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Genetic study of some drought tolerance indicators in the first generation of durum wheat (*Triticum durum* Desf.)

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ABSTRACT

Because of the lack of rainfall in arid and semi-arid areas in the Kurdistan Region, it's required wheat genotypes suitable for these conditions. In; 2020-2021 ten wheat genotypes were crossed. In; 2021-2022 Grains of F1s and the parents were planted under rain-fed and supplementary irrigation in Koya Agriculture Research Station (Erbil) to study the genetic properties by Griffing and Jinks-Hayman method for some drought tolerance indices such as stress susceptibility index SSI; geometric mean productivity GMP; mean productivity MP; tolerance Index TOL; and yield stability index YSI; through the grain yield under stressed (Ys) and yield potential (Yp) conditions. Significant; differences were found among parents and F_1s for all indices. Results; of genetic analysis imply to high general combining ability GCA; of some parents for different indices. Some crosses had specific combining ability SCA; for most of the indices. The dominant; component (H_1) was higher than the additive ($\hat{D}$) and average degree of dominance ($\sqrt{H_1/D}$) was greater than one for all indices. Dominant; and recessive alleles in gene locations (H2/4H1) were less than 0.25 for all traits, showing that dominance was not distributed regularly among parents. The number; of dominant to recessive genes ratio (KD/KR) was more than one for Ys, SSI; GMP; and YSI; with values of (1.25, 1.61, 1.09 and 1.62) respectively, indicating the increase of dominant genes in parents for these traits, while it was less than one for Yp, MP and TOL; with values (0.54, 0.90 and 0.78) respectively shows increase of recessive genes in parents for these traits. Heritability; $H_{ns.}$ has ranged from 0.268 for Ys to 0.339 for Yp. Parents 1 and 3 were the best for GCA; and most of the traits. Crosses 1×7 and 1×8 had the best performance for most of the traits, and 4×9 was the best for SCA.

Keywords: Half Diallel, Rain-Fed, Supplementary Irrigated, Combining Ability, Genetic Properties and Heritability.

1. Introduction

Wheat is mainly grown in rain-fed regions in the northern part of Iraq, including the Kurdistan region; dryness is the most significant abiotic factor in reducing grain productivity. In; Iraq, the production of wheat had a significant reduction in 2021 estimated at 32% of the total production in comparison with 2020, due to severe drought conditions despite the increased planting area at that season by 10.4%[1]. The; studies that were done on genetic properties to study drought tolerance indices on wheat in the northern part of Iraq, including the Kurdistan region, less than wanted, so they reflected negatively on the development or derived new varieties of wheat in semi-arid areas in which the rainfall is a main factor for the growth of wheat. Thus; breeders need to focus on crossing programs to produce new genotypes having high productivity performance with more adapted to rain-fed areas. Through; the half-diallel crossing breeding programs which provide genetic effects information for some parental genotypes with general and specific combining ability variance components and heritability from chosen parental genotypes, wheat genotypes could be developed to tolerate extreme weather conditions such as drought[2]. Thus; drought resistance is usually quantified by grain yield potential of the genotypes under drought conditions however depends on the phenology of the genotype as well. For studding drought tolerance in F_1 generation of wheat several indices can be used to assess different genotypes for drought resistance based on their grain yield, such as stress susceptibility index SSI;[3], geometric mean productivity GMP;[4], mean productivity MP;[5], yield stability index YSI;[6] and tolerance Index TOL;[5]. According; to Richards 1996[7], all the recognized and unknowing factors that contribute to drought tolerance are integrated into the selection process for yield. Combining ability; and gene action effects mode for agronomic characteristics of wheat may help in selecting superior hybrids for drought tolerance[8, 9]. Diallel crosses approach is a proper biometric method to investigate the effect of general and specific

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combining ability and gene action analysing, and by using Griffing[12], Hayman[13] and Jinks and Hayman[14] methods can obtain the genetic attributes studied indices of drought tolerance[10]. Estimation; of available genetic variances in the early generations of crosses could be beneficial for a plant breeder[11], so by consideration of selecting parents genetically different for resistance and sensitivity to drought situations using F1 diallel cross combinations and their parents of half-diallel cross of wheat varieties helps screen drought-tolerant genotypes. Hence; selected genotypes can be recommended for planting in drought-exposed areas. Many; researchers have studied drought tolerance indices and their genetic properties in wheat using F_1 generation. As the previous studies conducted by others of genetic properties for drought tolerance indices in wheat[18, 21] found the number of parents with high and positive GCA; for these traits. At the same time, they also found some crosses revealed positive specific combining ability for the many of studied indices, with the significant role of additive genetic component ($\hat{D}$) for yield in drought-stressed Ys, Mean productivity MP; Geometric mean productivity GMP; and Stress Susceptibility Index SSI; with the higher dominant effect of genes (H_1) as compared to ($\hat{D}$) and finding that all indices were controlled by over dominance gene action. And;[22] in their investigation found significant differences among used parents and their F1s for GMP; and MP;, with significant GCA; for GMP; MP; and TOL; while not significant for SSI; They; also found high and significant SCA; effects for GMP; and MP; with the importance of additive gene effect more than dominant effects. For; heritability in narrow-sense, they found that it is very low for SSI; low for TOL; and moderate for GMP; and MP. The objective of this investigation is to study the genetic variations and understand the genetic properties of drought tolerance indices in durum wheat under-rain fed conditions to develop suitable genotypes for the arid and semi-arid areas.

2. Methods and Materials

Ten durum wheat genotypes which are genetically diverse in their resistance and sensitivity to drought according to the results available at Koya Agricultural Research Station, have been chosen as parents (Table 1), and they crossed by using the half-diallel mating approach in the 2020-2021 planting season at the experiment Farm of Agricultural Research Station/Koya, Erbil. Grains; of 45 F_1s and the 10 parents were planted during the 2021-2022 growing season with two different trials, the first was under the rain-fed conditions of 368.2 mm precipitation, and the second condition was with supplementary irrigation conditions after receiving the average precipitation of 368.2 mm for the season of filed trial. The; experiment was set up with Randomized Complete Block Design with three replications. The; parents and all their F_1 crosses were planted as experimental units. Each; plot consists of one row with a 2 m length and 30 cm space between rows, and 10 cm between plants within a row. The Supplementary, irrigated trial was given four supplemental irrigates at four different stages of growing, including tillering, jointing, heading and grain filling period by adding a total of 120 mm fresh water, which is equivalent to 30 mm water for each stage. Uniform; field management practices were used throughout the growing season for both the trials. After; harvesting, the data on grain yield was collected from all of the plots of both experiments, and the measurement was recorded for genetic analysis.

Some physical and chemical properties of the study location soil were as below, according to the soil test results from Erbil Agri-research Centre soil Lab.

Physical: Clay: 40.6% Silt: 41.1% Sand: 18.3% Texture: Silty Clay

Chemical: Ec Mm/cm: 0.3 PH: 7.6 N: 12% P(ppm): 8.8 K(ppm): 120 O.M: 1.2%

2.1 Drought tolerance indices:

Some of the drought resistance indicators were calculated for all genotypes as follows:

1. Stress Susceptibility Index SSI; [3]:

$SSI = \frac{1-Ys/Yp}{SI}$ Where: SI = stress intensity = $1-\bar{Y}s/\bar{Y}p$

Yp = yield in a non-stressed condition

Ys = yield in drought-stressed condition

$\bar{Y}p$ = mean of the yield in a non-stressed condition

$\bar{Y}s$ = mean of the yield in drought-stressed condition

2. Geometric mean productivity GMP;[4]:

$$GMP = \sqrt{(YP \times YS)}$$

3. Mean productivity MP[5]:

MP = (YP+YS)/2

4. Tolerance Index TOL;[5]:

TOL; = Yp –Ys

5. Yield Stability Index YSI;[6]:

YSI =Ys /Yp

Table 1: Wheat genotypes and their sources used to develop F1 crosses.

Genotype number	Pedigree	Source
1	LD357 (LD308/Nugget)	Erbil A.R.C
2	Cemito (Capeiti 8 / Valnova)	Erbil A.R.C
3	Acsad 65(STORK CM 470-1M-2y-CMXGDAV2 490-AA'SS")	Erbil A.R.C
4	Omrabi5 (Jori c69/Hau)	ICARDA
5	Geromtel1/Icasyr1/5/Sebatel1/4/Gnt/3/Gdfl/ T.dicds20013//Bcr	ICARDA
6	Shaba/5/OmRabi3/T.urartu500651/4/ICAMOR TA0463/3/Bcr/Gro1//Mgnl1	ICARDA
7	Sebatel1/7/Ossl1/Stj5/5/Bidra1/4/BezaizSHF// SD19539/Waha/3/Stj/Mrb3/6/Icajihan1	ICARDA
8	Ouasloukos1/5/Azn1/4/BEZAIZSHF//SD195	ICARDA

	39/Waha/3/Gdr2/6/Tilling/ch113/7/Terbol97 5/Geruftel2	
9	Icasyr1/3/Bcr/Sbl5//Turartu/4/EMN096	ICARDA
10	Amedakul1/TdicoJCol//Cham1/3/Younes/Td icoAlpCol//Korifla	ICARDA

2.2 Statistical Gene Analysis:

Analysis of variance and Combining ability:

Analysis of variance was carried out for drought tolerance indices. The; data were analyzed to ascertain the significant differences among mean values of genotypes and also to estimate general and specific combining ability according to the method of Griffing 1956[12] method 2, fixed model was used. According to this approach, the linear model equation is as follows:

$Y_{ijk} = M + g_i + g_j + S_{ij} + R_k + e_{ijk} \begin{bmatrix} i,j = 1,2,...10 \\ r = 1.2.3 \end{bmatrix}$ where:

Yijk = experimental unit value of the genotype *ij* in block k

M = total mean of the trait (general effect) Sij = the SCA effect of cross *ij*.

gi = GCA effect of the parent i. Sij = the SCA effect of cross ij.

gj = GCA effect of the parent j. Rk = the block effect of k.

eij = the experimental error effect.

The GCA effects for the parents and SCA effects for the F_1 crosses were calculated. Also, the variance of general and specific combining ability effects were estimated.

Gene action & genetic components of variation:

For gene action determination and genetic variation components, The analysis method of half-diallel cross developed by Hayman[13], Jinks[15], and Jinks & Hayman[14] that used by Singh and Chaudary[16] have been applied, using these parameters:

$\hat{D}$ = Variation attributed to additive genetics effects

$\hat{F}$ = The mean of relative frequency of alleles, and its positive sign means an increase in the dominant alleles, and the negative sign means an increase in the recessive alleles.

$\hat{H}_1 =$ Variation due to the dominant effects of genes

$\hat{H}_2 =$ Variation due to dominance genetics effects corrected for gene distribution.

$\sqrt{H_1/D}$= average degree of dominance.

$\bar{p}\bar{q}=H_2/4H_1$ = frequency product at loci exhibited dominance.

$KD/KR =$ The ratio of the total number of dominant to recessive genes in all parents.

$h^2{}_{(n.s.)}$ = narrow sense heritability

3. Results and Discussions

The analysis of variance, as shown in (Table 2) indicates significant differences among all genotypes (parents and crosses) for all drought tolerance indices under study, which proves the genetic variability between genotypes, different responses between genotypes to water deficits and also indicates the possibility of selecting drought tolerance genotypes. According to the mean performance values of parents and crosses for (Ys), (Yp) and indices of drought tolerance as shown in (Table 3) that under rain-fed conditions, crosses 1×7, 1×3, 1×8 and parent 3 have the maximum averages of grain yield per plant among genotypes, with 20.561, 18.040, 17.334 and 16.420 g plant^{-1}respectively. In contrast, crosses 5×10, 6×7 and parent 4 had the minimum grain yield per plant with the average of 6.815, 8.122 and 8.91 g plant^{-1}, respectively. Under, irrigated conditions, crosses 4×9, 8×9 and 3×9 with averages of 45.494, 42.154 and 41.185 g plant^{-1}, respectively, had the maximum grain yield. Genotypes; 2 and 7 are parents with an average of 15.741 and 16.792 g plant^{-1} had recorded the minimum values among the genotypes. The; Variation in Ys and Yp revealed the needed resources for obtaining drought resistance genotypes under this study. Regarding; drought tolerance indices, the purpose of their studying is to identify drought-tolerant genotypes, so the value of these indices are the major criteria of selection for the highest drought-tolerant genotypes. The; Stress Susceptibility Index SSI; was proposed in order to measure the yield stability of genotypes under conditions of water-stressed and non-stressed. A decrease in SSI; value indicates to a high level of drought tolerance[3]. So for the SSI; index in this study, crosses 9×10, 1×7, 1×4, 1×8, 1×3, with parents 3 and 2 were recorded as the lowest values for this indicator (0.116, 0.204, 0.348, 0.431, 0.473, 0.529 and 0.552, respectively) so due to this values of SSI; these genotypes are the most tolerant for drought among all genotypes. At the same time the most sensitive crosses for drought conditions through this indicator were 8×9, 5×9 and 5×10, giving the highest values (1.46, 1.40 and 1.39). Then; the Geometric Mean Productivity GMP; is used for the purpose of distinguishing highly productive genotypes under conditions of water-stressed and non-stressed the higher values of GMP; are an indicator for selecting higher drought-tolerant genotypes[4]. For; the geometric mean productivity GMP; here, crosses 4×9 and 3×9 recorded the highest values (26.10 and 23.33), followed by 1×5, 1×9 and 1×7 with values (22.57, 22.53 and 22.37, respectively) as more tolerant genotypes for drought according this indicator, while the parents 7, 2, and 4 and cross 5×10 were had the least value of this indicator (12.45, 12.60, 13.39 and 12.93 respectively) as an indication to low drought tolerance ability. And Mean Productivity MP; indicator is used to select between genotypes for drought-tolerant. Also the selection for high values of MP; is an indicator for selecting drought-tolerant genotypes;[4]. So the crosses 4×9 and 3×9 had the highest recorded values of the mean productivity MP; indicator (30.31 and 27.69), followed by 1×5, 5×9 and 1×9 with values (25.10, 24.95 and 24.56, respectively) as an indication to high tolerant genotypes, while the parents 7, 2 and 4 had lowest MP; values (13.03, 13.07 and 14.84 respectively) indicating to their low drought tolerance. The drought tolerance index TOL; as is known as the difference in the yield of genotypes under water-stressed and non-stressed, the genotypes with the lower value of this index are more drought-tolerant the genotype is[5]. In this study for tolerance index TOL; the cross 9×10 has been distinguished by the lowest value for this indicator (1.26), followed by crosses 1×7, 1×8, 2×7, 1×4 and parents 2 and 3 with values (4.89, 6.58, 6.86, 6.87, 5.34 and 6.37 respectively) that considered as the highest tolerant genotypes. While; crosses 8×9, 4×9, 5×9 and 3×9 had the highest value for this indicator (32.71, 30.36, 28.67 and 26.98, respectively) being with the least drought-tolerant for this indicator. And stress yield stability index YSI; which high values of it is indicating drought tolerant genotypes[6]. For this indicator YSI; the highest values were recorded for crosses 9×10, 1×7 and 1×4 with the values of 0.943, 0.884 and 0.808, respectively, followed by 1×8, 1×3 and parents 3 and 2 (0.771, 0.744, 0.723 and 0.704, respectively), indicating that these genotypes are the highest rate of drought tolerance. While; the crosses 8×9, 5×9 and 5×10 were the least drought tolerant that recorded values of 0.228, 0.266 and 0.267, respectively. Similar; results were found in those of[17, 18, 20-22], for; Ys, Yp, TOL; SSI; GMP; MP and YSI; with different genotypes of wheat.

Table 2: Analysis of variance for studied drought tolerance indices.

S.O.V	d.f	Mean Square						
		YS	YP	SSI	GMP	MP	TOL	YSI
Replications	2	3.068	15.485	0.041	1.916	3.110	24.666	0.040
Genotypes	54	**19.151***	**120.645****	**0.240***	**24.348****	**37.467****	**129.724****	**0.065***
Error	108	12.320	56.396	0.143	13.186	18.178	64.720	0.038

* Significant (P = 0.05) /** Significant (P = 0.01) Ys= Grain yield under stress, Yp= Grain yield under non-stress, SSI=Stress Susceptibility Index, GMP= Geometric Mean Productivity, MP=mean productivity, TOL=Tolerance Index, YSI= Yield Stability Index.

Table 3: Mean values of parents and hybrids for drought tolerance indices.

Parents &crosses	YS	YP	SSI	GMP	MP	TOL	YSI
1	12.525	26.613	1.003	18.158	19.569	14.088	0.472
2	10.400	15.741	0.552	12.605	13.071	5.341	0.704
3	16.420	22.790	0.529	19.334	19.605	6.370	0.723
4	8.913	20.779	1.105	13.394	14.846	11.866	0.417
5	11.231	20.432	0.852	15.140	15.831	9.202	0.552
6	11.969	21.567	0.841	16.027	16.768	9.598	0.557
7	9.268	16.792	0.844	12.457	13.030	7.524	0.558
8	11.086	26.531	1.087	17.059	18.808	15.445	0.432
9	11.678	20.398	0.811	15.383	16.038	8.721	0.576
10	12.505	23.357	0.859	17.038	17.931	10.851	0.551
1×2	13.546	22.780	0.757	17.535	18.163	9.235	0.602
1×3	18.040	26.044	0.473	21.073	22.042	8.004	0.744
1×4	14.791	21.663	0.348	17.481	18.227	6.872	0.808
1×5	14.667	35.545	1.073	22.576	25.106	20.879	0.435
1×6	14.309	27.320	0.900	19.454	20.815	13.011	0.525
1×7	20.561	25.459	0.204	22.378	23.010	4.898	0.884
1×8	17.334	23.921	0.431	20.125	20.627	6.588	0.771
1×9	15.471	33.660	0.997	22.537	24.565	18.189	0.479
1×10	14.847	30.490	0.943	20.673	22.669	15.643	0.510
2×3	10.135	20.035	0.947	14.218	15.085	9.901	0.505
2×4	13.836	20.814	0.636	16.746	17.325	6.979	0.670
2×5	13.418	21.091	0.656	16.729	17.255	7.673	0.652
2×6	10.619	21.944	1.018	14.889	16.281	11.326	0.470
2×7	13.724	20.590	0.653	16.702	17.157	6.865	0.658
2×8	10.419	23.218	1.040	15.480	16.819	12.799	0.456
2×9	9.921	33.034	1.272	17.873	21.478	23.113	0.335
2×10	10.610	23.364	1.044	15.744	16.987	12.755	0.452
3×4	13.457	29.541	1.016	19.841	21.499	16.084	0.469
3×5	12.513	33.998	1.206	20.594	23.255	21.486	0.367
3×6	12.357	30.358	1.098	19.294	21.357	18.001	0.423
3×7	10.129	28.741	1.202	16.942	19.435	18.611	0.371
3×8	12.911	31.185	1.116	20.036	22.048	18.274	0.415

3×9		14.203	41.185	1.086	23.333	27.694	26.982	0.435
3×10		13.237	23.847	0.845	17.727	18.542	10.610	0.557
4×5		13.636	30.617	1.034	20.375	22.127	16.980	0.457
4×6		14.511	28.811	0.907	20.324	21.661	14.300	0.523
4×7		14.236	26.198	0.851	19.206	20.217	11.963	0.551
4×8		12.149	25.261	0.913	17.282	18.705	13.112	0.517
4×9		15.125	45.494	1.226	26.105	30.310	30.369	0.357
4×10		12.420	23.730	0.905	17.115	18.075	11.311	0.525
5×6		11.306	34.246	1.159	18.733	22.776	22.939	0.386
5×7		13.603	25.656	0.897	18.660	19.630	12.053	0.529
5×8		9.358	22.194	1.099	14.378	15.776	12.837	0.422
5×9		10.616	39.287	1.402	20.330	24.951	28.671	0.266
5×10		6.815	24.819	1.399	12.935	15.817	18.004	0.267
6×7		8.122	25.747	1.283	14.315	16.934	17.626	0.324
6×8		14.807	26.516	0.781	19.605	20.662	11.709	0.589
6×9		11.147	30.379	1.166	17.954	20.763	19.232	0.385
6×10		10.654	22.464	1.000	15.382	16.559	11.811	0.477
7×8		10.983	25.752	1.125	16.308	18.368	14.769	0.413
7×9		12.095	26.517	0.983	17.763	19.306	14.422	0.482
7×10		13.912	22.965	0.691	17.511	18.438	9.053	0.637
8×9		9.436	42.154	1.469	19.800	25.795	32.719	0.228
8×10		12.775	30.963	1.042	19.679	21.869	18.188	0.454
9×10		14.652	15.919	0.116	15.195	15.286	1.267	0.943
parents	Grand mean	11.60	21.5	0.849	15.660	16.550	9.901	0.554
	L.S.D 0.05	4.030	5.779	0.471	4.016	3.952	6.071	0.246
Crosses	Grand mean	12.831	27.678	0.942	18.421	20.255	14.847	0.505
	L.S.D 0.05	5.680	12.154	0.612	6.183	6.900	13.021	0.317
Parents &crosses	Grand mean	12.607	26.555	0.925	17.919	19.581	13.948	0.514
	L.S.D 0.05	6.043	13.08	0.647	5.873	7.353	14.111	0.335

Ys=Grain yield under stress, Yp=Grain yield under non-stress, SSI=Stress Susceptibility Index, GMP= Geometric Mean Productivity, MP= mean productivity, TOL=Tolerance Index, YSI= Yield Stability Index.

Combining ability

Variances analysis of general and specific combining ability for the drought tolerance indices (Table 4) reveals significant GCA; for YS; YP; and all other indices. Therefore; all studied indices could be considered heritable. Also, SCA; effect was significant for YP; SSI; M; TOL; and YSI. This means that additive and dominance gene effects were both involved in the expression of these indices. SCA; for YS; and GMP; was not significant, and this is an indication of the importance of additive gene action for these two parameters.

Regarding general combining ability (Table 5) showed that parent 1 had positive and desirable GCA; effects for grain yield under drought (Ys) and for GMP; MP; and YSI; indices while having negative and undesirable GCA; effects for SSI; and TOL. Parent 2 showed desirable and positive GCA; effects only on YSI; and it showed negative values for the rest of the traits. While; Parent 3 had a desirable and positive GCA; effect for Ys, Yp, GMP; and MP; while had negative GCA; for SSI; Parent 5 showed a positive GCA; effect for Yp, SSI; and TOL; indices and a negative for Ys, GMP; and YSI; Parent 6 showed desirable positive GCA; effects for SSI; only and negative for Ys, Yp, GMP; MP and YSI; Parent 8 had a desirable positive GCA; effect for SSI; and TOL; while it had negative effects for Ys, GMP; and YSI; The parent; 9 had the positive desirable GCA; effect for Yp, SSI; GMP; MP and TOL; but had negative effects for Ys; and YSI; Parents with positive GCA; effects, which are desirable, could be used in plant breeding as a source of desired, genes.

Relevant data of SCA; effects presented in (Table 6) revealed that cross 4×9 had positive desirable SCA; effects for the (Ys, Yp and all drought indices except YSI; had a negative effect), followed by crosses (1×5), (1×10), (2×9), (2×10), (3×5), (3×8) and (5×9) which showed positive desirable SCA; effects for Yp, SSI; GMP; MP and TOL; while showed negative effect for YSI. And crosses (3×9) and (8×10) showed positive desirable SCA; effects for Ys, Yp, GMP; MP and TOL; and had negative effects for YSI; Then crosses (1×7), (2×7), (5×7), (6×8) and (7×10) showed desirable SCA; effects for Ys, GMP; MP and YSI; while they had negative SCA; effects for SSI and TOL. Followed by crosses (4×5), (4×6) and (4×7) had positive SCA effects for Ys, Yp, GMP; and MP; and negative, which is undesirable for SSI. Then, crosses (1×9), (5×6) and (8×9) showed positive desirable SCA; for Yp, SSI; GMP; and MP; , Yp, GMP; MP and TOL; and Yp, SSI; MP and TOL; respectively while they showed negative SCA; effects for YSI; they were followed; by crosses (3×6), (3×7) and (6×7) with positive SCA; effects for Yp, SSI; and TOL; and negative for YS; and SSI; Then cross (2×5) had positive effects for Ys, GMP; and YSI; and negative for Yp, SSI; and TOL; Followed by crosses (1×3), (1×8), (2×4) and (9×10) with positive SCA; for Ys and YSI; and negative for YP, SSI; MP and TOL; The cross (5×10) had a positive SCA; effect for SSI; and TOL; and a negative for the rest. Finally, crosses (1×2), (2×3), (2×6), (2×8), (3×4) and

(7×8) showed positive and desirable SCA; effects for SSI; only, and crosses (1×4) had the positive SCA; effect for YSI; only and negative for the rest of indices. Also; some other researchers indicated parental positive desirable and negative undesirable GCA; effects and crosses with positive and negative SCA; effects by using different genotypes for variable drought resistance indices, including these studied indices and yield traits[18-22].

Table 4: Variances analysis of the GCA and SCA of the studied drought tolerance indices - using

Drought tolerance indices Variances	d.f	YS	YP	SSI	GMP	MP	TOL	YSI
$\sigma^2_{G.C.A}$	9	38.60**	237.56**	0.31*	54.27**	81.22**	227.41**	0.08*
$\sigma^2_{S.C.A}$	45	15.26ns	97.26**	0.22*	18.36ns	28.71*	110.18**	0.06*
σ^2_E	108	12.32	56.39	0.14	13.18	18.17	64.72	0.040
$\sigma^2_{G.C.A}$ / $\sigma^2_{S.C.A}$		0.74	0.37	0.16	0.66	0.50	0.30	0.16

* Significant (P = 0.05) /** Significant (P = 0.01) / NS = non-significant Ys= Grain yield under stress, Yp= Grain yield under non-stress, SSI=Stress Susceptibility Index, GMP= Geometric Mean Productivity, MP= mean productivity, TOL=Tolerance Index, YSI= Yield Stability Index.

Table 5: GCA effects of 10 parents for drought tolerance indices in 10 × 10 half diallel cross of Durum wheat.

Parents	YS	YP	SSI	GMP	MP	TOL	YSI
1	2.495	0.667	-0.171	1.920	1.581	-1.827	0.088
2	-0.971	-4.479	-0.088	-2.165	-2.725	-3.508	0.046
3	0.928	1.534	-0.011	1.218	1.231	0.606	0.007
4	0.275	0.132	-0.011	0.346	0.204	-0.144	0.005
5	-0.857	1.351	0.121	-0.126	0.247	2.208	-0.064
6	-0.576	-0.099	0.068	-0.425	-0.337	0.477	-0.036
7	-0.232	-2.575	-0.050	-1.034	-1.403	-2.343	0.026
8	-0.528	1.010	0.084	-0.024	0.241	1.538	-0.044
9	-0.222	4.693	0.097	1.212	2.236	4.915	-0.050
10	-0.312	-2.236	-0.040	-0.922	-1.274	-1.923	0.022
S.E($\hat{gi}$)	0.580	1.240	0.062	0.600	0.704	1.329	0.032

Ys= Grain yield under stress, Yp= Grain yield under non-stress, SSI= Stress Susceptibility Index, GMP= Geometric Mean Productivity, MP= mean productivity, TOL=Tolerance Index, YSI= Yield Stability Index.

Table 6: SCA effects of F1 generation for drought tolerance indices in10 × 10 half diallel cross of Durum wheat.

indices crosses	YS	YP	SSI	GMP	MP	TOL	YSI
1×2	-0.585	0.037	0.090	-0.139	-0.274	0.623	-0.046
1×3	2.010	-2.712	-0.271	0.016	-0.351	-4.722	0.136
1×4	-0.586	-5.691	-0.396	-2.704	-3.138	-5.105	0.202
1×5	0.422	6.972	0.197	2.864	3.697	6.550	-0.102
1×6	-0.217	0.197	0.077	0.040	-0.010	0.414	-0.040
1×7	5.690	0.811	-0.501	3.573	3.251	-4.879	0.257
1×8	2.760	-4.311	-0.408	0.311	-0.776	-7.071	0.214
1×9	0.591	1.744	0.145	1.486	1.168	1.154	-0.073
1×10	0.058	5.504	0.228	1.757	2.781	5.446	-0.114
2×3	-2.430	-3.575	0.120	-2.754	-3.002	-1.145	-0.062
2×4	1.924	-1.393	-0.190	0.646	0.265	-3.317	0.105
2×5	2.639	-2.336	-0.303	1.101	0.152	-4.975	0.156
2×6	-0.442	-0.033	0.112	-0.439	-0.237	0.409	-0.054
2×7	2.320	1.088	-0.134	1.982	1.704	-1.231	0.072
2×8	-0.689	0.132	0.118	-0.249	-0.278	0.821	-0.060
2×9	-1.493	6.265	0.337	0.907	2.386	7.758	-0.176
2×10	-0.714	3.524	0.246	0.912	1.405	4.238	-0.131

3×4	-0.354	1.320	0.113	0.358	0.483	1.674	-0.056
3×5	-0.166	4.558	0.171	1.583	2.196	4.724	-0.090
3×6	-0.603	2.367	0.116	0.582	0.882	2.970	-0.061
3×7	-3.175	3.226	0.338	-1.161	0.026	6.401	-0.176
3×8	-0.097	2.086	0.117	0.924	0.994	2.182	-0.062
3×9	0.889	8.402	0.075	2.983	4.646	7.513	-0.036
3×10	0.013	-2.006	-0.030	-0.488	-0.996	-2.020	0.014
4×5	1.611	2.579	-0.001	2.236	2.095	0.968	0.002
4×6	2.204	2.223	-0.075	2.484	2.213	0.019	0.041
4×7	1.585	2.086	-0.013	1.975	1.835	0.501	0.006
4×8	-0.206	-2.436	-0.086	-0.958	-1.321	-2.230	0.042
4×9	2.464	14.114	0.215	6.627	8.289	11.650	-0.113
4×10	-0.151	-0.721	0.030	-0.228	-0.436	-0.570	-0.016
5×6	0.132	6.438	0.045	1.366	3.285	6.306	-0.027
5×7	2.085	0.325	-0.099	1.902	1.205	-1.760	0.053
5×8	-1.864	-6.722	-0.032	-3.390	-4.293	-4.858	0.016
5×9	-0.913	6.687	0.259	1.325	2.887	7.600	-0.135
5×10	-4.622	-0.851	0.392	-3.935	-2.737	3.771	-0.206
6×7	-3.678	1.866	0.340	-2.144	-0.906	5.544	-0.179
6×8	3.304	-0.950	-0.296	2.136	1.177	-4.254	0.155
6×9	-0.663	-0.771	0.076	-0.752	-0.717	-0.108	-0.043
6×10	-1.065	-1.756	0.046	-1.189	-1.411	-0.691	-0.023
7×8	-0.865	0.762	0.165	-0.553	-0.052	1.626	-0.083
7×9	-0.059	-2.157	0.011	-0.334	-1.108	-2.098	-0.009
7×10	1.849	1.220	-0.144	1.549	1.534	-0.629	0.075
8×9	-2.422	9.896	0.363	0.693	3.737	12.318	-0.193
8×10	1.008	5.634	0.072	2.707	3.321	4.625	-0.039
9×10	2.579	-13.093	-0.866	-3.014	-5.257	-15.672	0.456
$S.E.(\hat{S}_{ij})$	0.748	1.601	0.081	0.774	0.909	1.715	0.042

Ys= Grain yield under stress, Yp= Grain yield under non-stress, SSI= Stress Susceptibility Index, GMP= Geometric Mean Productivity, MP= mean productivity, TOL= Tolerance Index, YSI= Yield Stability Index.

Gene action:

Jinks – Hayman Analysis of Estimating Genetic Variance

The result of the estimation of genetic constants (Table 7) revealed that there is no significant additive genetic component ($\hat{D}$) for any of the studied drought indices, the value of component (*F*) was positive but not significant for any of the traits and indices which indicate the frequency of the dominant alleles are more than that of recessive alleles. It means the distribution of recessive and dominant gene allele frequencies in the parents was unequal. Values of dominance genetic variance (H_1 and H_2) differed for all studied traits. It is also noted that the values of H_1 were higher than H_2 for all traits, and when considering the values of each of the additive and dominant variances *D* and H_2 as in the results, it noted that the variance of dominance (H_1 and H_2) was higher in value than the variance of additive (*D*) and for all studied traits. Therefore; the importance of dominant genetic variation could be indicated more than additive variation in the inheritance of these indices. The ratio of genetic parameters and heritability (Table 8) showed that the average degree of dominance ($\sqrt{H_1/D}$) was greater than one for Ys and Yp, and All drought indices and ranged from 3.87 for Ys to 13.87 for Yp suggests that these traits are controlled by over-dominant genes and a large range of heterosis breeding in durum wheat. The; dominant and recessive alleles (*H2/4H1*) in gene locations showed that dominance was not distributed regularly among parents, as evidenced by the fact that the value of this ratio was less than 0.25 as it ranged from 0.197 for both SSI; and YSI; to 0.213 for Ys. The; ratio of dominant/ recessive genes number (*KD/KR*) was more than the integer one for Ys, SSI; GMP; and YSI; has ranged from 1.09 GMP to 1.62 for YSI; as indicating an increase in the dominant genes in parents for these traits, At the same time it was less than integer one for Yp, MP and TOL; with ranges from 0.54 for YP; to 0.90 for MP; This confirms the increase of recessive genes in parents for other traits. Narrow sense heritability $H_{n.s.}$ was moderate for all studied traits, with range between 0.268 for Ys to 0.339 for Yp. This, result indicates that selection to improve these traits will be effective. This are corresponds with what some researchers such as[18,21and 22] have found for different drought indices.

Comparing the degree of dominance for parents with their mean values (Table 9) indicates to matching some parents in terms of this comparison, such as parent 1 for Ys and SSI; parent 6 in Ys, and parent 10 in SSI; and it means the possibility of benefiting from these parents as a genetic source in improving these traits, as for the rest of traits and the parents, the sequence of the degree of parental dominance was different from the sequence of its means in these traits, and it means that there are other influences that had an impact on the difference in values of the parents. However; this does not diminish the importance of indicating some distinct parents, whether the sequence of their degree of dominance or in the sequence of their mean in the studied traits. For example: parent 9 came first in terms of the degree of dominance in Yp, GMP; MP and TOL; while parent 3 was the first in the consequence parents according to their mean values in Ys, GMP; MP and YSI; and this is a great indicator for the possibility of benefiting from these parents and recommending their inclusion in breeding programs by crossbreeding in the future, or even recommending the possibility of adopting new variety parents as found by other researchers[18, 19, 21.22].

Table 7: Genetic parameters for drought tolerance indices.

Statistical constants	YS	YP	SSI	GMP	MP	TOL	YSI
D ± S.E	3.11 ± 1145.42	1.22 ± 15170.30	0.03 ± 16.82	0.11 ± 71.67	2.39 ± 3843.20	5.79 ± 14172.43	0.01 ± 4.43
F ± S.E	2.730 ± 6.813	10.068 ± 90.234	0.065 ± 0.100	0.040 ± 0.426	1.276 ± 22.860	9.573 ± 84.299	0.018 ± 0.026
H1 ± S.E	46.633 ± 6.142	233.619 ± 81.349	0.603 ± 0.090	1.710 ± 0.384	72.493 ± 20.609	270.527 ± 75.998	0.164 ± 0.024
H2 ± S.E	39.724 ± 5.163	192.901 ± 68.386	0.477 ± 0.076	1.442 ± 0.323	61.317 ± 17.325	219.981 ± 63.888	0.130 ± 0.020

Ys= Grain yield under stress, Yp= Grain yield under non-stress, SSI= Stress Susceptibility Index, GMP= Geometric Mean Productivity, MP= mean productivity, TOL= Tolerance Index, YSI= Yield Stability Index,
D = variation attributed to additive genetics effects, *F*= relative frequency of dominant to recessive alleles in the parental populations and the variation level over loci, *H1*= variation due to dominance genetics effects, *H2*= variation due to dominance genetics effects corrected for gene distribution.

Table 8: Genetic parameters ratio and narrow sense heritability for drought tolerance indices.

Ratio genetic parameters	YS	YP	SSI	GMP	MP	TOL	YSI
$\sqrt{H1/D}$	3.872	13.861	4.357	3.893	5.503	6.838	4.266
$H2/4H1 = \bar{p}\bar{q}$	0.213	0.206	0.197	0.210	0.211	0.203	0.197
KD /KR	1.256	0.540	1.613	1.096	0.908	0.784	1.626
Heritability $h^2_{(n.s)}$	0.268	0.339	0.280	0.320	0.326	0.330	0.278

Ys= Grain yield under stress, Yp= Grain yield under non-stress, SSI= Stress Susceptibility Index, GMP= Geometric Mean Productivity, MP= Mean productivity, TOL= Tolerance Index, YSI= Yield Stability Index,
$\sqrt{H_1/D}$= Average degree of dominance, $H2/4H1 = \bar{p}\bar{q}$ = Frequency product at loci exhibited dominance,
KD /KR= The ratio of the total number of dominant to recessive genes in all parents, $h^2_{(ns)}$= narrow sense heritability.

Table 9: Parents' order according to average and degree of dominance for studied drought indices.

drought tolerance indices	Parent sequences according to the degree of dominance (dominance ——>>——>>—— recessive)										Parent sequences according to their averages (high ——>> ——>>—— low)									
YS	7	1	3	6	9	8	10	5	4	2	3	1	10	6	9	5	8	2	7	4
YP	9	3	4	8	1	10	5	2	6	7	1	8	10	3	6	5	9	4	7	2
SSI	1	7	9	10	3	4	2	8	5	6	4	1	8	10	5	7	6	9	3	2
GMP	9	4	3	5	8	10	7	1	6	2	3	1	8	10	6	9	5	4	2	7
MP	9	4	3	8	5	10	7	1	6	2	3	1	8	10	6	9	5	4	2	7
TOL	9	3	8	1	5	4	10	6	2	7	8	1	4	10	6	5	9	7	3	2
YSI	1	9	7	10	4	3	2	8	5	6	3	2	9	7	6	5	10	1	8	4

Ys= Grain yield under stress, Yp= Grain yield under non-stress, SSI= Stress Susceptibility Index, GMP= Geometric Mean Productivity, MP= mean productivity, TOL= Tolerance Index and YSI= Yield Stability.

Conclusions

To derive new cultivars of wheat that adapt to a wide range of environments, breeders need to calculate drought tolerant indices and study their genetic properties from the yield of the grain under rain-fed conditions for crosses and their parents. In the present study of using half diallel crossing method for the number of parents of durum wheat, crosses 1×7 and 1×8 showed considerable value in yield under rain fed along with desirable values for tolerance indices. combining ability analysis by Griffing 1956 method was significant for all studied indices except SCA; for yield under stress Ys and GMP. Analysis of gene action and heritability by the Jinks and Hayman method showed that the dominant genetic effect had a larger role in the inheritance of all drought indices. Possibility; of using parents 1 and 3 of high and significant values of GCA; effect for the studied indices in the crossing program to improve grain yield productivity under rain-fed conditions and possibility of using some obtained crosses to derive new genortpes with high adaptability to water stress conditions. Narrow sense heritability was moderate for Ys and all drought tolerant indices thus, selection will be effective in the next generations to improve new genotypes for rain-fed areas.

Conflict of interests

No conflict

Author’s contribution

This paper is a part of PhD dissertation of the first author.

The first author conducted the experiment and data collection with analysis, while the second and third authors supervised the experiment in all field works, data analysis and reviewing the research paper.

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