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Combining ability of some sunflower parental lines in both normal and drought stress conditions

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Abstract: General and specific combining abilities of three cytoplasmic male sterile and four restorer lines of sunflower were studied in a randomized complete block design with three replications under normal irrigation and drought stress conditions in Eslamabad-e-Gharb, Iran during two growing season (2019 and 2020). Drought stress reduced seed yield, oil yield, thousand seeds weight and head diameter by 21.9%, 18.1%, 14.3% and 11.5%, respectively. Line × tester analysis indicated that the effect of lines was significant for the number of days to flowering, plant height, grain yield and seed oil percentage under both normal and drought stress conditions. The effect of lines was significant for number of days to maturity and number of seeds per head under normal condition and for thousand seeds weight under drought stress condition. Contribution of lines × testers were higher than the variances of lines or testers for of most of all the studied traits indicating the major role of non-additive effects on expression of theses traits. R131 was differentiated with the highest positive general combining ability for grain and oil yield in both normal and drought stress conditions. Among the testers, AGK32 and AF81-222 had the highest general combining ability for grain yield under normal and stressed conditions, respectively. R131×AGK38, with grain yields of 4414 and 3457 kg ha^{-1} under normal and drought stress conditions respectively, had the highest specific combining ability for grain and oil yield under both conditions. The results of this study showed that the genetic materials and

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environmental conditions can affect the nature of gene effect and combining ability of sunflower parent lines and crosses.

Keywords: additive effect; dominance effect; general combining ability; inheritance; limited irrigation.

Introduction

Sunflower is one of the most important oil seeds, that in terms of production, it ranks fourth in the world after oil palms, soybeans and canola. Sunflower seeds contain 40–50% oil (Naeem et al. 2019). In recent years, the importance of producing sunflower hybrids, in compared with open pollinated cultivars has increased in many important sunflower producing countries, due to higher yield, uniformity and resistance to pests and diseases (Karasu et al. 2010).

The production of high-yielding hybrids of sunflower has played an important role in accepting this crop as a major oilseed in the world (Lakshman 2020). Sunflower hybrid breeding programs was begun with the discovery of the cytoplasmic male sterile system by Leclercq (1986) and fertility restorer genes by Kinman (1970). The heterosis of a hybrid depends on the combining ability of its parents (Kadkol et al. 1984).

Kaya and Atakisi (2014) reported that top hybrids are obtained from the crossing of lines with high general and specific combining ability. High heterosis for sunflower has been reported in many studies (Goksoy et al. 2004; Kaya and Atakisi 2014; Khan et al. 2008; Rezaeizad and Siahbidi 2015). However, in the F1 generation the superiority of heterosis is not appearance in all hybrid combinations, so breeding hybrids is difficult and time consuming (Hladni et al. 2007).

Choosing the appropriate parents is one of the requirements for producing suitable sunflower hybrids, which is possible by evaluating the general and specific combining ability of these parents. Also, determining the type of action of genes controlling for important agronomic traits related to seed yield can play a significant role in hybrid production. Drought stress is one of the largest challenges to crop production in the twenty-first century, and sunflower is no exception from this challenge (Salehi-Lisar and Bakhshayeshan-Agdam 2016).

Sunflower is one of the crops which, despite its higher water requirement, has a wide range of climatic adaptation and is better able to drought tolerate than other crops. sunflower has a relative tolerance to drought stress, but under severe drought stress, its grain yield is significantly reduced (Hussain et al. 2018). Finding suitable parents to produce hybrid cultivars in sunflower under normal and drought stress conditions is of great importance. In order to identify suitable parents, a population of inbred lines with high general combining ability must be improved and then, it identified inbred lines with high specific combining ability for important agronomic traits under both normal and drought stress conditions (Rezaeizad and Siahbidi 2015). Determination of combining ability and type of genetic effects of traits affecting drought tolerance is usually done using genetic designs such as line × tester or other genetic designs (Arefi et al. 2015). According to drought and diminished ground water resources, it is necessary to consider drought stress conditions in breeding programs and determine the inbred composition of inbred lines obtained from breeding programs and genetic control of traits should be studied in such conditions, to identify genetic materials that can be more drought tolerant (Rezaeizad and Siahbidi 2015). There is a little information about combining ability of sunflower inbred lines under drought stress conditions (Ghaffari and Shariati 2018). Darvishzadeh et al. (2014) showed that under drought stress and normal conditions, most agronomic traits such as head diameter, number of grains per head, head weight and grain yield have a different hereditary and in drought stress condition, non-additive effects have a major role for controlling these traits. Tyagi et al. (2018) also studied the number of 60 sunflower hybrids obtained from the crossing of 15 cytoplasmic male sterile lines with four fertility restorer lines under both normal irrigation and drought stress conditions. The results showed that the share of male sterile cytoplasmic lines in the expression of agronomic traits were higher than the fertility restorer lines. In the present study, it has been tried a combination of sunflower parental lines under normal conditions and drought stress was investigated in this way, the results obtained can be used to produce drought tolerant hybrids.

Materials and methods

In order to evaluate the general and specific combining ability of some male sterile inbred lines and fertility restorer lines, the number of 12 sunflower hybrids obtained from three cytoplasmic male sterile lines (AF81-222, AGK32, AGK38) and four fertility restorer lines (RF81-112, R131, RGK33, RGK15), were studied in a randomized complete block design with three replications under normal irrigation and drought stress conditions during two years (2019 and 2020) in agricultural research station of Eslamabad-e-Gharb. Water limitation was imposed by water withholding in R1–R6 (as defined by Schneiter and Miller 1981) growth stages. Each plot consisted of three rows of four m length with 60 and 25 cm spacing between and within rows respectively. Agronomic characteristics including days to physiological maturity, plant height and head diameter were recorded during the growing season. Harvesting was done from two rows in the middle of each plot by excluding margins. Grain yield and thousand seeds weight were measured after harvesting. The percentage of seed oil were measured using NIR model DA7200 from Partan Sweden. Data of recorded traits were subjected to the line × tester analysis (Singh and Chaudhary 1977) followed that, genetic components including additive and non-additive genetic components, dominance, heritability values and combining abilities were estimated using the following relations.

General Combining ability of restorers (Line): $\mathrm{GCA}_{i0} = X_{i0} - \overline{X}_{00}$

General combining ability of male sterile lines (tester): $\mathrm{GCA}_{0j} = X_{0j} - \overline{X}_{00}$

Specific Combining ability: $\mathrm{SCA}_{ij} = X_{ij} - \mathrm{GCA}_{i0} - \mathrm{GCA}_{0j} - \overline{X}_{00}$

In the above equations, X_{i0}, $\overline{X}_{00}$, X_{0j}, X_{ij}, GCA_{i0} and GCA_{0j} it is equivalent to the mean of restorer lines, total average, mean of male sterile line, hybrid mean, general combining ability of restorer lines and general combining ability of male sterile lines, respectively.

The following equations were used to calculate the values of standard error (SE) in order to significant test of the effects of general and specific combining ability:

Standard error of combining ability of male sterile lines (tester): $\mathrm{SE}_{\mathrm{gca}}(\mathrm{CMS}) = \sqrt{\frac{f-1 \times \mathrm{MSe}}{f \times m \times r}}$

Standard error of combining ability of fertility restorer lines (Line): $\mathrm{SE}_{\mathrm{gca}}(\mathrm{restorer}) = \sqrt{\frac{m-1 \times \mathrm{MSe}}{f \times m \times r}}$

Standard error of specific combining ability: $\mathrm{SE}_{\mathrm{sca}} = \sqrt{\frac{(m-1) \times (f-1) \times \mathrm{MSe}}{f \times m \times r}}$

In the above equations, f and m are the number of male sterile lines (tester) and fertility restorer lines (line), respectively. Statistical analysis was performed using SAS software (Ver 9.1).

It should be noticed that all materials and methods that were applied or used in this study are legal and are in accordance with the national and international laws and policies.

Results and discussion

The results of combined variance analysis of the data in both normal and drought stress conditions showed that the hybrids were significantly different for seed yield, oil percentage and oil yield under both normal and drought stress conditions, but for traits, number of days to maturity, plant height and number of seeds per head were significantly different only under normal conditions (Table 1). The mean comparison of data showed that in both normal and drought stress conditions, AGK38 × R131 and AF81-22 × RF81-112 had the highest seed and oil yield, respectively. The variance of public and private combinability is not calculated (Tables 2 and 3).

Seed yields of AGK38 × R131 were 4415 and 3458 and AF81-22 × RF81-112 were 4358 and 3385 kg ha^{-1}, under normal and stressed conditions respectively. These results indicated that these two hybrids can a good function in normal and drought stress conditions. The results showed that the most variation (reduction) due to drought stress with 21.9, 18.1, 14.3 and 11.5% were related to seed yield, oil yield, thousand seed weight, and head diameter, respectively. The line × tester analysis was performed for the traits that the effect of hybrids was significant. The variance analysis of line × tester showed that the effect of line in normal and drought stress conditions were significant for the number of days to flowering, plant height, seed yield, seed oil percentage. The effect of line for number of days to maturity and number of seeds per head only under normal conditions and for thousand seed

Table 1: Combined variance analysis of line × tester of Sunflower hybrid under normal and drought stress conditions.

S. O. V.	*df*	Flowering period		Maturity		Plant height		HEAD diameter		Seed weight	
		Normal	Stress	Normal	Stress	Normal	Stress	Normal	Stress	Normal	Stress
Year	1	369**	288**	9.4	747**	7180[a]	27,261**	45.3[a]	23.2**	783[a]	2.8
Replication/year	4	5.4	0.8	1.4	4	964	135.6	3.4	1	46	50.7
Hybrid	11	6.8**	106**	8.4[a]	1.3	281**	317.9	0.95	1.4	53	54.1
Year × hybrid	11	5.6**	6.4**	9[a]	3.5	286	681.6**	1.5	1.9	164	127.3**
Line	3	3.4**	11**	12.1**	1.87	186.4[a]	569.1[a]	0.84	2.1	97.8	123.9[a]
Tester	2	17.8**	12.5**	0.04	0.39	279.5[a]	149.6	0.38	1.1	55.8	12.6
Line × tester	6	4.9**	9.8**	9.4**	1.3	328.5**	248.4	1.2	1.1	30	33
Line × year	3	2.4[a]	2.5	15.6**	3.1	81.8	418	0.31	1.4	246.4[a]	241.5**
Tester × year	2	6.7**	11.4**	1.4	0.7	382.6	1,689**	0.48	0.6	103.3	27.4
Line × tester × year	6	6.9**	6.6	8.2**	4.6	356.3**	477[a]	2.4[a]	2.6	142.6	103.5[a]
Error	71	0.58	0.68	1.9	1.4	56.1	171.5	0.88	1.3	71	39.1
σ^2GCA		0.14	0.04	−0.09	−5.45	−1.69	–	–	–	–	–
σ^2SCA		0.72	1.52	1.25	–	46.25	–	–	–	–	–
σ^2GCA/σ^2SCA		0.19	0.03	−0.07	–	−0.04	–	–	–	–	–
Relative contribution of lines		13.64	2.83	39.29	39.23	18.09	48.82	24.11	40.91	50.33	62.46
Relative contribution of testers		47.59	2.14	0.09	5.45	18.08	8.56	7.27	14.29	19.14	4.23
Relative contribution of line × tester		39.3	5.04	61.04	54.55	63.77	42.62	68.9	42.86	30.87	33.27

S. O. V.	*df*	Seed number		Grain yield		Oil percentage		Oil yield	
		Normal	Stress	Normal	Stress	Normal	Stress	Normal	Stress
Year	1	1,613,407[a]	3E+06**	9,894	732,252	336.3**	1334**	484,292[a]	485,605**
Replication/year	4	63,206	11,862	415,331	276,346	4.4	1.03	65,258	46,291
Hybrid	11	109,839**	47,745	1,585,508**	467,616**	14.7[a]	8.4**	297,590**	81,430**
Year × hybrid	11	174,297**	42,650	1,967,549**	632,122**	21.2	8.3**	412,454**	138,339**

Table 1: (continued)

S. O. V.	*df*	Seed number		Grain yield		Oil percentage		Oil yield	
		Normal	Stress	Normal	Stress	Normal	Stress	Normal	Stress
Line	3	177,620**	96,141	2,288,999**	802,823**	16.7**	7.8[a]	310,577[a]	109,521**
Tester	2	124,974[a]	2,564	230,343	693,829**	13.1**	14.3[a]	74,122	65,925
Line × tester	6	70,902	38,608	1,685,484**	224,608	14.2**	6.7[a]	365,586**	72,553[a]
Line × year	3	382,500**	35,613	3,580,443**	353,474[a]	30.8**	4.9	609,418**	82,196[a]
Tester × year	2	124,869[a]	52,744	410,434	691,994**	19	22.9**	55,642	137,519**
Line × tester × year	6	86,671[a]	42,803	1,680,140**	751,489**	17	5.1	432,909**	166,684**
Error	71	33,382	48,049	507,859	114,008	2.1	2.8	87,362	23,070
σ^2GCA		–	–	−12,378	–	0.01	0.1	−3860.4	211.97
σ^2SCA		–	–	196,271	–	2.017	0.65	46,371	8247.2
σ^2GCA/σ^2SCA		–	–	−0.06	–	–	0.15	−0.08	0.03
Line portion percentage		44.1	54.92	39.37	46.82	30.98	25.32	28.46	36.68
Tester portion percentage		20.69	0.98	2.64	26.98	16.2	30.95	4.53	14.72
Line × tester portion percentage		35.21	44.11	57.98	26.2	52.69	43.51	67.01	48.6

[a]For traits where the effect of line × tester is not significant. **Significant at 0.01% probability.

Table 2: General compatibility of lines and testers and private compatibility of sunflower hybrids under normal conditions.

Line	Flowering period	Maturity	Height	Head diameter	Seed weight	Seed number	Grain yield	Oil percentage	Oil yield
R131	0.1**	0.9**	2.28	0.05	2.35	41.5	350.75**	−1.45**	112*
RGK33	−0.6**	−1**	3.28**	0.15	1.05	−68.5*	−407.25**	0.25	−163**
RGK15	0.4**	−0.2	−2.72*	−0.45**	−0.35	120.5**	241.75*	0.45	101*
RF81-112	0.1	0.3	−2.82*	0.25	−3.05*	−93.5**	−185.25	0.75**	−50
SE_i	0.13	0.23	1.19	0.16	1.4	30.45	118.77	0.24	49.26
Tester									
AF81-222	−0.8**	−0.07	−2.7*	0.03	0.67	−81*	−13.67	−0.73*	−36.33
AGK32	0.9**	0.03	3.8**	0.13	−1.73	58	104.33	0.77**	63.67
AGK38	−0.1	0.03	−1.1	−0.17	1.07	23	−90.67	−0.03	−27.33
SE_j	0.16	0.28	1.46	0.19	1.72	37.29	145.47	0.3	60.33
Line × tester									
R131*AF81-222	0.41*	0.83*	−8.53**	−0.32	3.62	−96.36	−192.39	−0.54	−117.68
R131*AGK32	−0.62**	−1.43**	−0.7	−0.7**	−1.65	18.64	−361.56	−1.62**	−198.68*
R131*AGK38	0.38	0.73*	9.2**	0.28	−1.88	76.97	554.11**	2.28**	315.82**
RGK33*AF81-222	0.28	−0.1	−1.37	−0.67*	−0.43	−4.86	192.11	−0.49	70.82
RGK33*AGK32	0.24	0.3	6.63**	0.15	−0.32	−80.86	−178.39	1.18**	−34.51
RGK33*AGK38	−0.59**	−0.2	−5.3**	−0.22	0.8	87.47	−12.06	−0.71	−36.01
RGK15*AF81-222	−1.39**	0.1	4.3*	1.22**	−0.98	76.31	529.61**	0.26	236.15**
RGK15*AGK32	0.91**	−0.67	−0.2	0.57*	0.03	86.47**	50.11	−0.42	−4.85
RGK15*AGK38	0.41*	0.5	−3.97*	0.48	0.87	−163.03**	−579.56**	0.16	−231.01**
RF81-112*AF81-222	0.74**	−0.73	5.57**	−0.28	−2.12	25.64	−530.89**	0.76	−190.51*
RF81-112*AGK32	−0.46*	1.83**	−5.6**	−0.08	1.88	−24.36	489.44*	0.78	239.15**
RF81-112*AGK38	−0.29	−1.17**	−0.03	−0.42	0.2	−2.03	39.44	−1.61**	−48.68
SE_{ij}	0.22	0.4	2.06	0.27	2.43	52.74	205.72	0.42	85.32

*and ** are significant at 0.05 and 0.01% probability, respectively.

Table 3: General and specific combining ability of lines, testers and the hybrids under drought stress condition.

Line	Flowering period	Maturity	Height	Head diameter	Seed weight	Seed number	Grain yield	Oil percentage	Oil yield
R131	0.25*	0.45*	4.53*	0.33	2.38*	−8.8	234.75**	−0.75**	83.25**
RGK33	−1.15**	−0.25	3.72	−0.17	1.98*	−71.3*	−131.25*	−0.15	−62.75**
RGK15	0.75**	−0.15	−7.78**	0.23	−1.23	101.9**	115.75*	0.05	49.25**
RF81-112	0.15	−0.05	−0.47	−0.38*	−3.13**	−21.8	−219.25**	0.85**	−69.75**
SE_i	0.14	0.2	2.18	0.19	1.04	36.53	56.28	0.28	25.31
Tester									
AF81-222	−0.37*	−0.13	−2.8	−0.2	−0.5	−1.33	148.67*	0.43	39
AGK32	0.83**	−0.03	0.9	0	−0.3	−9.33	36.67	0.43	21
AGK38	−0.47**	0.17	1.9	0.2	0.8	10.67	−185.33**	−0.87*	−60*
SE_j	0.17	0.24	2.67	0.23	1.28	44.74	68.92	0.34	31
Line × tester									
R131* AF81-222	0.46	0.32	0.79	−0.03	0.19	−47.85	−199.44*	−1.76**	−107.43
R131*AGK32	−1.04**	−0.28	−2.41	−0.53	−0.81	−28.05	−285.34**	−0.06	−104.93
R131*AGK38	0.56*	0.02	1.59	0.57	0.59	75.95	484.86**	1.84**	212.78**
RGK33*AF81-222	0.16	0.22	0.79	−0.03	−0.01	−2.55	2.16	−2.36**	−12.43**
RGK33*AGK32	0.46	0.12	2.19	0.17	0.39	−31.35	−205.34*	−0.06	−95.52*
RGK33*AGK38	−0.54*	−0.28	−2.91	−0.03	−0.51	33.85	204.66*	2.54**	107.58*
RGK15*AF81-222	−1.74**	−0.58	−8.11*	−0.13	2.69	−46.05	197.56*	0.04	127.78**
RGK15*AGK32	1.56**	0.02	7.69*	0.48	−2.81	36.15	−337.14**	−0.46	−138.23**
RGK15*AGK38	0.06	0.62	0.39	−0.42	0.29	9.95	139.16	0.24	11.08
RF81-112*AF81-222	1.06**	0.12	6.49	0.17	−2.81	97.35	−0.94	−1.16*	−8.52
RF81-112*AGK32	−0.94**	0.22	−7.61*	−0.13	2.99	21.65	−60.84	0.44	16.28
RF81-112*AGK38	−0.04	−0.48	1.09	−0.13	−0.21	−119.05	60.66	0.74	−8.42
SE_{ij}	0.24	0.34	3.78	0.33	1.81	63.28	97.47	0.48	43.85

*and ** are significant at 0.05 and 0.01% probability, respectively.

weight only under drought stress conditions were significant. The effects of testers were significant for the number of days to flowering and seed oil percentage under normal and drought stress conditions. The effect of the tester for plant height and number of seeds per head only under normal conditions and for seed yield only under drought stress conditions were significant. The line × tester effect was significant for the number of days to flowering, seed oil percentage and oil yield under normal and drought stress conditions.

This effect only under normal conditions was significant for number of days to maturity, plant height and seed yield. The significance of the line × tester mean squares showed that for these traits the lines reaction with different testers were different and indicated the role of the dominance and non-additive effect of gene in controlling the mentioned traits and indicated the specific combining ability between the crosses. In the study of Zohdi Aghdam et al. (2019), the average degree of dominance for most of the traits ranged from incomplete dominance to over-dominance, suggesting the existence of non-additive gene action for these agronomic traits in sunflower. Therefore, it seems that both additive and non-additive effects of gene were involved in the control of these traits, however, the contribution of these effects in the control of traits can be different. As it is clear from the results of variance analysis, the effect of line, tester and line × tester was different for some traits under normal conditions and drought stress. These results showing that the effect of drought stress on the studied traits is different affecting the way of traits inheritance.

Darvishzadeh et al. (2014) showed that most agronomic traits such as head diameter, number of seeds per head, head weight and seed yield have different heredity under drought stress and normal conditions and non-additives effects have more role in controlling these traits under drought stress condition. For the number of days to maturity, the results of variance analysis of line × tester showed that in normal and drought stress conditions, the portion of line × tester in explaining the sum of squares of hybrids was more than the portions of lines and testers, so that this portion in normal and drought stress conditions were 61 and 54%, respectively. For the number of days to maturity, the results showed that the ratio of variance of σ^2GCA/σ^2SCA was less than one (Table 1) and therefore the role of non-additive effects in controlling the number of days to maturity was more than the additive effects. In the study of Khan et al. (2009) the variance of specific combining ability for the number of days to maturity was higher than general combining ability and non-additive effects played a greater role in controlling this trait. In this case, in the study Esfahlani et al. (2018), the above ratio in both normal and drought stress conditions were about one, which indicates the control of this trait by both additive and non-additive effect. Ghaffari and Shariati (2018) reported Significant heterosis for early maturity in sunflower.

Considering that the early maturity of the studied hybrids is one of the breeding goals in the production of sunflower hybrids, as a result, the negative combining ability is desirable for this trait. Heterosis in the negative direction is desired with respect to days to flowering, since it is closely related with days to maturity even though there is a genetic difference from flowering to maturity (Hilli and Shobha 2021). AGK32 × R131 had the highest negative specific combining ability in normal condition for the number of days to maturity. RGK33 had the highest negative combining ability for this trait, and for the male sterile lines, the AF81-222 had more negative combining ability for the number of days to maturity than the other two lines. Neither of these two lines had a share in the AGK32 × R131 hybrid, on the other hand, the hybrid parents each had a positive combination for the number of days to maturity. Therefore, in the present study predict the status of the number days to maturity of sunflower hybrids it was not possible based on the status of their parents. When the parents of superior hybrids (favorable direction for the trait) have combining ability in the unfavorable direction of the trait, it can indicate over dominant and epistatic effects (Chandra et al. 2011). For plant height, the effect of line, tester and line × tester was significant only under normal conditions. The contribution of the three components in explaining the variance of the sum of squares were 39.2, 5.45 and 61.4%, respectively. These results indicated that the portion of specific combining ability for plant height was higher than general combinability. The ratio of σ^2GCA/σ^2SCA was less than one and therefore the portion of non-additive effects in controlling sunflower plant height was greater than the additive effects. In according with these results, in the study of Machikowa et al. (2011) the variance of specific combining ability for plant height was higher than the variance of general combining ability. However, in the study of Rezaeizad and Siahbidi (2015), were mentioned that additive effects as the main effects for controlling the plant height of the sunflower. Hladni et al. (2018) reported significant general combining ability for plant height, 1000-seeds weight and seed number per head. A negative and significant combining ability for plant height is a desirable breeding trait. The experimental materials used can affect the type of gene effect controlling traits and therefore different gene effects for a trait have been reported in different studies. Regarding that dwarfing and increasing of plant density are considered in the production of new sunflower hybrids, as a result the negative combining ability for this trait is desirable. The results indicated that the lines of RF-81-112 and RGK15 and the tester of AF81-222 had the highest negative combining ability for this trait. AF81-222 × R131 with 167 cm had the lowest plant height and the highest negative combining ability for this trait. For hybrid AF81-222 × R131, one of parent had a negative combining ability and the other had positive combining ability for plant height. If the parental combining ability of the studied hybrids is high combining ability × low combining ability, it indicates additive × dominance effects (Chandra et al. 2011). Naeem et al. (2019) reported that the interaction between positive alleles (favorable) from one parent and negative alleles (unfavorable) from another parent could cause heterosis in the next generation. For thousand seed weight as one of the important components of sunflower seed yield, only the effect of line under stress conditions was significant. The results showed that additive effects of gene have a major role in controlling this trait. In the studies of Rezaeizad and Siahbidi (2015) were reported that the genetic diversity created for thousand seed weight was more related to fertility restorer lines. Among the studied lines, R131 had the highest positive combining ability for thousand seed weight. This line had the highest thousand seed weight in both normal and drought stress conditions with 56.5 and 51.4 g, respectively. On the other hand, RF81-112 had the highest negative combining ability for thousand seed weight.

The line × tester analysis for number of seeds per head showed that under stress conditions none of the effects were significant for this trait and under normal conditions the effect of line and tester were significant. The contribution of line, tester and line × tester in explaining the variance of sum squares were 44.1, 20.69 and 35.2%, respectively. These results showed that, similar to the thousand seed weight, fertility restorer lines play an important role in determining the general combinability for the number of seeds per trait under normal conditions. But in the study of Mohyaji et al. (2014) dominance effects (line × tester interaction) were significant head seed number under water stress. Therefore, these characters were controlled mainly by dominant gene action. In this study, the line of RGK15 and the tester of AGK32 had the highest positive general combining ability for number of seeds per head. The average of seeds number per head of these two lines was 1274 and 1211, respectively. On the other hand, the lines of RF81-112 and AF81-222 had the lowest combining ability for the number of seeds per head. In accordance with these results, Khani et al. (2005) reported that in stress and normal conditions, the role of fertility restorer lines in controlling this trait were more than the other two components. In the study of (Esfahlani et al. 2018) in normal and drought stress conditions, the role of non-additive effects in controlling the number of seeds per head were more than the additive effects. Whereas in some studies have been reported the simultaneous effects of dominance and additive in control of this trait (Ghaffari and Shariati 2018; Memon et al. 2015). For the percentage of seed oil, the effect of line, tester and line × tester was significant in both normal and stress conditions. The contribution of these three components of variance (line, tester and line × tester) in explaining the variance for the sum of squares in normal conditions was 31, 16 and 53%, respectively, and in stress conditions was 25, 31 and

44%, respectively. These results showed that in both conditions specific combining ability has a major role in controlling the percentage of seed oil. The ratio of σ^2GCA/σ^2SCA for this trait, in both normal and drought stress conditions was less than one, which indicates that non-additive effects have a greater role in controlling this trait. Similar to other studied traits, there are different reports on the gene controlling effect for seed oil percentage. In the study of Hladni et al. (2007), non-additive effects were mentioned as the main effects in controlling of the seed oil percentage. Whereas in the study of Singh and Chaudhary (1977) the variance of general combining ability for seed oil percentage was higher than the variance of specific combining ability. Based on our results, under normal conditions, the line of RF81-112 and the tester of AGK32 and under stress conditions the line of R131 and the tester of AF81-222 had the × RGK33 had the highest positive combining ability for the seed oil percentage under both normal and drought stress conditions. Variance analysis of line × tester for seed yield, were indicated that the effects of line and line × tester was significant and the effect of tester was insignificant under normal conditions, and under stress conditions, the effect of line and tester was significant and the effect of line × tester was insignificant. Chahal et al. (2019) also indicated the importance of dominant genes in controlling the seed yield in sunflower. The effect of line and tester was significant for oil yield under normal conditions and the effect of line × tester was insignificant and in stress conditions the effect of line and line × tester was significant and the effect of tester was insignificant. The contribution of line, tester and line × tester in explaining the variance of sum squares of seed yield under normal conditions were 39, 3 and 58%, respectively, and under drought stress conditions were 47, 27 and 26%, respectively. These ratios for seed oil percentage were 28, 5 and 67% under normal conditions and 37, 15 and 49% under drought stress, respectively. These outcomes showing that for seed yield under normal conditions and oil yield in both conditions, specific combining ability plays a major role. On the other hand, the ratio of σ^2GCA/σ^2SCA for these two traits was less than one in both normal and drought stress conditions and this suggest that in controlling seed and oil yield, non-additive effects play a major role. The results showed that for both seed and oil yield traits, the contribution of variance of the sum of squares for the lines was higher than the testers and this suggest that the lines (fertility restore lines) play an important role in determining the sunflower hybrids yield. Ghaffari and Shariati (2018) reported that Selection of restorer lines for the agronomic traits would be more efficient than the selection of CMS lines. They concluded that heritability of a trait determines the kind of SCA in response to different environments and the SCA effects are more stable for traits with higher heritability.

This situation was also present in the study of Singh and Chaudhary (1977). On the other hand, according to the results, the variance of specific combining ability was higher than general combining ability, which shows that the role of non-additive effects in controlling this trait is major.

Seed yield is strongly influenced by water availability; hence moisture stress is reflected in the depressed yields. The plants under control recorded highest seed yield, whereas the stressed plants exhibited lower yield. R131 had the highest positive general combining ability for seed and oil yield under normal and drought stress conditions. The results show that the line of R131 has a major role in increasing of sunflower hybrids yield (as one of the parents of hybrids). The tester of AGK32, under normal conditions and the tester of AF81-222, under stress conditions had the highest general combining ability for seed yield. The results showed that the combining ability of fertility restorer lines (positive or negative) for seed yield was much higher than the combining ability of male sterile lines. The important role of fertility restorer lines in heterosis of sunflower hybrids has been reported by Haddadan et al. (2020). AGK38 × R131 had the highest specific combining ability for seed and oil yield under normal and drought stress conditions. This hybrid had the highest seed yield under normal conditions with 4414 kg ha^{-1} and under stress conditions with 3457 kg ha^{-1}. This hybrid had the highest oil yield under normal conditions and drought stress with 1887 and 1438 kg ha^{-1}, respectively. In the study of Abdel-Rahem et al. (2021), the variance due to specific combining ability for seed and oil yield was higher than the variance of general combining ability, which indicated the role of non-additive effects of genes controlling these traits. Similar to other traits, there are different reports about the type of gene effects that control seed and oil yield. Aleem et al. (2015) were emphasized the greater role of specific combining ability for yield and yield components, whereas in a study of Machikowa et al. (2011), were emphasized the greater role of general combining ability for these traits. Most studies have emphasized the Important and decisive role of non-additive effects in controlling the yield and yield components of sunflower (Chahal et al. 2019; Lakshman et al. 2019).

The results of the study showed that in order to achieve high yielding sunflower hybrids, it is necessary for at least one of the parents used for the yield or one of the yield components to have a high general combining ability in the positive direction. This situation is true for the AGK38 × R131, so that this hybrid had the highest specific combining ability for seed yield and on the other hand one of its parents (R131) had the highest positive general combining ability for the thousand seed weight as one of the important components of seed yield in normal and drought stress conditions. This issue has been confirmed by Attia et al. (2020) and Lakshman (2020). So that, in these studies, the superior hybrids in terms of seed yield had at least one parent with high general combining ability for seed yield. In case, one of the parents of the superior sunflower hybrid has high combining ability in terms of seed yield and the other has negative combining ability, it indicates additive × dominance effects (Chandra et al. 2011). Naeem et al. (2019) reported that may be there are an interaction between positive alleles from one parent and negative alleles from another parent in hybrids. According to, the most ideal combination of sunflowers hybrids is those that have a high specific combining ability and as well as the degree of general combining ability in one or both parents is high and significant. While a superior hybrid of sunflower, the combining ability of both parents is low and in a negative direction, it indicates over dominant and epistatic effects (Chandra et al. 2011).

The results of the present study and its compatibility with other studies showed that the studied experimental materials and environmental conditions can play an important role in determining the combining ability and type of genes effect, and accordingly, combining ability and gene effects in some of the studied traits in the present study were different under normal and drought stress conditions.

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Ethical statement: This material is the authors' own original work, which has not been previously published elsewhere. The paper is not currently being considered for publication elsewhere. The paper reflects the authors' own research and analysis in a truthful and complete manner. The paper properly credits the meaningful contributions of co-authors and co-researchers. The results are appropriately placed in the context of prior and existing research. All sources used are properly disclosed (correct citation). All authors have been personally and actively involved in substantial work leading to the paper, and will take public responsibility for its content.

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