICSR 89022 and the most unstable B-line was ICSA-14. They gave W_i estimates of 328.58 and 179.80, respectively. The hybrid between them, which showed Wi value of 263.29 was not the worst hybrid concerning stability. The most unstable hybrid was ICSA14 x ICSR89037 which gave Wi value of 345.87. This hybrid was composed by crossing the most unstable maternal line ICSA 14 with the unstable paternal R-line ICSR 89037, that showed Wi values of 179.80 and 260.75, respectively. The role of heterosis and other factors in hybrid stability is manifested. This means that stability of performance might be a heritable trait and the stable parents transmitted stability genes to their crosses. Similar results were obtained by (Jensen 1970 and Redden and Jensen 1974). Studying yield stability on forage crops, Breese and Hayward (1972) stated that production stability was highly heritable. Similar conclusion was also reported by Tan and Tan (1980), Wu (1975) Bucio-Alan *et al.* (1969). In contrast, Fatunla and Frey (1976) and Eagles and Frey (1977) found that the regression stability index is not a very heritable trait for oats.

To understand the role of additive and non-additive genes and their interaction with different environment, the G.E effects of three hybrids differing in stability were partitioned into the effect of GCA interaction with environments and SCA interaction with environment for the eight environments (Table 9) along with variances and co-variances of these effects. The G.E of the hybrids was recalculated using hybrid means from a separate analysis. The tested hybrids had different ecovalence values. The hybrid ICSA-88004 x ICSR-92003 was the most stable , the hybrid ICSA-14 x ICSR-89037 was the most unstable one while the hybrid ICSA-14 x ICSR-93004 intermediate the ecovalence values. The results obviously reveal that the formulae 5 and 6 (in Materials and Methods) are simple and able to calculate G.E fractions that coincide with the expected from formula 4.

The hybrid ICSA 88004 x ICSR 92003 has low G.E values ranging from -3.92 to 4.37 with a variance of about 8.82. These low values might be due to low G.E effects of GCA values with low variances of 11.89 and 9.62 of maternal and paternal G.E effects, respectively. In the same time, the G.E effects due to SCA were also very low so the variance was 40.28. The co-variances between G.E of SCA with either G.E of GCA of maternal or paternal parent were negative. These results revealed that the different directions (sign) of the interaction of the additive and non-additive genes with the environments diminish the G.E effect of the hybrids and consequently decrease W_i values indicating the increased stability obtained.

In contrast, the hybrid ICSA14 x ICSR89037 has high G.E values that ranged from -23.13 to 24.24 with variance of about 301.12. Obviously, it was one of the most unstable hybrids in this study. The variances of the interactions between environments with genetic effects were very high, 46.02 and 25.52 for the GCA.E effects of maternal and paternal parent, respectively. These values reach four and two times of the counterpart effects of the most stable hybrid. The role of stable additive genes constituting the genetic system of stable hybrid is apparent. The G.E effects due to SCA were quite low so the variance was 47.08, but the co-variances between G.E of SCA with either G.E of GCA of maternal or paternal parent are positive. Therefore, when these variances and co-variances participate in the final performance of the hybrid display very high W_i value and indicate the hybrid instability. Remarkably, the relationships between G.E effects of SCA of a particular hybrid with G.E effects of the GCA of its parents control its stability measured as W_i. The negative relationship increases hybrid stability and positive relationship decreases it.

The hybrid ICSA14 x ICSR93004 displayed moderate stability with W_i value of about 140.88 resulting from less stable additive genes of the maternal parent and stable additive genes of the parental parent so that the variances of these effects were 46.02 and 12.32, respectively. Moreover, these effects varied in their direction in each environment so the co-variance between these effects was negative with a value of 25.83. The participation of the interaction between environments with

Table (9) Genotype environment effects, their partitions and their variance or covariance over eight environments of three particular hybrids.

Effect	E1	E2	E3	E4	E5	E6	E7	E8	Variance	Item
ICSA 88004 x ICSR 92003 (high stability)										
G.E	2.04	-3.22	-2.31	4.37	-0.67	2.02	1.7	-3.92	8.82	Var(G.E)
GCA.E of F	3.45	3.67	-4.75	-3.41	3.91	0.94	-1.66	-2.17	11.89	Var(GCA.E)
GCA.E of M	4.37	0.02	3.72	-2.97	2.13	-3.25	-0.88	-3.12	9.62	Var(GCA.E)
SCA.E	-5.78	-6.91	-1.28	10.75	-6.71	4.33	4.24	1.37	40.28	Var(SCA.E)
									5.28	Covar(GCA.EF,GCA.EM)
									-27.01	Covar(GCA.EF,SCA.E)
									-24.61	Covar(GCA.EM,SCA.E)
ICSA14 x ICSR89037 (low stability)										
G.E	-5.17	-23.13	19.35	-12.8	-7.45	-10.79	15.76	24.24	301.12	Var(G.E)
GCA.E of F	-1.2	-7.33	10.61	-6.52	-0.43	-6.45	3.97	7.37	46.02	Var(GCA.E)
GCA.E of M	-5.04	-6.35	3.09	-2.17	-3.27	1.74	3.42	8.56	25.52	Var(GCA.E)
SCA.E	1.07	-9.46	5.64	-4.12	-3.75	-6.08	8.37	8.31	47.08	Var(SCA.E)
									41.59	Covar(GCA.EF,GCA.EM)
									72.52	Covar(GCA.EF,SCA.E)
									45.62	Covar(GCA.EM,SCA.E)
ICSA14 x ICSR93004 (intermediate stability)										
G.E	-12.13	0.74	20.32	-17.6	0.35	1.18	-3.07	10.24	140.88	Var(G.E)
GCA.E of F	-1.2	-7.33	10.61	-6.52	-0.43	-6.45	3.97	7.37	46.02	Var(GCA.E)
GCA.E of M	3.14	-1.48	-6.23	0.56	4.55	3.22	-2.77	-0.94	12.97	Var(GCA.E)
SCA.E	-14.06	9.55	15.94	-11.63	-3.76	4.42	-4.26	3.83	106.32	Var(SCA.E)
									-25.83	Covar(GCA.EF,GCA.EM)
									44.06	Covar(GCA.EF,SCA.E)
									-39.69	Covar(GCA.EM,SCA.E)

genes having additive effects was low . However , the effects of the interaction between environments and genes having non-additive effect were very high, so that their variance was 106.32. This result clarifies the important role of the interaction between environments and genes having non-additive effects on the final stability of some hybrids. The co-variances between G.E effects of SCA with G.E effects of GCA of both parents were 44.06 and -39.69 for maternal and paternal parent, respectively. It is clear that the negative relationship between the interactions of additive effects of both parents caused the opposite co-variances with G.E effects of SCA. In the case of the hybrid ICSA14 x ICSR93004 its instability is due to the instability of genes having non-additive effects.

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تحليل الثبات الوراثي والقدرة على التآلف لبعض الهجن وآبائها في محصول الذرة الرفيعة للحبوب

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ملخص

أجريت هذه التجربة في ثمانية بيئات مختلفة لتقييم سلوك ودراسة الثبات الوراثي لعدد ثمانية وعشرين هجينا وآبائهم الإحدى عشر بالإضافة إلى هجينين هما شندويل ١، شندويل ٢ كأصناف للمقارنة.

اقترح نموذج لتقسيم التأثير التفاعلي البيئى والوراثى فى الهجن.

اظهر تحليل التباين ان مجموع المربعات الراجعة بين البيئات والتراكيب الوراثية والتفاعل بين التراكيب الوراثية والبيئات كانت معنوية لكل الصفات المحصولية تحت الدراسة.

وبمقارنة معامل الاختلاف(C.V.) بين الصفات المدروسة الراجع للتفاعل ركز الاهتمام على صفة المحصول وذلك لوضوح تأثير التفاعل الوراثى البيئى فى هذه الصفة. حدث اختلاف وتباين واضح فى القدرة الإنتاجية للهجن فى البيئات المختلفة واظهر ثلاثة هجن منها تفوقا عن الهجين التجارى (شندويل ١). كما اظهر التحليل وجود اختلاف معنوى بين الآباء والهجن والتفاعل بينهما. وتبين ان مشاركة التأثير السيادى فى التباين ضعف مشاركة التأثير المضيف. واظهر التفاعل بين البيئة وكلا من التأثيرات الوراثية للآباء والأمهات والتفاعل بينها انه غير معنوى مما يدل على اختلاف استجابة العوامل المضيفة وغير المضيفة للبيئات المختلفة.

وقد حسبت القدرة على التالف فى عديد من البيئات للحصول على تقديرات غير متميزة للتأثيرات الوراثية . تم إجراء تحليلات الكشاف x السلالة لكل بيئة على حدة. وكانت السلالة الأميّة ICSA88004 ذات قدرة عالية على التالف العام بينما كانت القدرة الخاصة على الائتلاف لتسع هجن معنوية وموجبة. أوضحت النتائج أن مشاركة التباين الراجع للانحراف عن الاستجابة الخطية (S^2di) اكثر أهمية من التباين الراجع للاستجابة الخطية (bi). و أوضحت قيم المكافئ البيئي (Wi) للآباء وهجنها ان التهجين بين سلالتين عالية الثبات الوراثي قد لا ينتج هجنا عالية الثبات وتدل على ان قوة الهجين لها دور في درجة الثبات للهجن وبمقارنة

الهجن الثلاثة ICSA88004 x ICSR92003 هو الأعلى ثباتاً والهجين ICSA14 x ICSR93004 متوسط الثبات والهجين ICSA14 x ICSR89037 هو الأقل ثباتاً. اظهرت النتائج ان اختلاف اتجاه (الإشارة) للتفاعل GCA.EMx GCA.EF يؤدى الى تناقص قيمة التأثير الوراثي البيئى G.E للهجن وبالتالى انخفاض قيمة المكافئ البيئى Wi والحصول على هجن اكثر ثباتاً. تساعد هذه النتائج مربى النبات في التنبؤ بأفضل الهجن ثباتاً والتى يمكن التوصية بزراعتها فى البيئات المختلفة.

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