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GENE ACTION OF YIELD RELATED CHARACTERS UNDER NORMAL AND DROUGHT STRESS CONDITIONS IN *BRASSICA NAPUS* L.

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Abstract

Climate change is threat multiplier of existing problems. It is causing many more stresses including abiotic and biotic. Among the abiotic stresses, drought is the big challenge for researchers and farmers. The easiest and cost-effective approach for various stresses due to climate change is adaptive genes deployment. For this purpose, information related to gene action is very much necessary for developing climate resilient crops. The purpose of this study was to determine the gene action of various yields and yield related characters of *Brassica napus* under drought stress. Three drought sensitive and eight drought tolerant varieties were collected and hybridized by following the Line × Tester fashion. Developed breeding material and their parents were assessed at maturity stage. RCBD with split plot arrangement was used, in this experiment. Two drought stress and a normal treatment were applied. Data were recorded for different yield and its associated characters. Observation of genetic variability was done amongst the developed breeding material for most of the traits. Highest genetic variation suggested that selection will be more fruitful under drought stress and normal treatments. Potential parents were chosen from the results of Line × Tester analysis i.e. ZmR-4 and ZmR-10. Among all the crosses Zmm-5 × Rainbow exhibited better performance for yield and yield associated characters under both conditions. Yield/plant showed non-additive gene action under drought stress and normal condition that might be exploited in next generation.

Key words: Drought; Gene action; Oilseed crops; Potential parent; Best cross combination; Brassica; Randomized Complete block design (RCBD); Reactive oxygen species (ROS); Oil seed research group (OSRG); Plant breeding and genetics (PBG); General combining ability (GCA) ; Specific combining ability (SCA).

Introduction

World changing climate is the biggest threat to agriculture. Climate change refers to the change in average weather conditions. It may occur due to extreme weather conditions. It affects agriculture in many ways such as growth rate, photosynthesis, transpiration rate, quantity and quality of the crops etc. (Mahato, 2014). Among abiotic stresses drought is the most critical threat to sustainable agriculture. Unavailability of sufficient water in a specific region to sustain it, is called as drought. It is mainly due to lack of rainfall for a longer period of time. Agriculture has great importance for food security, specifically for two reasons. First it provides food for people. Secondly it gives livelihood to 36% people in the world. But climate change affects agricultural production by putting the rural population at risk and also their food insecurity risk is increased (Farooq *et al*., 2012). *Water scarcity is the biggest problem of Pakistan from many years. 1000m^3/capita is per person available water in Pakistan and is reducing day by day* (Shahzad, 2016).

Total requirement and local production of edible oilseeds/oil is 3.264 and 0.462 million tons. Edible oil imported during 2016-2017 was 2.802 million tons. Main oilseed crops of Pakistan are sunflower, rapeseed, canola and cotton. Among major oilseed crops *Brassica napus* ranks at 2nd. It contributes 14.06% in local oil production. Total oil produced from canola and rapeseed is 0.006 and 0.061 million tons from 0.0133 and 0.199-million-hectare respectively (Govt. of Pakistan, 2016-17).

Drought stress has great effect on different Brassica species. Different plant characters' number of tillers, chlorophyll content, plant height, seed oil content, leaf size and photosynthesis rate, are reduced due to water stress. Shoot length of canola plant is also decreased caused by water scarcity due to reduction in division. It executes oxidative stress in *Brassica campestris*, *Brassica juncea*, and *Brassica napus*. Drought stress has more effect on flowering period, No. of pods/plant are significantly reduced because of pod termination due to reduced photosynthetic rate. *It decreases germination rate and stand development.* Water deficit conditions may inhibit cell enlargement by disturbing flow of water from xylem to adjacent extending cells. Drought stress decreases transpiration rate, water-use efficiency, turgor pressure and reduction in nutrient absorption as well as their usage by the crop plant. Ceased growth and photosynthetic ability of the plant is also the result of stability loss between ROS production and antioxidant defense, under drought stress. As a result, oxidative stress is produced in lipid membranes, proteins and in some other cell constituents. Increased production of reactive oxygen species degrade nucleic acids as well as functional and structural proteins (Farooq *et al.,* 2009).

Genetic variability is important for a plant breeder. In conventional breeding, variations are created through hybridization. There are three components of biological variation phenotypic, genotypic and environmental. Phenotypic variation can be observed directly by visualizing. It contains environmental and genetic variation. Genotypic variation components are additive, dominance and epistasis. Gene action mentions the way of gene expression in a genetic population. It assists to select better parents. Combining ability variances and effects are mainly calculated by gene action. Combining ability is the aptitude of a genotype to transfer greatest traits to its crosses. Two types of gene action are 1) additive 2) non-additive. Additive genetic variance and additive × additive class of epistatic variance are included in additive gene action. Additive × dominance, dominance × dominance and dominance variance are included in non-additive gene action.

There are various breeding approaches which are used in plant breeding. But line × tester is an efficient and appropriate breeding method which can measure combining abilities and their effects. It can be used to determine gene action, which is involved to express many quantitative traits. By using Line × Tester technique, desirable parents can be selected for hybridization in breeding program. More number of accessions can be evaluated by using this technique. Gene action of yield and yield related characters under drought stress and normal conditions, can be very helpful to develop breeding material and in selection of potential parents.

This experiment was performed to know the genetic variability among germplasm, better cross-combinations and parent's selection. Inheritance of various yield related parameters under drought stress was also determined.

Material and Methods

Eight drought tolerant Zmm-5, ZmR-4, ZmR-10, Zm-21, B-56, Km-256, B-18, Pb-Sarson and three drought sensitive accessions Rainbow, ZmR-18 and Zmm-12 were collected from OSRG of PBG, University of Agriculture, Faisalabad, Pakistan. These accessions were already screened from available germplasm. Female parents (lines) were taken as drought accepting and male parents (testers) as drought sensitive accessions. These line and testers were crossed by using Line × Tester breeding scheme. Emasculation and pollination of nine plants of each line of *Brassica napus* was done. Each pollinated plant was bagged and tagged. Daily observation and bags were changed to avoid the any kind of attack. Harvesting of plants was done at the stage of maturity. Seeds threshing was done and stored for next growing season. Twenty-four crosses and their parents were grown in field by using RCBD with split plot arrangement, consisting of three blocks and three treatments. Three seeds of each entry per treatment per block were sown. One normal and two drought treatments were used in this experiment.

Treatments:
T_0 = Normal irrigation (6 irrigations)
T_1 = Alternate irrigation was skipped
T_2 = No irrigation except Rauni

Application of DAP (one bag) was done during field preparation and one bag of urea was applied in three turns at 1) first irrigation 2) flowering phase 3) silique formation phase. Necessary agronomic practices were applied regularly and evenly. Each entry consisted of five plants per replication per treatment, were tagged. Data were note down on number of primary branches, yield per plant, number of silique/plant, number of seeds/silique, plant height, number of secondary branches, 1000 seed weight and number of leaves/plant. Noted data were subjected to Line × Tester analysis to know combining ability and genetic variability as proposed by (Kempthorne, 1957).

Results and Discussion

Crosses, lines, testers, entries, parents, Line × Tester interaction and parents vs crosses exhibited significant differences for all the characters (Table 1). Noteworthy dissimilarities between Brassica types for yield and yield related characters were also reported by (Bilibio *et al.*, 2011; Khalili *et al.*, 2012). Genetic variability presence suggested that the breeding material can be used for further breeding program. Selection is more effective in present developed germplam due to high genetic variation. Mean values of yield and its related characters under drought stress and normal conditions are mentioned in Table 2.

A decreasing trend of yield/plant was observed under drought stress conditions. Decrease in yield/plant was also seen due to the increase in drought stress by (Din *et al.*, 2011; Choukri *et al.,* 2020). Yield per plant ranged from parents 4.18-5.69 (normal irrigation= T_0), 3.75-5.12 (Drought stress = T_1) and 3-4.88 (Drought stress T_2). For crosses it was from 4.31-5.87 (normal irrigation= T_0), 3.67-5.66 (Drought stress = T_1) and 3.76-5.22 (Drought stress $T_{2)}$. Similarly, one thousand seed weight was also reduced by increasing the drought stress levels. Parents range was 3.55-4.54 (normal irrigation= T_0), 3.22-4.32 (Drought stress = T_1) and 2.35-4 (Drought stress T_2). While in crosses it ranged from 3.23-4.41(normal irrigation= T_0), 2.67-4.32 (Drought stress = T_1) and 2.46-4 (Drought stress T_2). In literature, it ranged from 3.7-4.5g under normal irrigation and 2.77-3.37g under drought stress (Rad & Zandi, 2012; Mirzaei *et al*., 2013).

Number of silique/plant is another important yield related parameter. It also showed decreasing trend under drought stress conditions as compared to normal irrigation. It ranged from 62-100 (normal irrigation= T_0), 57-88 (Drought stress = T_1) and 43-75 (Drought stress T_2) in parents. While in crosses it ranged from 36-98 (normal irrigation= T_0), 36-83 (Drought stress = T_1) and 30-75 (Drought stress T_2). In literature, it ranged from 55.1-82.5, reported by (Mirzaei *et al*., 2013) and showed a great loss in number of silique due to the high drought stress level. Due to the reduction in No. of silique/plant, No. of seeds/silique were also decreased, caused by increase in drought stress level. In parents No. of seeds per silique ranged from 14-17 (normal irrigation= T_0), 12-16 (Drought stress = T_1) and 9-14 (Drought stress T_2). While in crosses, it ranged from 15-20 (normal irrigation= T_0), 13-18 (Drought stress = T_1) and 9-16 (Drought stress T_2). In literature, it ranged from 9.9-15.8 under normal and 15.8-25.4 under drought stress (Rad & Zandi, 2012; Mirzaei *et al*., 2013).

Fruit bearing branches are considered as the imperative contributing factor to plant yield. No. of primary and secondary branches in Brassicas are also affected negatively by the drought stress (Nasri *et al*., 2008). In this research. No. of primary branches of parents ranged from 2-3 (normal irrigation= T_0), 1.4-2.5 (Drought stress = T_1) and 1-2 (Drought stress T_2). While in crosses ranges under normal and drought stress treatments were very much similar to the parent's ranges. Number of secondary branches of parents ranged from 1-1.8 (normal irrigation= T_0), 1-1.6 (Drought stress = T_1) and 0.8-1.5 (Drought stress T_2). In crosses, it ranged from 1-1.9, 0.6-1.6 and 0.3-1.3 under T_0, T_1 and T_2 respectively.

Table 1. Line × Tester analysis of *Brassica napus* under normal (T_0) and drought stress treatments (T_1 and T_2).

SOV	D.F	Treatments	P.H	N.PB	N.SB	N.L/P	N.S/P	N.S/S	Y/P	1000-SW
		T_0	4.8667**	0.2000*	0.0667*	0.6952*	0.0068*	3.0952*	1.8381*	0.0129*
Replications	2	T_1	11.6667**	0.5810*	0.1238*	0.2381*	0.0006*	2.9429*	1.6095*	0.0208*
		T_2	3.4381*	0.3714*	0.1524*	0.3714*	4.3524**	0.3524*	0.0138*	0.0084*
		T_0	10.9036**	960.1720**	2.3793**	0.9204*	1.1228*	2147.8347**	37.0185**	0.6922*
Accessions	34	T_1	22.5725**	646.3322*	2.3681**	1.1860*	2.1772**	2405.786**	51.6174**	2.0995**
		T_2	1229.1429**	2.2622**	1.7132*	31.3008**	1395.5978**	19.9507**	2.6550*	2.6551*
		T_0	5.3636**	275.6182**	1.0909*	0.4000*	1.2017*	3342.4848**	41.6242**	1.1855*
Parents	10	T_1	16.5879**	385.5879**	4.4000**	1.9394*	3.9977**	3023.7212**	75.5636**	3.1554**
		T_2	1601.1515**	3.8970**	0.5212*	27.8303**	1742.539**	22.7394**	4.9042**	3.8474**
		T_0	10.9994**	1283.4493**	2.7675**	1.1594*	1.0828*	1637.1878**	29.6226**	0.4800*
Crosses	23	T_1	25.4179**	781.6081**	0.7609*	0.8961*	1.3536*	2116.6957**	32.4438**	1.6322*
		T_2	1038.738**	1.6135*	2.2844*	31.1008**	985.4106**	19.4179**	1.7526*	2.2451*
		T_0	19.9821**	2286.0000**	2.7123**	2.4762**	1.3867*	2411.8988**	42.4425**	0.5121*
Lines (L)	7	T_1	45.1984**	1087.4742**	1.1032*	0.8810*	0.9541*	2025.9048**	44.6964**	1.5699*
		T_2	1132.4266**	2.9841*	2.5536*	68.7599**	1543.269**	26.4365**	3.0724**	4.1554**
		T_0	3.5556**	585.3750**	2.9306*	0.1250*	0.6411*	4441.0000**	21.1806**	0.0124*
Testers (T)	2	T_1	12.9306**	283.9306**	0.2917*	0.3889*	2.6610*	572.5417**	12.5417**	3.4958*
		T_2	248.4306**	0.7222*	0.5417*	23.4306**	46.8472**	46.6806**	0.2059*	0.4706*
		T_0	7.5714**	881.8988**	2.7718**	0.6488*	1.1743*	1713.0774**	24.4187**	0.5307*
L × T	14	T_1	17.3115**	699.7718**	0.6567*	0.9762*	1.3666*	2382.6845**	29.1607**	1.3971*
		T_2	1104.7956**	1.0556*	2.3988**	13.3671**	840.5615**	12.0139**	1.3137*	1.5434*
		T_0	5.7784	2.8569	0.5667	0.3129	0.0052	28.7423	1.4361	0.0100
Error	68	T_1	9.6667	3.9339	0.7218	0.5616	0.0004	2.9919	1.2762	0.0120
		T_2	7.8597	0.5185	0.5543	1.0185	8.4700	1.8818	0.0096	0.0093

SOV=Sources of variation, D.F = Degrees of freedom, P.H = Plant height, N.PB = Number of primary branches, N.SB = Number of secondary branches, N.L/P = Number of leaves/plant, N.S/P = Number of silique/plant, N.S/S = Number of seeds/silique, Y/P=Yield/plant and 1000-SW=1000 Seed weight

Table 2. Ranges of mean values of yield and its related characters for parents and crosses under normal (T_0) and drought stress treatments (T_1 and T_2).

Entries	Treatments	P.H	N.PB	N.SB	N.L/P	N.S/P	N.S/S	Y/P (g)	1000-SW
	T_0	131-159	2-3	1-1.8	5-12	14-17	62-100	4.18-5.69	3.55-4.54
Parents	T_1	121-148.6	1.4-2.5	1-1.6	4-11	12-16	57-88	3.75-5.12	3.22-4.32
	T_2	76-132	1-2	0.8-1.5	3-10	9-14	43-75	3.00-4.88	2.35-4
	T_0	109-170.3	2-3	1-1.9	1.6-8	15-20	36-98	4.31-5.87	3.23-4.41
Crosses	T_1	100-153	1.2-2.7	0.6-1.6	1.3-7.6	13-18	36-83	3.67-5.66	2.67-4.32
	T_2	87-126	1-2	0.3-1.3	1-7	9-16	30-75	3.76-5.22	2.46-4

Leaves per plant are the photosynthetic machineries so, yield is very much related to No. of leave per plant. Results showed decreasing trend of No. of leaves/plant under water scarcity as compared to normal (Sabagh *et al*., 2019; Kapoor *et al*., 2020). In parents, it ranged from 5-12 (normal irrigation= T_0), 4-11 (Drought stress = T_1) and 3-10 (Drought stress T_2). While in crosses, it ranged from 1.6-8, 1.3-7.6 and 1-7 under T_0, T_1 and T_2 respectively. In most of the studies, plant height is directly linked with yield and affected by drought stress in many crops. In present study, results showed decreasing trend of plant height while increasing the drought stress levels. In parents, it ranged from 131-159 (normal irrigation= T_0), 121-148.6 cm (Drought stress = T_1) and 76-132cm (Drought stress T_2). In crosses, it ranged from 109-170.3cm (normal irrigation= T_0), 100-153 cm (Drought stress = T_1) and 87-126 cm (Drought stress T_2). In literature, it ranged from 102.8-194.5 cm under normal irrigation and 92-80 cm under drought stress condition (Germchi *et al*., 2010).

Analysis of GCA: Analysis of eight parents for GCA was done to determine their potential and presented in Table 3. Under normal irrigation (T_0), among lines, Line B-56 showed significant and positive general combining ability for many traits subsequently ZmR-4, ZmR-10 and Km-256. Among testers, ZmR-18 had significant effects of GCA, for Number of primary branches, Number of seeds/silique and yield per plant followed by rainbow. (Farshadfar *et al*., 2013) also determined significant and positive GCA effects for different characters in different genotypes of Brassica under normal condition.

Under drought stress treatment T_1, ZmR-10 showed positive significant general combining ability effects for yield and related characters followed by ZmR-4 and Zm-21. Among testers, Zmm-12 showed positive significant GCA for, No. of silique/plant, and 1000-sed weight, No. of primary branches and No. of seeds silique^{-1} followed by ZmR-18. Under drought stress treatment T_2, line B-18 exhibited positive significant general combining ability effects for 1000-seed weight, No. of primary and secondary branches, No. seeds/silique, number of silique/plant and yield/plant followed by ZmR-4, ZmR-10 and Km-256. Amongst testers, Rainbow had significant positive general combining ability effects for plant height, number of seeds/silique, number of leaves per plant, number of silique/plant, yield per plant and thousand seed weight followed by ZmR-18. Significant and positive GCA effects for different traits were also observed by (Shehzad *et al*., 2015) under drought environment.

Table 3. General combining ability effects of lines and testers in *Brassica napus* under normal (T_0) and drought stress treatments (T_1 and T_2).

Parents	Treatments	P.H	N.PB	N.SB	N.L/P	N.S/P	N.S/S	Y/P	1000-SW
					Lines				
	T_0	-2.21*	-24.94 **	0.24	-0.28	-0.28 **	-15.96 **	2.38 **	-0.09 *
Zmm-5	T_1	0.25	-9.57 **	-0.42	0.14	0.001	17.22 **	2.04 **	0.02
	T_2	11.43 **	-0.44	0.24	1.96 **	-0.83	-0.64	-0.32 **	-0.14 **
	T_0	0.24	14.50 **	0.46	-0.17	0.25**	19.04**	1.15*	-0.11 **
ZmR-4	T_1	0.25	4.99 **	0.03	0.58*	-0.04**	6.00**	1.93 **	0.19**
	T_2	8.32 **	0.22	-0.32	4.51**	21.28**	1.03*	0.71 **	1.04 **
	T_0	-0.10	4.50 **	-0.65 *	-0.2	0.40**	-0.40	1.15 *	0.11 *
ZmR-10	T_1	2.81*	7.99 **	0.25	0.03	0.12**	14.22**	2.26 **	0.06 **
	T_2	4.54 **	-0.01	-0.10	2.85 **	4.94 **	-0.53	0.28 **	0.49 **
	T_0	-0.88	7.83 **	0.01	-0.28	0.43**	0.26	-0.18	0.40 **
Zm-21	T_1	0.69	-5.79 **	-0.31	-0.19	0.57**	-12.89**	1.82**	0.71**
	T_2	-8.46 **	-0.56 *	-0.32	-2.60 **	-16.28 **	-0.86	-0.92 **	-0.98 **
	T_0	2.57 **	5.83 **	0.57*	-0.28	0.21**	3.04	0.04	0.26 **
B-56	T_1	2.58*	-0.90	0.36	-0.31	-0.30 **	-13.67**	-1.51 **	-0.48 **
	T_2	6.32 **	0.22	-0.32	-2.60 **	-5.83 **	-1.19 *	-0.12 **	-0.49 **
	T_0	0.68	1.72 **	0.35	1.17 **	-0.14 **	7.26 **	1.71 **	-0.09 *
Km-256	T_1	-2.19	-14.13 **	0.03	-0.19	0.30**	-21.89 **	-1.51 **	0.29 **
	T_2	5.43 **	0.33	0.24	-1.38 **	9.94 **	1.47 **	0.73 **	0.53 **
	T_0	-1.32	15.06 **	0.01	0.39 *	-0.45 **	8.04 **	-4.18 **	-0.34 **
B-18	T_1	-0.53	-3.13 **	0.47	-0.31	-0.33 **	-3.11 **	-3.29 **	-0.28 **
	T_2	-5.46 **	1.00 **	1.13 **	-0.38	4.28 **	3.03 **	0.15 **	0.17 **
	T_0	1.01	-24.50 **	-0.99 **	-0.28	-0.43 **	-21.29 **	-2.07 **	-0.13 **
Pb-Sarson	T_1	-3.86 **	20.54 **	-0.42	0.25	-0.33 **	14.11 **	-1.74 **	-0.53 **
	T_2	-22.13 **	-0.78 **	1.13 **	-2.38 **	-17.50 **	-2.31 **	-0.53 **	-0.62 **
					Testers				
	T_0	-0.44	3.63 **	0.22	-0.04	0.05 **	1.57	-0.97 **	-0.01
Rainbow	T_1	-0.78	-1.07 **	-0.13	-0.14	-0.01	-5.46 **	-0.17	-0.06 **
	T_2	2.28 **	0.14	0.17	0.90 **	1.36 **	1.10 **	0.10 **	0.14 **
	T_0	0.22	2.00 **	0.18	-0.04	-0.04 *	6.86 **	0.90 **	0.03
ZmR-18	T_1	0.10	-2.78 **	0.04	0.11	-0.33 **	3.96**	0.79 **	-0.35 **
	T_2	1.40 *	-0.19	-0.13	0.15	0.07	-1.57 **	-0.08 **	-0.14 **
	T_0	0.22	-5.63 **	-0.40*	0.08	-0.01	-8.43 **	0.07	-0.01
Zmm-12	T_1	0.68	3.85 **	0.08	0.03	0.34**	1.50**	-0.63**	0.41**
	T_2	-3.68 **	0.06	-0.04	-1.06 **	-1.43 **	0.47	-0.03 **	-0.01 *

P.H = Plant height, N.PB = Number of primary branches, N.SB = Number of secondary branches, N.L/P = Number of leaves/plant, N.S/P = Number of silique/plant, N.S/S = Number of seeds/silique, Y/P = Yield/plant and 1000-SW = 1000 Seed weight

Amongst lines, ZmR-10 and ZmR-4 and among testers, ZmR-18, Zmm-12 and Rainbow exhibited significant and positive GCA effects for yield and its related characters under normal and drought stress treatments.

Anlaysis of SCA: SCA under drought stress and normal treatments are mentioned in Table 4(a), 4(b) and 4(c). Under normal condition, cross Pb-Sarson × Zmm-12 exhibited positive significant specific combining ability effects for number of primary and secondary branches, number of silique/plant, number of seeds/silique, yield/plant and 1000-seed weight followed by ZmR-10 × Zmm-12, Zm-21×Zmm-12 and B-18×ZmR-18 (Farshadfar *et al.*, 2013) also determined significant specific combining ability effects for different characters in genotypes of Brassica.

Under drought stress treatment T_1, cross Zmm-5 × ZmR-18 showed positive significant Specific combining ability effects for No. of primary branches, No. of silique/plant, No. of seeds/silique and 1000-seed weight followed by ZmR-10×Zmm-12, Zm-21×ZmR-18 and Zmm-5×Rainow. (Shehzad *et al.*, 2015) stated significant and positive specific combining ability effects for various traits in Brassicas.

Under drought stress treatment T_2, B-18 × Rainbow shown significant positive SCA effects for, number of secondary branches, No. of leaves/plant, No. of silique/plant, number of seeds/silique, yield/plant, thousand seed weight and plant height followed by Km-256 × ZmR-18, Zmm-5 × ZmR-18 and Km-256 × Zmm-12 (Farshadfar *et al.*, 2013) also reported positive and significant specific combining ability effects for different characters in Brassica genotypes under drought stress conditions.

Gene action: Gene action of various parameters under drought and normal conditions is mentioned in Table 5. Almost all entries had positive and significant GCA and SCA effects for number of primary branches/plant, yield/plant and number of secondary branches/plant, under normal irrigation. SCA effects for these characters were higher as matched with the effects of GCA. It leads towards non-additive gene action. Under drought stress environment (T_1), No. of seeds per silique, thousand seed weight and yield per plant had positive and significant GCA value lesser than the SCA value. While under highest drought stress level, thousand seed weight, plant height and yield per plant had highest value of GCA than SCA value. It leads towards additive gene action and selection of these traits will be beneficial, in this case.

Table 4(a). Specific combining ability effects of crosses of *Brassica napus* under normal conditions (T_0).

Cross	P.H	N.PB	N.SB	N.L/P	N.S/P	N.S/S	Y/P	1000-SW
Zmm-5 × Rainow	-2.67	-0.85	0.22	0.15	0.66 **	18.54 **	1.08	0.15 *
Zmm-5 × ZmR-18	2.67	-20.56 **	0.60	0.15	0.06	1.92	-1.13	-0.03
Zmm-5 × Zmm-12	-0.00	21.40 **	-0.82	-0.31	-0.72 **	-20.46 **	0.04	-0.11
ZmR-4 × Rainbow	0.22	1.38	0.33	0.38	-0.63 **	5.54	1.64 *	-0.29 **
ZmR-4 × ZmR-18	-0.44	18.00 **	0.71	0.04	0.03	7.92 *	0.43	0.12
ZmR-4 × Zmm-12	0.22	-19.38 **	-1.04 *	-0.42	0.59 **	-13.46 **	-2.07 **	0.17 *
ZmR-10 × Rainbow	0.22	-8.96 **	0.11	0.15	-0.72 **	-8.68 *	1.31	-0.51 **
ZmR-10 × ZmR-18	-1.44	0.00	-0.18	0.15	0.28 **	-12.97 **	-1.57 *	0.02
ZmR-10 × Zmm-12	1.22	8.96 **	0.07	-0.31	0.45 **	21.65 **	0.26	0.49 **
Zm-21 × Rainbow	0.33	-5.63 **	-0.56	0.15	0.26 **	-8.01 *	-0.36	0.50 **
Zm-21 × ZmR-18	-0.67	10.67 **	-1.18 **	-0.18	-0.48 **	-28.64 **	-1.24	-0.27 **
Zm-21 × Zmm-12	0.33	-5.04 **	1.74 **	0.03	0.23 **	36.65 **	1.60 *	-0.24 **
B-56 × Rainbow	-0.78	27.04 **	0.22	0.15	0.48 **	8.21 *	0.42	0.35 **
B-56 × ZmR-18	-0.11	-8.33 **	0.26	0.15	-0.17 **	33.58 **	1.54 *	-0.24 **
B-56 × Zmm-12	0.89	-18.71 **	-0.49	-0.31	-0.31 **	-41.79 **	-1.96 *	-0.11
Km-256 × Rainbow	1.44	11.15 **	0.44	-0.96 **	0.51 **	4.32	-4.92 **	0.35 **
Km-256 × ZmR-18	1.44	-2.22 **	0.82	0.38	0.34 **	1.69	6.21 **	0.17 *
Km-256 × Zmm-12	-2.89	-8.93 **	-1.26 **	0.58	-0.85 **	-6.01	-1.29	-0.52 **
B-18 × Rainbow	0.11	-20.85 **	-0.22	-0.18	-0.46 **	-22.46 **	0.97	-0.49 **
B-18 × ZmR-18	-0.56	10.11 **	-0.51	-0.51	0.48 **	8.58 *	-0.90	0.56 **
B-18 × Zmm-12	0.44	10.74 **	0.74	0.69 *	-0.02	13.87 **	-0.07	-0.07
Pb-Sarson × Rainbow	1.11	-3.29 **	-0.56	0.15	-0.10	2.54	-0.14	-0.07
Pb-Sarson × ZmR-18	-0.89	-7.67 **	-0.51	-0.18	-0.54 **	-12.08 **	-3.35 **	-0.32 **
Pb-Sarson × Zmm-12	-0.22	10.96 **	1.07 *	0.03	0.64 **	9.54 *	3.49 **	0.39 **

P.H = Plant height, N.PB = Number of primary branches, N.SB = Number of secondary branches, N.L/P = Number of leaves/plant, N.S/P = Number of silique/plant, N.S/S = Number of seeds/silique, Y/P = Yield/plant and 1000-SW = 1000 seed weight

Table 4(b). Specific Combining ability effects of crosses of *Brassica napus* under normal conditions (T_1).

Cross	P.H	N.PB	N.SB	N.L/P	N.S/P	N.S/S	Y/P	1000-SW
Zmm-5 × Rainow	-2.33	-8.26 **	0.46	-0.31	0.14 **	-18.43 **	1.83 **	0.29 **
Zmm-5 × ZmR-18	2.79	10.11 **	-0.38	0.11	0.65 **	60.49 **	0.21	0.58 **
Zmm-5 × Zmm-12	-0.46	-1.85	-0.08	0.19	-0.78 **	-42.06 **	-2.04 **	-0.87 **
ZmR-4 × Rainbow	-0.33	13.18 **	0.01	0.58	-0.40 **	12.79 **	2.61 **	-0.78 **
ZmR-4 × ZmR-18	-0.54	13.89 **	0.18	-1.00 *	0.59 **	2.04	-6.01 **	0.72 **
ZmR-4 × Zmm-12	0.88	-27.07 **	-0.19	0.42	-0.20 **	-14.83 **	3.40 **	0.06
ZmR-10 × Rainbow	3.44	2.85 **	-0.21	-0.19	-0.01	-10.76 **	3.28 **	0.42 **
ZmR-10 × ZmR-18	-1.43	-18.11 **	0.29	0.56	-0.78 **	-26.85 **	-4.01 **	-0.79 **
ZmR-10 × Zmm-12	-2.01	15.26 **	-0.08	-0.36	0.78 **	37.61 **	0.74	0.37 **
Zm-21 × Rainbow	-1.78	-15.71 **	-0.32	0.03	-0.65 **	-0.65	-2.28 **	-0.20 **
Zm-21 × ZmR-18	-0.32	5.00 **	-0.15	-0.56	0.66 **	-2.40 *	1.76 **	0.48 **
Zm-21 × Zmm-12	2.10	10.71 **	0.47	0.53	-0.01	3.06 **	0.51	-0.28 **
B-56 × Rainbow	-0.33	10.40 **	0.01	0.14	-0.04 **	15.13 **	-1.61 *	-0.41 **
B-56 × ZmR-18	-0.54	-5.22 **	0.18	-0.11	0.06 **	-8.29 **	2.43 **	0.19 **
B-56 × Zmm-12	0.88	-5.18 **	-0.19	-0.03	-0.03 *	-6.83 **	-0.82	0.21 **
Km-256 × Rainbow	1.44	-4.38 **	-0.32	0.03	0.53 **	-5.99 **	-1.94 **	0.57 **
Km-256 × ZmR-18	0.90	-12.33 **	0.85	-0.22	0.13 **	-7.74 **	3.10 **	0.09 **
Km-256 × Zmm-12	-2.35	16.71 **	-0.53	0.19	-0.66 **	13.72 **	-1.15	-0.66 **
B-18 × Rainbow	-3.22	-4.71 **	0.24	0.14	0.43 **	-9.43 **	-0.17	0.29 **
B-18 × ZmR-18	1.24	-2.00 *	-0.26	0.22	-0.43 **	16.15 **	-0.46	-0.52 **
B-18 × Zmm-12	1.99	6.71 **	0.03	-0.36	-0.00	-6.72 **	0.63	0.23 **
Pb-Sarson × Rainbow	3.11	6.63 **	0.12	-0.42	-0.01	17.35 **	-1.72 **	-0.17 **
Pb-Sarson × ZmR-18	-2.10	8.67 **	-0.71	1.00 *	-0.89 **	-33.40 **	2.99 **	-0.76 **
Pb-Sarson × Zmm-12	-1.01	-15.29 **	0.58	-0.58	0.89 **	16.06 **	-1.26 *	0.93 **

P.H=Plant height, N.PB=Number of primary branches, N.SB=Number of secondary branches, N.L/P=Number of leaves/plant, N.S/P=Number of silique/plant, N.S/S=Number of seeds/silique, Y/P=Yield/plant and 1000-SW=1000 Seed weight

Table 4(c). Specific Combining ability effects of crosses of *Brassica napus* under normal conditions (T_2).

Cross	P.H	N.PB	N.SB	N.L/P	N.S/P	N.S/S	Y/P	1000-SW
Zmm-5 × Rainow	-1.39	-0.47	-0.61	0.21	23.58 **	0.01 **	0.01 **	0.11 **
Zmm-5 × ZmR-18	-5.18 **	0.86 *	0.35	3.29 **	23.04 **	-0.99	0.08 **	0.17 **
Zmm-5 × Zmm-12	6.57 **	-0.39	0.26	-3.50 **	0.54	0.97	-0.08 **	-0.07 **
ZmR-4 × Rainbow	-3.94 *	0.19	-0.06	1.65 **	14.64 **	0.01	-0.14 **	-0.18 **
ZmR-4 × ZmR-18	4.93 **	-0.81	-0.10	-1.26 *	-9.07 **	-0.99	-0.74 **	-0.79 **
ZmR-4 × Zmm-12	-0.99	0.61	0.15	-0.39	-5.57 **	0.97	0.88 **	0.97 **
ZmR-10 × Rainbow	-12.83**	0.42	-0.28	-0.01	15.64 **	-2.10 *	-0.02	-0.06 **
ZmR-10 × ZmR-18	7.04 **	-0.25	-0.32	-0.93	-0.07	2.57 **	0.60 **	0.65 **
ZmR-10 × Zmm-12	5.79 **	-0.17	0.60	0.94	-15.57 **	-0.47	-0.58 **	-0.58 **
Zm-21 × Rainbow	-5.83 **	-0.36	-0.06	-1.24 *	-6.81 **	1.24	-0.40 **	-0.60 **
Zm-21 × ZmR-18	-5.63 **	-0.03	-0.10	0.51	2.49 *	-2.10 *	-0.11 **	-0.00
Zm-21 × Zmm-12	11.46 **	0.39	0.15	0.72	4.32 **	0.86	0.50 **	0.60 **
B-56 × Rainbow	-1.28	0.19	-0.06	-0.90	0.08	-0.10	-0.12 **	0.26 **
B-56 × ZmR-18	-0.07	-0.47	-0.10	-0.15	-2.62 *	0.24	-0.12 **	-0.47 **
B-56 × Zmm-12	1.35	0.28	0.15	1.06	2.54 *	-0.14	0.25 **	0.20 **
Km-256 × Rainbow	-23.39**	-0.58	-0.94 *	-2.13 **	-22.69 **	-2.10 *	-0.85 **	-0.76 **
Km-256 × ZmR-18	4.82 *	0.42	1.35 **	0.63	7.93 **	3.57 **	0.55 **	0.68 **
Km-256 × Zmm-12	18.57 **	0.17	-0.40	1.50 *	14.76 **	-1.47	0.30 **	0.07 **
B-18 × Rainbow	47.17 **	0.75	2.17 **	3.54 **	24.64 **	2.68 **	1.00 **	1.26 **
B-18 × ZmR-18	-14.29**	0.08	-1.21 *	-2.38 **	-12.07 **	-2.65 **	0.02 *	-0.32 **
B-18 × Zmm-12	-32.88**	-0.83 *	-0.96 *	-1.17	-12.57 **	-0.03	-1.02 **	-0.95 **
Pb-Sarson × Rainbow	1.50	-0.14	-0.17	-1.13	-1.92	0.35	0.52 **	0.19 **
Pb-Sarson × ZmR-18	8.38 **	0.19	0.13	0.29	-9.63 **	0.35	-0.28 **	0.07 **
Pb-Sarson × Zmm-12	-9.88 **	-0.06	0.04	0.83	11.54 **	-0.69	-0.24 **	-0.26 **

P.H = Plant height, N.PB = Number of primary branches, N.SB = Number of secondary branches, N.L/P = Number of leaves/plant, N.S/P = Number of silique/plant, N.S/S = Number of seeds/silique, Y/P = Yield/plant and 1000-SW = 1000 seed weight. L/P = leaves per plant, Y/P = Yield per plant, 1000-SW = 1000-seed weight, S/P = Silique/plant and S/S = Seeds/silique

Table 5. Characters having high combining ability effect under normal (T_0) and drought stress treatments (T_1 and T_2).

Normal irrigations (T_0)	Alternate irrigation was skipped (T1)	No irrigation except rauni (T_2)
No. of primary branches per plant	No. of seeds per silique	Plant height
No. of secondary branches per plant	1000 seed Weight	1000 seed weight
Yield per plant	Yield per plant	Yield per plant

Conclusion

Genetic variability among Brassica entries suggested that this germplasm can be used further in breeding program to develop accessions, which are drought tolerant. Among parents ZmR-4 and ZmR-10 performed best under drought stress and normal conditions and these are considered as potential parents. These might be used in crossing program to develop hybrids, which are tolerant to drought. Cross Zmm-5 × Rainbow had highest yield/plant under drought stress and normal conditions. This cross should be evaluated in different ecological zones. Yield/plant had highest significant and positive GCA effects for various characters as compared to SCA effects under normal and drought stress conditions. So, it possessed non-additive gene action that can be exploited in next segregating generation.

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