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INHERITANCE STUDIES FOR MORPHO-PHYSIOLOGICAL TRAITS IN WHEAT UNDER RAINFED CONDITION.

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ABSTRACT

Wheat (*Triticum aestivum* L.) the most widely grown crop across the globe is considered as the staple food of about 35% population of the world. Being a water-deficit country, Pakistan faces major reduction in wheat production especially in rainfed areas. Photosynthate or current assimilates are among the major carbon sources used during the grain filling period, whereas during moisture stress these may not be available. Hence reserves present in stem and other parts of the plant are important carbon sources for grain filling under stress conditions. Under treatment of Potassium iodide genotype LLR-22 showed the better performance while Nacozari showed the highest grain yield under rainfed conditions. Among crosses, cross LLR 20 x Parula showed the highest value for yield under both environments. Combining ability analysis revealed that under stress conditions, the traits showed different behaviour than the control condition. GL, GW, NGS, PH, DH and SL showed non-additive gene action (GCA< SCA) under control conditions while GW, TGW, YLS and NGS depicted non-additive gene action under treated conditions. GL, PH and DH showed additive type of gene action under treated condition. The crosses Nacozari x LLR 22, LLR 22 x CB 42, CB 42 x LLR 21 and LLR 22 x LLR 20 showed highest SCA effects for traits under study viz. grain yield, grains per spike, plant height and days to heading respectively. LLR 21 can be considered as the best general combiner for multiple agronomic traits under study.

Key words: Stem reserve translocation, photosynthetic assimilates, GSC, SCA, combining ability

INTRODUCTION

Pakistan has been facing water scarcity and drought since last few decades due to less amount of along with increasing temperature. Production of wheat, both in irrigated as well as rain-fed areas is being hampered due to these stresses. Minimizing the effects of water and temperature stresses, drought and heat resilient varieties are needed to be developed having the ability of the maximum utilization of available irrigation water. For the development of a drought and heat stress resilient variety, breeding for stem reserves is important. Stem reserves play significant role in increasing the yield by improving grain filling (Blum, 1988). Stem reserve mobilization plays an important role under stress conditions as have been reported by many researchers (Bidinger, 1977; Blum, 1988; Ehdaie, 1989). Stem reserves are water soluble carbohydrates and their availability depends highly on environmental conditions and cultivar. Under any biotic or abiotic stress, stem reserves can play an important role during grain filling. Hence, losses because of stress can be overcome or minimized with the availability of cultivars having better mobilization efficiency of stem reserves. The two vital sources for stabilizing grain yield are the capacity for photosynthetic assimilates storage and its remobilization efficiency to the grain (Moayedi, 2009). Under dry land conditions as compared to irrigated conditions, only 50% of the WSC (water soluble carbohydrates) were available for translocation during grain filling (Hussain and Rivandi, 2007). Stem reserve storage is affected by the stem length, which is controlled by height genes (Rht1 and Rht2) have been found for reduction in reserve storage by 35% and 39% as length was reduced to 21% (Borrel *et al*. 1993). Decline of photosynthesis after anthesis have been reported by Johnson *et al*., (1981), that limits the contribution of current photosynthate to the grain. Occurrence of severe drought stress may result in reduced grain filling, leaf desiccation and reduced photosynthesis. The objective of the study was to identify the efficient genotypes under rainfed conditions and to find out the best combiner for agronomic traits.

MATERIALS AND METHODS

The purposed study has been executed under experimental field area of the Plant Breeding & Genetics Department of PMAS Arid Agri. University Rawalpindi, Pakistan during Rabi 2011-13. The experimental materials were comprised of six wheat accessions viz, Nacozari, LLR 20, LLR 21, LLR 22 and CB 42, Parula, screened for stem reserves mobilization efficiency and their direct crosses. parents along with F1 their crosses have been planted in the field under triplicated Randomized Complete Block Design (RCBD). Two sets of this experiment were sown under rain-fed condition, one was kept as control while other one treated with potassium iodide at the time of 50% anthesis to create chemical desiccation. Row length was kept 5m and distance between rows and plants 30cm and 15cm respectively. Three seeds per dibble were placed using dibbler and thinning was carried out thinned to maintained one seedling per hill after germination; all cultural and agronomic practices were carried out uniformly according to the recommendation of the extension department during whole the experiment. At the time of physical maturity, ten guarded plants have been selected and tagged from each replication randomly to record data for agronomic traits under study.

COLLECTION OF DATA: The data were recorded for the following traits at required stage from ten guarded plants randomly selected from each replication.

Plant height (cm), Grain width (mm), Grain length (mm), Days to heading, Spike length (cm), 1000 grain weight (g), Numbers of grains per spike, and Grain yield (g) were recorded from the tagged plants and then average was taken for further data analysis and interpretation.

STATISTICAL ANALYSIS: The data collected for the traits under study have been subjected to ANOVA according to the method given by Steel *et al.* (1997). The combining ability analysis has been carried out following the procedure Method-2, Model-II given by Griffing's (1956). Correlation coefficient was also calculated. Hetrosis was calculated according to Hallauer and Miranda (1981).

RESULTS

LSD and Analysis of variance (ANOVA) (Table 1 and 2) depicted significant differences as compared between control and treated conditions for almost all traits under study Analysis of variance (combining ability) for treated (treated with potassium iodide to cause stress) condition showed significant results (P<0.05) for GCA and SCA (Table 4.1). GCA of control condition was non-significant (P>0.05) for all observed traits except for tillers per plant, while SCA were observed with significant value for plant height, number of grains per spike, and days to heading and yield per plant (Table 4.2). Detailed results and discussions are discussed in further for each trait as follows.

Table 1: Mean values of treatments with LSD for traits studied in 21 genotypes under treated and control conditions

Treatment	GL	GW	TGW	YLD	GS	PH	NT	DH
Control	8.309a	3.349a	38.779a	2117.095a	42.270a	70.767a	8.746a	88.127a
Treated	7.558b	3.086b	31.661b	1597.365b	29.540b	70.999a	8.952a	88.127a
LSD	0.042	0.091	0.210	21.943	1.128	1.858	0.4859	0.6901

GL=grain length (mm), GW=grain width (mm), TGW= 1000grain weight (g), YLD= yield per plant (g), GS= no of grains per spike, PH= plant height (cm), NT= tillers per plants, DH= days to heading, SL= spike length (cm)

Table 2: Mean squares for six wheat varieties and fifteen F1 crosses

SOV	df	GL	GW	TGW	YLD	GS	PH	NT
Treatment	1	17.771**	2.187**	1596.09**	8508762.3**	5104.794**	1.694**	1.341**
Error	4	0.000	0.000	0.348	2712.222	11.016	6.646	16.151
Genotype	20	0.632	0.143	87.728	797280.21	522.043	904.41	29.798
treat x genotype	20	0.273**	0.035**	10.107**	49662.627**	127.927**	1.067**	1.541**
Error	80	0.009	0.001	0.35	3891.431	10.083	28.545	1.167
CV		1.19%	1.20%	1.68%	3.36%	8.84%	7.54%	12.21%

* and **, Significant at 5% and 1% probability level, respectively. ns: Non-significant.

GL=grain length (mm), GW=grain width (mm), TGW= 1000grain weight (g), YLD= yield per plant (g), GS= no of grains per spike, PH= plant height (cm), NT= tillers per plants, DH= days to heading, SL= spike length (cm)

Table 4.1: ANOVA for combining ability (GCA & SCA) for 14 characters in 6 x 6 diallel (Control)

SOV	df	GL	GW	TGW	YLD	GS	PH	NT	DH	SL
GCA	5	0.0082	0.005	0.906	32254	67.203	71.17	8.53**	6.3561	0.3697
SCA	15	0.0087	0.003	0.6461	69378.2*	73.326*	94.8*	3.46**	13.073**	0.4161
Error	40	0.0135	0.0076	7.3616	32446.7	35.558	41.35	1.0942	4.9372	0.4996

Table 4.2: ANOVA for combining ability (GCA & SCA) for 14 characters in 6 x 6 diallel (treated)

SOV	df	GL	GW	TGW	YLD	GS	PH	NT	DH	SL
GCA	5	0.30**	0.02**	15.9**	101565**	61.50**	248.3**	5.48**	56.5**	1.45**
SCA	15	0.25**	0.04**	18.2**	154568**	66.5**	111.7**	3.69**	9.24**	1.17**
Error	40	0.005	0	0.0067	2504.1	2.86	9.587	0.4833	1.3038	0.125

* and **, Significant at 5% and 1% probability level, respectively. ns: Non-significant.
GL=grain length (mm), GW=grain width (mm), TGW= 1000grain weight (g), YLD= yield per plant (g), GS= no of grains per spike, PH= plant height (cm), NT= tillers per plants, DH= days to heading, SL= spike length (cm)

Grain width: The GCA effects of parents for control condition (rain-fed condition) were non-significant for all the parents but were significant for two of the parents for treated condition (treated with potassium iodide to induce stress), Nacozari and LLR 21. Nacozari showed negative value for GCA while LLR 21 showed significant positive value as good general combiner for grain width. Based on performance of all parents for grain width, LLR 21 is responsible for higher grain width (Table 7). The interesting fact revealed by this study is that trait like grain width was expressing under treated condition. Under rain-fed condition all the parents behaved same for grain width (Table-3). The value for SCA effects is considered as very important to select cross combinations having higher probability of creating trans-grassive segregation. Out of 15 crosses LLR 20 x CB 42 and LLR 20 x Parula showed positive significant value of SCA under rain-fed condition, while crosses Nacozari x LLR 22, LLR 22 x LLR 21, LLR 20 x LLR 21 and Parula x LLR 21 were observed with significant value of SCA for treated condition (Table-7).

ABLE 3: Mean values of 21 wheat genotypes for traits under treated and control condition

	Control (Rainfed condition)								Treated (treated with KI)							
Genotypes	GL	GW	TGW	YLD	GS	PH	NT	DH	GL	GW	TGW	YLD	GS	PH	NT	DH
Nacozari	8.32	3.43	37.13	2671.00	47.66	78.97	9.33	94.00	7.70	3.20	30.30	2132	35.00	80.60	10.00	94.00
LLR 22	8.43	3.47	40.48	2665.30	50.00	96.00	10.66	94.00	8.10	3.10	38.00	2235	40.60	94.30	11.30	94.00
LLR 20	7.98	3.21	39.26	1730.66	52.66	88.00	8.66	88.00	7.30	2.80	32.30	1066	30.30	86.00	9.30	88.00
CB 42	8.11	3.38	41.22	2213.00	33.00	72.21	8.66	89.00	6.70	2.60	28.70	1474	27.00	72.50	7.00	89.00
Parula	8.50	3.12	35.98	1986.00	62.33	71.54	8.66	91.00	7.30	2.90	29.10	1367	39.60	71.20	9.00	91.00
LLR 21	8.40	3.27	39.11	2370.00	44.33	77.10	8.66	93.00	8.00	2.90	33.40	1957	35.30	77.50	7.60	93.00
Nacozari x LLR22	8.36	3.42	42.23	1950.00	42.66	60.83	13.00	91.00	7.90	3.20	36.00	1335	27.00	61.30	12.00	91.00
Nacozari x LLR 20	8.10	3.32	40.74	1410.60	24.66	73.60	12.33	90.00	7.10	2.80	29.30	1073	26.60	73.40	11.00	90.00
Nacozari x CB 42	8.64	3.09	32.21	1565.30	51.00	76.93	11.00	82.00	8.00	2.90	24.80	1320	40.00	77.00	11.60	82.00
Nacozari x Parula	8.46	3.11	31.85	2033.00	17.00	75.94	6.33	84.00	7.20	2.90	25.20	1659	18.30	77.20	7.60	84.00
Nacozari x LLR 21	8.34	3.43	44.52	2191.60	35.00	65.41	8.33	94.66	7.90	3.20	40.00	1881	18.00	65.90	8.00	94.60
LLR 22 x LLR 20	8.34	3.51	40.54	1971.60	36.33	75.08	6.66	80.00	7.50	3.30	32.00	1445	22.60	75.10	7.60	80.00
LLR 22 x CB 42	8.25	3.23	37.89	2459.00	51.33	67.05	6.66	84.00	7.80	3.00	30.40	2022	39.60	67.60	6.30	84.00
LLR 22 x Parula	7.91	3.19	31.16	2355.60	59.66	80.24	13.33	83.00	6.30	2.90	24.90	1836	33.60	80.50	12.00	83.00
LLR 22 x LLR 21	8.44	3.53	44.56	1440.00	43.33	48.63	11.00	84.00	7.20	3.20	32.80	960	24.60	49.20	11.60	84.00
LLR 20 x CB 42	8.14	3.50	42.29	2231.30	48.66	42.82	5.66	86.66	7.60	3.30	35.60	1796	36.00	43.50	7.60	86.60
LLR 20 x Parula	8.33	3.41	40.05	2592.30	41.33	53.52	7.33	84.00	6.80	3.00	29.20	2137	30.60	54.00	7.60	84.00
LLR 20 x LLR 21	8.83	3.38	38.79	2492.00	50.66	74.12	10.33	83.33	7.40	3.10	33.30	1475	14.60	75.10	10.30	83.30
CB 42 x Parula	8.30	3.37	37.14	1856.00	17.66	79.75	6.00	90.00	7.90	3.20	30.60	1268	19.00	79.30	6.60	90.00
CB 42 x LLR 21	0.51	3.48	42.51	2253.30	32.00	62.68	4.33	92.33	8.10	3.30	37.40	1443	25.30	63.00	6.00	92.30
Parula x LLR 21	8.47	3.40	34.64	2021.00	46.33	65.60	6.67	92.66	8.00	3.10	30.80	1659	36.00	65.80	7.30	92.60

GL=grain length (mm), GW=grain width (mm), TGW= 1000grain weight (g), YLD= yield per plant (g), GS= no of grains per spike, PH= plant height (cm), NT= tillers per plants, DH= days to heading, SL= spike length (cm)

1000 Grain weight: As shown in results significant values for mean squares for GCA as well as for SCA displayed the significance of both additive and dominance genetic effects for 1000-grain weight under treated conditions but were non-significant for control condition. Similar findings have been reported by Arshad and Chowdhry (2002) and Mahantashivayogayya et al., (2004). Greater SCA variance for 1000 grain weight depicted the Importance of dominance under treated condition. While under control condition showed additive gene action, the present results are similar as early findings of Chandrashekhar and Kerketta (2004), Zalewski (2000) and Yao et al. (2004), who reported additive gene action for the inheritance of 1000grain weight. Under control condition (rain-fed condition) the GCA effects of parents were non-significant for all the parents. For treated condition (treated with potassium iodide to induce stress) Nacozari, LLR 22 and LLR 21 showed positive significant value for GCA and remaining showed negative value for general combining ability. Results indicated that LLR 21 was highly responsible for contribution of pre-anthesis assimilates to grain (Table-3). However, the parents LLR 20, CB 42 and Parula showed negative GCA values and were responsible for less contribution of pre-anthesis assimilates to grain. Under control condition all the crosses showed non -significant results, while the crosses Nacozari x LLR 22, Nacozari x LLR 20, LLR 22 x LLR 21, LLR 20 x CB 42 and Parula x LLR 21 were observed with significant value of SCA for treated condition. Cross Parula x LLR 21 showed highest value for SCA under treated conditions (Table-7).

Yield per plant: GCA and SCA mean squares were significant for grain yield per plant control and treated condition except for GCA variance under control condition. Significant mean square values for corresponding to GCA as well as SCA for yield per plant have also been reported by Mahmood and Chowdhry (2002) and Mahantashivayogayya (2004). Estimation of variance components revealed a greater GCA and dominance variance under both control and treated condition indicating the importance of additive genetic inheritance for grain yield per plant. Reported results has been found contradictting with the findings of Chowdhry *et al.,* (1999), Kashif and Khaliq (2003), Saeed *et al.,* (2005), and Farooq et al., (2006). The GCA effects of parents for control condition (rain-fed condition) were non-significant for all the parents. For treated condition (treated with potassium iodide to induce stress) Nacozari and CB 42 showed positive significant value for GCA and remaining showed negative value for general combining ability. Results indicated that Nacozari was highly responsible for contribution of yield per plant (Table-3). However, the parents LLR 20, LLR 22, LLR 21 and Parula showed negative GCA values and were responsible for less contribution of yield per plant (Table-7).

Grains per spike: The results revealed that differences due to GCA and SCA for grains per spike were highly significant under treated condition and non-significant for GCA under control condition. Chowdhry *et al.,* (1999a), Arshad and Chowdhry (2002) and Kashif and Khaliq (2003) also observed significant mean squares due to GCA and SCA for grains per spike. Variance components revealed a greater dominance variance under both plantings. Much greater SCA variance highlighted the importance of dominance due to greater dominance variance under both plantings. Thus, non-additive effects were involved in the inheritance of grains per spike as reported by Chowdhry *et al.,* (1999a) and Shoran *et al.,* (2003). While Hassani *et al.,* (2005) and Farooq *et al.,* (2006) indicated high ratio GCA to SCA variance for this trait. The GCA effects of parents for control condition (rain-fed condition) were non-significant for all the parents. For treated condition (treated with potassium iodide to induce stress) Nacozari and CB 42 showed positive significant value for GCA and remaining showed negative value for general combining ability. The results indicated that Nacozari is highly responsible for contribution of grains per spike (Table-3). However, the parents LLR 20, LLR 22, LLR 21 and Parula showed negative GCA values and were responsible for less contribution of grains per spike. Under control condition Nacozari x Parula, Nacozari x LLR 21, LLR 22 x LLR 20, LLR 22 x CB 42, LLR 20 x LLR 21 and Parula x LLR 21 significant results and cross LLR 22 x CB 42 showed highest value for SCA under control conditions. While the crosses Nacozari x LLR 22, Nacozari x Parula, Nacozari x LLR 21, LLR 22 x CB 42, LLR 20 x CB 42 and LLR 20 x Parula were observed with significant value of SCA for treated condition Cross LLR 22 x CB 42 showed highest value for SCA under treated conditions (Table-7).

Table 7: Ranking of good cross combination based on SCA effect in a 6 × 6 diallel cross of wheat for treated condition i.e. under stress

Traits	Parents with higher performance for SCA	Good Crosses	Superior common crosses
GL	LLR 20 x CB 42 Parula x LLR 21 LLR 22 x CB 42 Nacozari x LLR 22 Nacozari x LLR 21	LLR 20 x CB 42 Parula x LLR 21 LLR 22 x CB 42	Parula x LLR 21
GW	Parula x LLR 21 LLR 22 x LLR 21 LLR 20 x LLR 21 Nacozari x LLR 22	Parula x LLR 21 LLR 22 x LLR 21 LLR 20 x LLR 21	Parula x LLR 21 LLR 22 x LLR 21
TGW	Parula x LLR 21 Nacozari x LLR 22 LLR 22 x LLR 21 Nacozari x LLR 20 LLR 20 x CB 42	Parula x LLR 21 Nacozari x LLR22 LLR 22 x LLR 21	Parula x LLR 21 Nacozari x LLR 22
YLD	Nacozari x LLR 22 LLR 20 x CB 42 CB 42 x Parula LLR 20 x Parula LLR 22 x Parula	Nacozari x LLR22 LLR 20 x CB 42 CB 42 x Parula	Nacozari x LLR 22 LLR 20 x CB 42
GS	LLR 22 x CB 42 LLR 20 x CB 42	LLR 22 x CB 42	

	Nacozari x Parula Nacozari x LLR 22 LLR 20 x Parula	LLR 20 x CB 42 Nacozari x Parula	LLR 22 x CB 42 LLR 20 x CB 42
PH	CB 42 x LLR 21 Nacozari x LLR 22 LLR 22 x CB 42 LLR 20 x Parula Nacozari x LLR 20	CB 42 x LLR 21 Nacozari x LLR22 LLR 22 x CB 42	Nacozari x LLR 22
NT	LLR 20 x Parula LLR 20 x LLR 21 CB 42 x LLR 21 LLR 22 x CB 42 Nacozari x LLR 22	LLR 20 x Parula LLR 20 x LLR 21 CB 42 x LLR 21	LLR 20 x Parula
DH	LLR 22 x LLR 20 LLR 22 x LLR 21 Parula x LLR 21 LLR 20 x CB 42 Nacozari x LLR 22	LLR 22 x LLR 20 LLR 22 x LLR 21 Parula x LLR 21	Parula x LLR 21

Plant height: It was revealed that SCA mean squares were greater and significant for plant height under control condition but under treated condition GCA were greater than SCA and highly significant. Rehman et al., (2002), Kashif and Khaliq (2003) and Chandrashekhar and Kerketta (2004) also reported significant mean squares values corresponding to GCA as well as SCA. Higher GCA and additive variance for plant height (Table 5 & 6) was also indicated by variance components in control condition. Additive genetic effects have been reported by Chowdhry *et al.,* (1999b) and Iqbal and Chowdhry (2000). However, non-additive effects for plant height were reported by Chowdhry *et al.*, (1999a), Shoran *et al.*, (2003) and Chowdhry *et al.*, (2005). For arents the GCA effects under control condition (rain-fed condition) were non-significant for all the parents. For treated condition (treated with potassium iodide to induce stress) Nacozari showed positive significant value for GCA, and CB 42 and LLR 21 showed negative value for general combining ability. The results indicated that Nacozari is responsible for contribution of grains per spike (Table-3). However, the parents CB 42 and LLR 21 showed negative GCA values and were responsible for less contribution of grains per spike. Under the control condition LLR 22 x LLR 20 showed significant result. While the Nacozari x LL-R 22, Nacozari x LLR 20, LLR 22 x CB 42, LLR 22 x Parula, LLR 20 x Parula and CB 42 x LLR 21 were observed with significant value of SCA for treated condition Cross CB 42 x LLR 21 showed highest value for SCA under treated conditions.

Table 5: Estimates of GCA and SCA effects of six parents and their direct crosses for morphological traits under control condition

Parents	GL	GW	TGW	YLD	G/S	P HT	NT	DH	SL
Nacozari	-0.02 ns	-0.01 ns	-0.01 ns	41.00 ns	3.01 ns	0.67 ns	1.22 **	0.18 ns	-0.14 ns
LLR 22	0.05 ns	-0.01 ns	-0.35 ns	-33.54 ns	-2.36 ns	4.00 ns	-0.40 ns	1.01 ns	0.18 ns
LLR 20	-0.03 ns	0.01 ns	-0.01 ns	20.71 ns	3.10 ns	2.48 ns	0.51 ns	-0.07 ns	0.24 ns
CB 42	0.02 ns	-0.03 ns	0.34 ns	-5.67 ns	-1.74 ns	-1.25 ns	-0.40 ns	0.39 ns	0.07 ns
Parula	-0.02 ns	-0.01 ns	-0.39 ns	-102.46 ns	1.51 ns	-4.16 ns	0.72 *	-1.65 *	-0.01 ns
LLR 21	0.01 ns	0.04 ns	0.41 ns	79.96 ns	-3.53 ns	-1.74 ns	-1.65 **	0.14 ns	-0.34 ns
SCA EFFECTS									
Nacozari x LLR 22	0.00 ns	-0.08 *	0.01 ns	65.78 ns	2.41 ns	3.57 ns	0.43 ns	1.68 ns	1.11 **
Nacozari x LLR 20	0.13 *	-0.07 ns	-0.36 ns	-536.14 **	-5.38 *	-3.58 ns	2.18 **	-0.57 ns	0.35 ns
Nacozari x CB 42	0.07 ns	0.05 ns	0.02 ns	-80.10 ns	-14.21 **	1.41 ns	-0.57 ns	-1.36 ns	-0.91 **
Nacozari x Parula	-0.06 ns	-0.02 ns	-0.64 ns	30.03 ns	7.54 **	-2.16 ns	-0.02 ns	-2.99 **	0.17 ns
Nacozari x LLR 21	-0.12 *	0.04 ns	1.26 ns	199.28 *	6.91 **	-11.63 **	0.35 ns	-3.78 **	0.16 ns
LLR 22 x LLR 20	-0.08 ns	0.02 ns	0.26 ns	246.40 **	6.99 **	13.78 **	1.14 *	2.93 **	0.62 *
LLR 22 x CB 42	-0.03 ns	-0.05 ns	0.12 ns	111.11 ns	9.83 **	-2.43 ns	0.06 ns	1.47 ns	0.53 ns
LLR 22 x Parula	0.04 ns	-0.05 ns	0.36 ns	-329.76 **	-3.09 ns	-0.24 ns	3.27 **	0.18 ns	0.04 ns
LLR 22 x LLR 21	0.02 ns	-0.03 ns	-0.66 ns	-98.85 ns	-5.71 *	-0.42 ns	-0.36 ns	-5.28 **	-0.80 *
LLR 20 x CB 42	-0.11 *	0.11 **	1.09 ns	310.20 **	3.04 ns	-13.82 **	-1.19 **	-3.78 **	-0.33 ns
LLR 20 x Parula	0.18 **	0.08 *	-0.36 ns	-10.35 ns	-15.21 **	1.99 ns	-4.32 **	6.26 **	-0.68 *
LLR 20 x LLR 21	-0.04 ns	-0.03 ns	0.39 ns	138.90 ns	8.83 **	22.14 **	1.06 *	3.80 **	0.71 *
CB 42 x Parula	0.06 ns	-0.04 ns	-0.34 ns	-376.97 **	-5.05 ns	5.31 ns	2.27 **	0.80 ns	0.39 ns
CB 42 x LLR 21	0.03 ns	-0.01 ns	0.06 ns	-132.05 ns	-8.67 **	4.47 ns	-0.69 ns	-1.32 ns	-0.55 ns
Parula x LLR 21	-0.11 *	0.05 ns	1.69 ns	341.40 **	5.08 *	-10.64 **	-0.82 ns	-1.95 *	-0.11 ns

* and **, Significant at 5% and 1% probability level, respectively, ns: Non-significant.

GL=grain length (mm), GW=grain width (mm), TGW= 1000grain weight (g), YLD= yield per plant (g), GS= no of grains per spike, PH= plant height (cm), NT= tillers per plants, DH= days to heading, SL= spike length (cm)

Tillers per plant: Highly significant mean squares values for GCA as well as SCA displayed the importance of additive and dominance genetic effects for tillers per plant under control as well as treated condition. Mahmood and Chowdhry (2002) and Srivastava (2005) have reported similar findings in their study. The results for combining ability study of plant height have been shown in the table 5 and 6. The GCA effects of parents for control condition (rain-fed condition) were significant for Nacozari and Parula. Under treated condition (treated with potassium iodide to induce stress) LLR 22 showed positive significant value for GCA, and CB 42, Parula and LLR 21 showed negative value for general combining ability. Results indicated that Nacozari was responsible for contribution of numbers of tillers per plant. However, the parents CB 42 and LLR 21 showed negative GCA values and are responsible for less contribution of numbers of tillers per plant. Under control condition Nacozari x LLR 20, LLR 22 x LLR 20, LLR 22 x Parula, LLR 20 x LLR 21 and CB 42 x Parula showed significant result (Table-3). While the crosses Nacozari x LLR 22, LLR 22 x CB 42, LLR 20 x Parula and CB 42 x LLR 21 were observed with significant value of SCA for treated condition. Cross LLR 20 x Parula showed highest value for SCA under treated conditions.

Table 6: Estimates of GCA and SCA effects of parents and their direct crosses for morphological traits under treated condition

Parents	GL	GW	TGW	YLD	G/S	P HT	NT	DH	SL
Nacozari	0.03 ns	-0.1**	0.08 **	147.81 **	4.53 **	8.27 **	0.21 ns	3.26 **	0.63 **
LLR 22	0.19 **	0.00 ns	1.00 **	-42.78 *	-1.14 *	1.71 ns	1.38 **	1.22 **	0.02 ns
LLR 20	-0.24 **	-0.0 ns	-0.9 **	-166.7**	-0.81 ns	1.26 ns	0.37 ns	-3.49 **	-0.31 **
CB 42	-0.09 **	-0.02 ns	-0.5 **	105.01 **	2.15 **	-7.93 **	-0.54 *	-2.65 **	0.17 ns
Parula	-0.15 **	-0.00 ns	-1.8 **	-25.19 ns	-2.64 **	0.97 ns	-0.88 **	-0.32 ns	-0.62 **
LLR 21	0.25 **	0.09 **	2.13 **	-18.07 ns	-2.10 **	-4.29 **	-0.54 *	1.97 **	0.10 ns
SCA EFFECTS									
Nacozari x LLR 22	0.00 ns	-0.08 *	0.01 ns	65.78 ns	2.41 ns	3.57 ns	0.43 ns	1.68 ns	1.11 **
Nacozari x LLR 20	0.13 *	-0.07 ns	-0.36 ns	-536.14 **	-5.38 *	-3.58 ns	2.18 **	-0.57 ns	0.35 ns
Nacozari x CB 42	0.07 ns	0.05 ns	0.02 ns	-80.10 ns	-14.21 **	1.41 ns	-0.57 ns	-1.36 ns	-0.91 **
Nacozari x Parula	-0.06 ns	-0.02 ns	-0.64 ns	30.03 ns	7.54 **	-2.16 ns	-0.02 ns	-2.99 **	0.17 ns
Nacozari x LLR 21	-0.12 *	0.04 ns	1.26 ns	199.28 *	6.91 **	-11.63 **	0.35 ns	-3.78 **	0.16 ns
LLR 22 x LLR 20	-0.08 ns	0.02 ns	0.26 ns	246.40 **	6.99 **	13.78 **	1.14 *	2.93 **	0.62 *
LLR 22 x CB 42	-0.03 ns	-0.05 ns	0.12 ns	111.11 ns	9.83 **	-2.43 ns	0.06 ns	1.47 ns	0.53 ns
LLR 22 x Parula	0.04 ns	-0.05 ns	0.36 ns	-329.76 **	-3.09 ns	-0.24 ns	3.27 **	0.18 ns	0.04 ns
LLR 22 x LLR 21	0.02 ns	-0.03 ns	-0.66 ns	-98.85 ns	-5.71 *	-0.42 ns	-0.36 ns	-5.28 **	-0.80 *
LLR 20 x CB 42	-0.11 *	0.11 **	1.09 ns	310.20 **	3.04 ns	-13.82 **	-1.19 **	-3.78 **	-0.33 ns
LLR 20 x Parula	0.18 **	0.08 *	-0.36 ns	-10.35 ns	-15.21 **	1.99 ns	-4.32 **	6.26 **	-0.68 *
LLR 20 x LLR 21	-0.04 ns	-0.03 ns	0.39 ns	138.90 ns	8.83 **	22.14 **	1.06 *	3.80 **	0.71 *
CB 42 x Parula	0.06 ns	-0.04 ns	-0.34 ns	-376.97 **	-5.05 ns	5.31 ns	2.27 **	0.80 ns	0.39 ns
CB 42 x LLR 21	0.03 ns	-0.01 ns	0.06 ns	-132.05 ns	-8.67 **	4.47 ns	-0.69 ns	-1.32 ns	-0.55 ns
Parula x LLR 21	-0.11 *	0.05 ns	1.69 ns	341.40 **	5.08 *	-10.64 **	-0.82 ns	-1.95 *	-0.11 ns

* and **, Significant at 5% and 1% probability level, respectively, ns: Non-significant.
GL=grain length (mm), GW=grain width (mm), TGW= 1000grain weight (g), YLD= yield per plant (g), GS= no of grains per spike, PH= plant height (cm), NT= tillers per plants, DH= days to heading, SL= spike length (cm)

Days to heading: The GCA effects of parents for control condition (rain-fed condition) were non-significant for all the parents. Under treated condition (treated with potassium iodide to induce stress) Nacozari, LLR 22 and LLR 21 showed positive significant value for GCA, and CB 42, Parula and LLR 20 showed negative value for general combining ability. Under control condition LLR 20 x LLR 21, LLR 22 x LLR 20 and LLR 20 x Parula showed significant results. While the Nacozari x LLR 22, LLR 22 x LLR 20, LLR 22 x LLR 21, LLR 20 x CB 42 and Parula x LLR 21 were observed with significant value of SCA for treated condition Cross LLR 22 x LLR 20 showed highest value for SCA under treated conditions.

Spike length: The GCA effects of parents for control condition (rain-fed condition) were non-significant for all the parents. Under treated condition (treated with potassium iodide to induce stress) Nacozari showed positive significant value for GCA; however, LLR 20 and Parula showed negative value for general combining ability. Results indicated that Nacozari is responsible for contribution spike length. Under control condition Nacozari x LLR 22, LLR 22 x LLR 20 and LLR 20 x LLR 21 showed significant results. While the crosses Nacozari x Parula, LLR 20 x CB 42, CB 42 x Parula and Parula x LLR 21 were observed with significant value of SCA for treated condition Cross LLR 20 x CB 42 showed highest value for SCA under treated conditions (Table-3).

Heritability estimates of all the characters under study, for both broad sense and narrow sense heritability have been presented in Table 8. The difference among two different treatments is obvious for heritability. The traits related directly to yield i.e. Grain length, thousand grains weight, yield per plant grains per spike and number of tillers showed higher heritability under stress conditions.

Correlation among all the traits has been shown for treated in Table 10. Results for correlation indicates that trait yield has significant positive correlation with plant height (r=0.114), days to heading (r=0.199), thousand grains weight (r=0.131) and grains per spike (r=0.3532). Thousand grain weight, being most important factor contributing to yield has shown significant positive association with days to heading (r=0.5043), grain length (0.522) and grain width (r=0.2447). Correlation matrix for morphological traits under control (rainfed condition) has been presented in Table 9, which depicted significant association of yield with days to heading, grains per spike, grain width and plant height.

Table 8: Estimates of heritability for all the traits under study heritability

	Control		Treated	
Traits	heritability BS	heritability NS	heritability BS	heritability NS
Grain length	69.83	4.06	79	32.81
Grain width	88.13	5.21	83	26.64
1000 grain weight	83.09	26.95	92	31.99
Yield per plant	72.12	7.82	95	14.61
Grains per spike	65.36	8.02	88	24.22
Plant height	67.72	16.81	83	39.14
Tillers per plant	52.57	35.83	72	23.71
Days to heading	70.36	4.80	83	63.05
Spike length	66.78	8.11	75	22.70
Yield per plant	72.12	7.82	95	14.61
Grains per spike	65.36	8.02	88	24.22
Plant height	67.72	16.81	83	39.14
Tillers per plant	52.57	35.83	72	23.71
Days to heading	70.36	4.80	83	63.05
Spike length	66.78	8.11	75	22.70

Table- 9: Correlation matrix of all the traits under study for control condition

	DH	**GL**	**GS**	**GW**	**NT**	**PH**	**SL**	**TGW**
DH								
GL	0.176							
GS	-0.074	-0.124						
GW	0.216*	-0.003	-0.188					
NT	-0.027	-0.236*	0.320*	-0.168				
PH	0.135	-0.119	0.052	-0.381	0.224			
SL	0.244*	0.307**	0.37	-0.007	0.011	-0.197		
TGW	0.259*	-0.053	-0.16	0.747**	-0.082	-0.405*	0.215*	
YLD	0.187**	-0.122	0.261**	0.191*	-0.190*	0.110*	0.082	-0.024

* and **, Significant at 5% and 1% probability level, respectively, ns: Non-significant. GL=grain length, GW=grain width, DMA= total dry matter at anthesis, DMM= total dry matter at maturity, TDM=translocation of dry matter, TE%= translocation efficiency percentage, CPA= contribution of post-anthesis assimilates, TGW= 1000grain weight, YLD= yield per plant, GS= no of grains per spike, PH= plant height, NT= tillers per plants, DH= days to heading, SL= spike length

Table 10: Correlation matrix of all the traits under study for treated condition

	DH	**GL**	**GS**	**GW**	**NT**	**PH**	**SL**	**TGW**
GL	0.4354**							
GS	0.1524	0.1391						
GW	0.1442**	0.2979**	0.0604					
NT	-0.0931	-0.1308*	0.1447*	-0.1331*				
PH	0.129	0.1032	0.0864	-0.2553	0.195*			
SL	0.24	0.1594*	0.4117**	0.0527	-0.000	-0.199*		
TGW	0.5043**	0.522**	-0.1621	0.2447*	-0.099	-0.200	0.097	
YLD	0.199*	0.0782	0.3532**	0.0801	-0.180	0.114*	0.094	0.131*

* and **, Significant at 5% and 1% probability level, respectively, ns: Non-significant. GL=grain length, GW=grain width, DMA= total dry matter at anthesis, DMM= total dry matter at maturity, TDM=translocation of dry matter, TE%= translocation efficiency percentage, CPA= contribution of post-anthesis assimilates, TGW= 1000grain weight, YLD= yield per plant, GS= no of grains per spike, PH= plant height, NT= tillers per plants, DH= days to heading, SL= spike length

Our results clearly suggest that stress induced condition with treatment of potassium iodide (desiccation agent) can be a useful tool for screening of genotypes and it can be integrated into breeding program for efficient selection of better performing genotypes. Overall, these results (presented in this paper) showed that good performance of a genotype under stress conditions is key factor for selection of better performance genotypes to cope with the challenging rainfed environment. Among parents with differential phenotypes, LLR 21 showed to be best general combiner while cross combination Nacozari x LLR 21 showed best performance for multiple traits associated with yield and yield contributing factors. Thus, these genotypes can be further explored for their performance under a breeding program.

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