SAARC J. Agri., 15(2): 177-192 (2017) *DOI: http://dx.doi.org/10.3329/sja.v15i2.35147*

SELECTION OF DROUGHT TOLERANT WHEAT GENOTYPES BY OSMOTIC STRESS IMPOSED AT GERMINATION AND EARLY SEEDLING STAGE

R.R. Saha[1*], A. Hannan[2], A. Nessa[2], M.A. Malek[3] and M.R. Islam[4]

[1]Plant Physiology Division, Bangladesh Agricultural Research Institute, Gazipur-1701, Bangladesh
[2]Seed Technology Division, Bangladesh Agricultural Research Institute, Gazipur-1701, Bangladesh
[3]Plant Genetic Resources Center, Bangladesh Agricultural Research Institute, Gazipur-1701, Bangladesh
[4]Regional Agricultural Research Station, BARI, Ishurdi, Pabna, Bangladesh

ABSTRACT

An experiment on hundred wheat genotypes under different levels of osmotic stress was carried out during 2014 to select the genotype(s) tolerant to drought at germination and early seedling stage. Different levels of osmotic stress were imposed by using polyethylene glycol (PEG). Three osmotic stress levels viz. control (distilled water), 15% PEG solution and 25% PEG solution were used. Among the 100 genotypes the rate of germination percentage, final germination (%), root and shoot dry weight, amount of respiration and vigour index under PEG treatment was found significantly lower than that of control condition. Compared to control condition relative decrease in rate of germination, final germination, amount of respiration and vigour index among the wheat genotypes were found more at 25% PEG than that of 15% PEG treatment. However, the seed metabolic efficiency was significantly higher in wheat genotypes under both 15% PEG and 25% PEG treatment compared to the control condition. A significant positive correlation exists between the important growth parameters like rate of germination (%), final germination (%), shoot dry weight, root dry weight and vigour index. On the basis of these physiological traits against osmotic stress, nine genotypes of wheat such as BD-480, BD-498, BD-501, BD-513, BD-514, BD-519, BD-592, BD-618 and BD- 633 were selected as drought tolerant.

Keywords: Drought tolerant, osmotic stress, wheat genotypes

INTRODUCTION

Wheat is one of the most important cereal crops of the world. In most areas of the world, wheat is a principal food. In Bangladesh, it is the second most important grain crop after rice and grown in winter season which prevailing drought condition due to

[*] Corresponding author e-mail: saharinarani@yahoo.com

Received: 17.04.2017 *Accepted: 04.08.2017*

lack of rains. Drought is a severe limitation of plant growth, development and productivity, particularly in arid and semi-arid regions (Galle et al., 2007). Seed germination and early seedling growth are potentially the most critical stages for water stress (Ahmad et al., 2009). Besides the reduction in total germination, comparatively low soil moisture availability results in delayed emergence, a criterion of particular importance in the vigor and subsequent yielding ability of many crops (Azam and Allen, 1976). The rate and degree of seedling establishment are extremely important factors in determining both yield and time of maturity (Brigg and Aylenfisu, 1979).

Abiotic stresses like drought can directly or indirectly affect the physiological status of an organism by altering its metabolism, growth, and development. Among these, drought is a worldwide problem, constraining global crop production seriously and recent global climate change has made this situation more serious (Pan et al., 2002). Plants respond to drought with physiological and biochemical changes. The impacts of drought condition depend on their severity and the stage of plant growth during which they occur. Seedling emergence is one of the most sensitive growth stages that are susceptible to water deficit. Therefore, seed germination, seedling vigour and coleoptiles's length are prerequisites for successful stand establishment of wheat under drought conditions. Simulation of drought stress by polyethylene glycol (PEG) induces drought stress on the plants (Jiang et al., 1995). PEG-6000 has long been utilized as a reliable marker under laboratory conditions for testing the drought tolerant genotypes which could be a cost effective and still potential approach. With this view the present study was conducted to select wheat genotype(s) for their drought tolerance at the germination and early seedling stage by using PEG induced water stress.

MATERIALS AND METHODS

The experiment was conducted in both the laboratories of Plant Physiology Division and Seed Technology Division, BARI, Gazipur during 2014. The experiment was laid out in a completely randomized design with two replications. Hundred wheat genotypes were tested under osmotic stress imposed by using polyethylene glycol (PEG6000). Solutions were prepared according to Baloch et al. (2012). There were three osmotic stress levels i.e. T_1-control (with distilled water), T_2-15% PEG solution and T_3-25% PEG solution. Thirty seeds were placed in Whatman number 1 filter paper in petridishes. After placing the seeds in petridishes, measured volume of 10 ml PEG solution or distilled water was given in the petridishes. Three days after placement of seeds in the petridishes, 10 ml distilled water was added in each petridishes to minimize the evapo-transpiration losses. Germination was counted at 24-hour interval and continued up to the 7 day. The seeds were considered germinated when plumule and radicle came out and longer than 2 mm. After 10 days of treatment, other parameters such as number of seedling, dry weight of shoot, root and remaining seed was taken on all seedlings of each treatment which having at

least 3 cm long in both root and shoot. The rate of germination was calculated using the formula according to Krishnasamy and Seshu (1990). Seed metabolic efficiency (SME) and amount of seed material respired (SMR) were calculated using the formula according to Rao and Sinha (1993). All percentage data were transformed into arcsine value and recorded data were analyzed statistically (ANOVA and correlation). Least Significant Difference (LSD) was used to compare the mean differences among the treatments.

RESULTS & DISCUSSION

Different seedling traits

Varying response of wheat genotypes to PEG treatment is very important for screening drought tolerant genotypes at early seedling stage before conducting extensive and expensive field tests. In the present study, rate of germination (%), final germination (%), root and shoot dry weight, amount of respiration of 100 wheat genotypes were significantly decreased due to osmotic stress i.e. PEG treatment compared to that of control treatment (Table 1 & 2). Roza et al. (2010) noted that significant decrease in shoot and root dry matter of wheat at PEG treatment. On the other hand, dry weight of remaining seed, root-shoot ratio and seed metabolic efficiency were significantly increased at PEG treatment than that of control condition (Table 2). It was observed that the range between maximum and minimum values of rate of germination (%) and final germination (%) among the 100 wheat genotypes under PEG treatment was higher than that of control treatment. It might be due to variable responses of wheat genotypes to osmotic stresses. It was also found that the rate of germination and final germination relatively decreased more in 25% PEG than that of 15% PEG treatment. This was probably due to depression in traits due to PEG desiccation. The remaining seed dry weight was higher in both 15% PEG and 25% PEG treatment than that of control treatment. The result indicated that PEG induced stress condition might be affected the transformation of seed reserve to available form which was essential for producing seedling organ i,e, root and shoot. It is also observed that dry matter was more or less equally distributed in root, shoot and remaining seed but slightly higher dry matter utilized for respiration under control condition. Whereas, in case of PEG treatment, most of the dry matter remained in seeds which might be due to inhibitory effect of osmotic stress on breakdown of seed reserves resulting lower accumulation of root and shoot dry matter as well as utilizing smaller amount of dry matter for respiration. For this reason, decreasing trend was presumably found in seed germination as well as seedling growth.

Root and shoot ratio significantly varied among the wheat genotypes under different level of stress (Table 2). Higher root-shoot ratio was observed in all the genotypes under drought stress condition i.e. PEG treatments compared to control condition. This might be due to the tendency of enhanced root growth for surviving under stress

condition. The development of root system under water deficit conditions appears to be a very viable criterion to select water stress tolerant genotypes of a crop because the roots take the moisture from lower layers of soil. Dhanda et al. (2004) reported that continued growth of roots in dry soil is particularly important to avoid drought stress. On the other hand, significantly decreasing amount of respiration was found in all the genotypes under PEG treatment than that of control condition which indicated a lower enzymatic activity under stressful conditions. However, the seed metabolic efficiency was significantly higher in wheat genotypes under both 15% PEG and 25% PEG treatment compared to the control. Under stress condition, the higher value of seed metabolic efficiency indicated the seeds may have higher efficiency to utilize seed reserves for producing root and shoot rather than respiration and/or unable to breakdown the seed reserve resulting higher remaining seed dry weight.

Vigour index

Vigour index differed significantly among the wheat genotypes under variable drought condition (Table 3). Due to PEG treatment considerable reduction was found in seed vigour index in all the genotypes compared to control condition. Relatively more reduction of vigour index was observed among the wheat genotypes at 25% PEG than that of 15% PEG treatment. Similar to present findings, Bayoumi *et al.* (2008) and Rauf et al. (2007) also noted significant reductions in all seedling traits by osmotic stress in wheat. However, among the 100 genotypes, nine genotypes such as BD-480, BD-498, BD-501, BD-513, BD-514, BD-519, BD-592, BD-618 and BD-633 showed relatively less reduction in vigour index at both 15% PEG and 25% PEG treatment and these genotypes were regarded as drought tolerant.

Correlations among seedling traits

Correlations are important statistical parameters for selection and crop improvement program (Baloch et al. (2012). Rate of germination showed significantly positive correlation with shoot dry weight (r = 0.64), amount of respiration (r = 0.46) and vigour index (r = 0.6) but negative correlation with remaining seed dry weight (r = - 0.57) and root-shoot ratio (r = - 0.39) (Table 4). Final germination (%) and root dry weight expressed significantly positive correlation with vigour index (r = 0.78 and 0.7, respectively). Shoot dry weight showed significantly positive correlation with amount of respiration (r = 0.54) and vigour index (r = 0.81) but significantly negative correlation with remaining seed dry weight, total seedling dry weight and root-shoot ratio. In case of remaining seed dry weight, significant positive correlation was found with total seedling dry weight (r = 0.88) but significantly negative correlation with amount of respiration (r = -0.64) and vigour index (r = - 0.65). Total dry weight of seedling positively correlated with seed metabolic efficiency (r = 0.48) and negatively correlated with amount of respiration (r = - 0.56). Similarly amount of respiration showed significantly negative correlation with seed metabolic efficiency(r = -0.8). Moreover, rate of germination (%), final germination (%), root and shoot dry weight and vigour index exhibited significant positive correlations with each other,

which suggesting that increase in any one of those traits correspondingly increase the other traits. It means that if one reliable trait is picked in osmotic stress and used as selection criterion that will lead to improve other seedling traits for drought conditions (Baloch et al., 2012). Several other workers (Bayoumi et al., 2008, Dhanda et al., 2004, Rauf et al., 2007 and Baloch et al., 2012) also noted positive correlations among wheat seedling traits under osmotic or water stress condition.

Table 4. Correlation coefficient (r) among different seedling traits of wheat genotypes as affected by polyethylene glycol (PEG-6000) treatment

	RG	FG	RDW	SDW	RSDW	TDW	R:S	ASR	SME	VI
		0.45	0.3	0.64	-0.57	-0.37	-0.39	0.46	-0.22	0.6
RG	1	NS	NS	**	**	NS	**	**	NS	**
			0.39	0.44	-.44	-0.25	-0.2	0.22	-0.08	0.78
FG		1	NS	NS	NS	NS	NS	NS	NS	**
				0.4	-0.29	0.1	0.37	0.12	0.22	0.7
RDW			1	NS	NS	NS	NS	NS	NS	**
					-0.73	-0.38	-0.63	0.54	-0.18	0.81
SDW				1	**	**	**	**	NS	**
						0.88	0.43	-0.64	0.39	-0.65
RSDW					1	**	NS	**	NS	**
							0.39	-0.56	0.48	-0.27
TDW						1	NS	**	**	NS
								-0.38	0.29	-0.25
R:S							1	NS	NS	NS
									-0.8	0.42
ASR								1	**	NS
										-0.06
SME									1	NS
VI										1

**Significant at 1% probability level, NS=Non-significant

RG-Rate of germination, FG-Final germination, RDW- Root dry weight, SDW-Shoot dry weight, RSDW- remaining seed dry weight, TDW-Total dry weight, R:S-Root –shoot ratio, SMR - amount of seed material respired, SME-Seed metabolic efficiency, VI-Vigour index

CONCLUSION

Significant positive correlation exists among some important growth parameters like rate of germination (%), final germination (%), shoot and root dry weight with vigour index. On the basis of these physiological traits against osmotic stress, nine wheat genotypes such as BD-480, BD-498, BD-501, BD-513, BD-514, BD-519, BD-592, BD-618 and BD- 633 were selected as drought tolerant.

REFERENCES

Ahmad, S., Ahmad, R., Ashraf, M.Y., Ashraf, M., and Waraich, E.A. (2009). Sunflower (*Helianthus Annuus* L.) response to drought stress at germination and seedling growth stages. *Pakistan Journal of Botany*, 41, 647-654.

Azam, G., and Allen, R.E. (1976). Interrelationship of seedling vigor criterion of wheat under different field situations and soil water potentials. *Crop Science*, 16, 615-618.

Baloch, M.J., Dunwell, J., Khakwani, A.A., Dennet, M., Jatoi, W.A., and Channa, S.A. (2012). Assessment of wheat cultivars for drought tolerance via osmotic stress imposed at early seedling growth stages. *Journal of Agricultural Research,* 50(3), 299-310.

Bayoumi, T.Y., Manal, H.E., and Metwali, E.M. (2008). Application of physiological and biological and biochemical indices as a screening technique for drought tolerance in wheat genotypes. *African Journal of Biotechnology*, 7(14), 2341-2352.

Brigg, K.G. and Aytenfisu, A. (1979). The effect of seedling rate, seeding date and location on grain yield, maturity, protein percentage and protein yield of some spring wheats in central Alberia. *Canadian Journal* of *Plant Science*, 59, 1129-1146.

Dhanda, S.S., Sethi G.S., and Behl, R.K. (2004). Indices of drought tolerance in wheat genotypes at early stages of plant growth. *Journal of Agronomy and Crop Science*, 190, 6-12.

Galle, A., Haldimann, P., and Feller, U. (2007). Photosynthetic performance and water relations in young pubescent oak (Quercus pubescens) trees during drought stress and recovery. *New Phytologist*, 174,799–810.

Jiang, Y., Macdonald, S.E., and Zwiazak, J.J. (1995). Effects of cold storage and water stress on water relations and gas exchange of white spruce (*Picea glauca*) seedlings. *Tree Physiology*, 15(4), 267-273.

Krishnasamy, V., and Seshu, D.V. (1990). Germination after accelerated aging and associated characters in rice varieties. *Seed Science and Technology*, 18, 353-359.

Pan, X.Y., Wang, Y.F., Wang, G.X., Cao, Q.D., and Wang, J. (2002). Relationship between growth redundancy and size inequality in spring wheat population mulched with clear plastic film. *Chinese Journal of Plant Ecology*, 26(2), 177-184.

Rao, D.G., and Sinha, S.K. (1993). Efficiency of mobilization of seed reserves in sorghum hybrids and their parents as influnced by temperature. *Seed Research*, 21(2), 97-100.

Rauf, M., Munir, M., Ul-Hassan, M., Ahmed, M., and Afzal, M. (2007). Performance of wheat genotypes under osmotic stress at germination and early seedling growth stage. *African Journal of Biotechnology*, 6(8), 971-975.

Roza, G. M., ShahzadJamaati-e-Somarin, K., and Zabihi-e-Mahmoodabad, R. (2010). Effects of polyethylene glycol and NaCI stress on two cultivars of wheat (*Triticum durum*) at germination and early seedling stages. *American-Eurasian Journal of Agricultural & Environmental Science*, 9, 86-90.

Table 1. Effect of drought stress through polyethylene glycol (PEG-6000) solution on rate of germination, final germination, dry weight of root and shoot wheat genotypes.

Genotypes	*Rate of Germination (%)			*Final Germination (%)			Root dry weight (mg)			Shoot dry weight(mg)		
	Control	PEG 15%	PEG 25%	Control	PEG 15%	PEG 25%	Control	PEG 15%	PEG 25%	Control	PEG 15%	PEG 25%
BD-466	49	22	10	82	71	24	3.7	3.6	3.3	6.7	4.6	4.3
BD-470	60	38	5	85	67	36	5.0	5.1	5.6	9.8	5.1	4.1
BD-473	82	42	7	92	74	63	3.6	4.5	3.7	7.9	5.0	3.9
BD-476	64	36	11	90	69	42	4.5	4.1	2.6	8.4	5.5	4.5
BD-479	75	35	7	93	72	41	3.9	4.3	3.3	8.1	4.9	4.2
BD-480	79	43	10	95	84	76	4.2	4.5	3.5	8.4	5.1	4.2
BD-481	68	44	10	88	69	59	3.4	4.2	3.7	7.2	5.5	4.7
BD-483	83	54	40	78	58	54	4.1	3.7	4.2	7.9	7.0	5.3
BD-487	56	29	10	88	77	38	4.0	4.6	3.0	8.2	5.5	4.0
BD-488	64	46	19	75	56	38	4.4	3.7	2.8	9.3	6.2	4.6
BD-489	76	43	11	95	75	62	4.1	5.3	4.0	8.4	5.5	3.9
BD-491	72	45	20	88	71	60	4.0	4.4	4.7	9.1	6.3	5.8
BD-493	94	83	20	87	65	63	5.1	6.4	0.5	9.9	7.8	8.3
BD-496	97	92	17	100	82	69	7.1	6.0	7.0	10.6	8.6	8.4
BD-497	98	91	8	85	72	64	5.7	6.6	7.1	11.6	7.0	8.6
BD-498	93	87	13	90	81	68	5.1	4.8	5.6	7.9	6.9	6.7
BD-499	98	88	16	98	83	70	5.5	6.6	8.2	10.6	9.5	9.5
BD-500	94	90	2	88	74	66	6.3	5.1	7.2	9.7	5.8	7.8
BD-501	93	91	15	95	81	70	6.5	7.1	7.2	9.2	9.5	7.8
BD-505	94	90	22	88	75	69	6.2	6.7	6.9	10.0	8.0	7.4
BD-507	96	76	11	88	72	70	5.9	5.3	6.9	9.9	5.8	8.8
BD-508	93	95	17	98	83	69	6.8	5.6	6.4	8.8	8.2	7.6
BD-509	86	77	4	98	57	56	5.6	5.6	6.1	9.5	7.8	7.6
BD-510	98	91	13	100	87	72	5.5	6.0	6.5	11.9	6.5	8.4
BD-511	73	70	19	87	72	68	7.1	5.7	6.9	9.1	5.7	6.2
BD-512	94	88	8	83	69	65	5.8	5.7	6.9	9.5	5.0	5.5
BD-513	93	91	16	75	63	65	6.1	7.8	6.7	7.0	6.2	5.7
BD-514	98	97	39	97	78	63	3.9	5.2	6.5	5.1	7.0	5.7
BD-516	97	90	20	98	81	71	5.2	5.1	7.0	9.9	5.5	5.7
BD-517	98	97	2	80	80	62	4.1	4.8	6.8	9.1	5.0	5.8
BD-519	98	95	19	95	81	67	3.0	5.1	7.1	7.0	5.0	5.4
BD-522	69	68	67	85	74	61	4.4	5.5	7.9	10.0	6.0	6.9
BD-524	97	95	18	95	84	68	4.7	4.4	7.0	7.7	4.8	6.8
BD-525	86	73	5	95	71	66	2.4	4.3	4.8	5.0	4.2	4.9
BD-527	98	81	2	92	75	62	2.8	3.8	4.2	6.1	4.1	4.2
BD-529	85	78	7	98	81	71	6.2	3.8	6.3	7.1	3.6	4.9

Genotypes	*Rate of Germination (%)			*Final Germination (%)			Root dry weight (mg)			Shoot dry weight(mg)		
	Control	PEG 15%	PEG 25%	Control	PEG 15%	PEG 25%	Control	PEG 15%	PEG 25%	Control	PEG 15%	PEG 25%
BD-531	98	97	6	97	81	71	6.7	6.8	3.8	8.7	5.4	3.3
BD-533	98	87	22	98	81	63	3.8	6.5	4.9	8.7	4.7	4.8
BD-534	98	51	40	98	78	57	6.8	6.0	4.3	7.9	5.0	4.6
BD-535	93	48	33	87	69	41	6.3	5.2	5.5	9.4	4.1	4.3
BD-536	98	54	22	98	87	69	9.0	4.3	6.5	8.8	5.7	4.6
BD-537	90	34	25	95	83	54	7.8	5.1	5.9	8.0	3.2	4.5
BD-539	90	25	30	88	78	36	8.8	5.0	3.2	10.0	4.2	3.1
BD-540	92	31	20	88	71	21	6.8	5.2	6.8	9.2	5.2	8.6
BD-541	98	27	33	98	81	51	7.6	5.3	3.9	9.5	4.5	4.9
BD-542	96	57	20	83	69	60	5.3	6.2	2.3	7.4	4.6	3.3
BD-545	73	32	18	93	81	60	8.7	5.3	4.9	9.4	3.6	4.5
BD-546	63	19	10	47	27	8	6.3	3.0	1.9	9.2	2.7	2.3
BD-547	97	43	11	98	86	68	7.1	5.0	4.5	8.7	4.3	5.3
BD-551	35	24	20	85	39	3	4.2	2.9	5.0	6.8	3.5	1.8
BD-552	82	28	9	90	68	66	5.7	6.2	4.1	8.3	6.1	4.0
BD-560	76	33	13	95	83	56	6.3	5.6	4.0	7.8	5.3	4.2
BD-562	95	54	21	100	84	72	7.1	6.7	5.0	9.5	5.7	4.8
BD-563	88	48	11	98	86	71	7.6	7.1	5.5	10.1	6.1	4.1
BD-567	84	54	22	98	86	74	6.7	5.3	3.9	6.9	5.4	4.6
BD-568	98	27	14	100	74	66	7.1	5.7	4.4	8.3	4.1	4.5
BD-569	85	20	16	100	89	59	7.1	6.0	4.8	9.0	5.6	4.5
BD-570	83	41	10	90	84	32	6.0	5.0	4.1	8.7	4.5	3.4
BD-574	85	40	3	97	80	32	5.6	6.6	4.1	7.7	5.4	4.5
BD-576	96	46	25	97	86	60	5.6	6.0	3.9	8.5	6.2	4.6
BD-579	95	39	8	98	86	51	8.1	6.7	3.3	9.2	6.4	4.4
BD-581	89	47	10	90	78	59	5.7	5.7	4.9	9.2	4.9	3.5
BD-582	95	58	32	93	77	68	8.0	8.0	6.5	9.5	6.2	4.8
BD-583	95	47	22	98	83	68	8.1	6.1	5.1	8.5	6.5	4.8
BD-584	97	42	27	97	78	69	6.1	6.0	3.6	9.1	6.8	4.0
BD-590	93	12	28	97	80	70	5.7	3.7	3.6	7.7	4.1	3.4
BD-592	94	98	19	85	84	74	6.5	8.2	7.1	9.4	7.7	6.1
BD-593	97	63	8	98	81	60	4.7	5.8	5.6	7.5	6.1	5.5
BD-598	97	93	7	100	87	60	5.8	8.0	6.5	9.8	6.0	4.4
BD-599	97	95	7	97	84	66	7.2	8.7	5.9	8.6	7.3	5.5
BD-600	97	88	7	97	87	72	7.4	8.5	5.7	10.5	7.8	6.2
BD-601	98	93	7	95	84	56	6.6	8.3	6.0	10.2	7.0	5.3
BD-602	96	98	20	95	80	72	5.9	6.9	5.2	9.3	8.2	6.6
BD-603	98	98	18	95	81	67	7.2	8.0	6.2	9.5	8.2	7.1
BD-604	98	93	27	93	82	71	4.4	6.3	4.7	10.0	7.3	6.1

Genotypes	*Rate of Germination (%)			*Final Germination (%)			Root dry weight (mg)			Shoot dry weight(mg)		
	Control	PEG 15%	PEG 25%	Control	PEG 15%	PEG 25%	Control	PEG 15%	PEG 25%	Control	PEG 15%	PEG 25%
BD-605	95	98	10	98	87	74	6.3	7.0	5.3	10.3	6.9	5.6
BD-607	92	87	22	85	75	60	5.5	7.1	4.7	10.0	6.7	5.5
BD-608	97	88	75	93	77	62	6.4	7.8	5.8	9.8	7.8	5.8
BD-610	40	10	10	85	33	11	4.6	4.5	3.6	9.0	7.0	4.8
BD-611	95	87	5	92	82	65	4.9	7.0	4.1	9.6	6.5	4.9
BD-612	97	90	65	93	83	67	5.9	6.8	8.1	9.5	6.7	5.7
BD-613	96	95	47	92	79	65	6.8	6.8	6.4	10.2	6.5	5.3
BD-614	96	88	25	92	81	60	5.9	7.0	4.1	8.4	8.2	7.1
BD-616	97	91	40	95	84	66	5.7	5.7	4.8	7.8	5.8	4.6
BD-617	95	90	55	95	75	59	5.8	7.5	5.9	9.3	7.6	4.8
BD-618	93	87	62	80	66	56	3.6	7.6	6.7	8.4	7.3	6.4
BD-622	97	93	64	98	86	77	4.6	5.7	2.2	8.7	7.3	5.6
BD-628	94	92	43	90	72	51	5.2	5.3	4.9	8.0	6.2	4.2
BD-629	98	86	16	87	71	51	3.6	7.0	6.2	9.0	5.8	4.4
BD-632	93	89	49	97	83	66	4.9	7.0	5.9	8.6	5.5	4.2
BD-633	95	91	44	90	74	68	5.3	7.3	6.2	8.3	9.0	6.1
BD-634	98	93	41	92	77	66	5.5	7.1	7.3	10.2	7.6	5.6
BD-635	93	93	31	100	77	69	5.5	5.8	5.1	10.5	7.3	5.0
BD-636	96	90	52	92	80	71	5.2	5.0	5.7	8.4	5.8	4.6
BD-638	95	91	11	93	83	48	5.6	4.0	5.3	10.8	7.7	4.9
BD-641	92	82	28	80	71	59	4.1	5.1	3.4	8.0	5.1	4.0
BD-642	98	93	64	77	71	59	4.1	5.7	3.4	8.2	5.5	5.5
BD-643	93	91	62	100	81	54	5.8	6.0	4.4	9.5	6.2	5.6
BD-644	98	95	65	85	71	51	4.2	5.0	4.3	9.0	6.1	4.3
BD-645	95	93	69	87	74	66	5.1	5.7	4.8	9.0	6.1	5.3
LSD (0.05)	14.36			9.93			1.47			1.46		
CV (%)	14.03			8.29			13.49			10.99		

* Percentage data were transformed into arcsine value for analysis

Table 2. Effect of drought stress through polyethylene glycol (PEG-6000) solution on remaining seed dry weight , Root - Shoot ratio, amount of respiration and seed metabolic efficiency wheat genotypes.

Genotypes	Remaining seed dry weight (mg)			Root:Shoot			Amount of respiration			Seed metabolic efficiency (g/g)		
	Control	PEG 15%	PEG 25%	Control	PEG 15%	PEG 25%	Control	PEG 15%	PEG 25%	Control	PEG 15%	PEG 25%
BD-466	4.4	10.0	12.2	0.6	0.8	0.8	6.0	2.7	3.0	1.7	3.0	2.5
BD-470	9.3	19.9	27.7	0.5	1.0	1.4	14.0	8.0	2.8	1.1	1.3	3.5
BD-473	7.2	15.1	18.3	0.5	0.9	0.9	13.1	7.1	5.8	0.9	1.3	1.3
BD-476	7.3	15.9	23.4	0.5	0.7	0.6	15.8	10.6	5.5	0.8	0.9	1.3
BD-479	7.2	17.5	21.5	0.5	0.9	0.8	17.6	10.1	7.9	0.7	0.9	0.9
BD-480	5.7	13.3	18.5	0.5	0.9	0.8	11.5	6.9	3.7	1.1	1.4	2.1
BD-481	6.9	13.3	17.4	0.5	0.8	0.8	15.1	9.5	6.7	0.7	1.0	1.3
BD-483	6.4	16.3	18.8	0.5	0.5	0.8	16.6	7.9	6.6	0.7	1.4	1.4
BD-487	5.7	14.0	18.4	0.5	0.8	0.8	12.2	6.1	4.9	1.0	1.6	1.4
BD-488	8.5	22.1	22.8	0.5	0.6	0.6	18.0	8.2	10.0	0.8	1.2	0.7
BD-489	5.1	15.3	21.2	0.5	1.0	1.0	15.0	6.5	3.6	0.8	1.6	2.2
BD-491	6.9	16.2	19.0	0.4	0.7	0.8	13.0	6.2	3.6	1.0	1.7	2.9
BD-493	4.0	7.7	6.2	0.5	0.8	0.1	12.2	9.3	6.2	1.2	1.5	1.4
BD-496	3.2	9.3	8.0	0.7	0.7	0.8	9.4	6.4	6.8	1.9	2.3	2.3
BD-497	4.1	9.7	7.8	0.5	0.9	0.8	9.1	7.2	6.9	1.9	1.9	2.3
BD-498	6.3	7.2	6.6	0.7	0.7	0.8	6.4	6.8	6.7	2.0	1.7	1.8
BD-499	8.9	11.5	10.7	0.5	0.7	0.9	14.2	11.7	10.8	1.1	1.4	1.6
BD-500	6.1	14.5	12.0	0.7	0.9	0.9	6.8	3.5	3.9	2.4	3.1	3.8
BD-501	6.8	9.4	10.2	0.7	0.8	0.9	14.5	10.9	11.8	1.1	1.5	1.3
BD-505	6.2	9.2	7.8	0.6	0.8	0.9	12.1	10.7	12.6	1.3	1.4	1.1
BD-507	6.1	13.0	10.4	0.6	0.9	0.8	11.1	8.9	6.9	1.4	1.3	2.3
BD-508	7.5	13.4	10.9	0.8	0.7	0.9	13.5	9.3	11.6	1.2	1.5	1.2
BD-509	8.2	12.5	12.5	0.6	0.7	0.8	10.8	8.1	7.8	1.4	1.7	1.8
BD-510	7.8	14.5	12.1	0.5	0.9	0.8	9.3	7.5	7.6	1.9	1.7	2.0
BD-511	6.8	17.4	16.3	0.8	1.0	1.1	8.7	2.9	3.5	1.9	3.9	3.7
BD-512	9.2	21.1	15.5	0.6	1.1	1.3	12.7	5.4	9.3	1.2	2.0	1.3
BD-513	14.9	17.4	16.9	0.4	1.3	1.2	9.4	4.1	5.2	1.1	3.4	2.4
BD-514	10.4	18.2	14.6	0.6	0.7	1.2	10.5	4.5	7.1	0.9	2.7	1.7
BD-516	10.8	23.7	16.2	0.5	0.9	1.2	11.2	2.8	8.2	1.4	3.8	1.6
BD-517	14.2	23.5	20.6	0.5	1.0	1.2	9.5	3.6	3.7	1.4	2.7	3.4
BD-519	13.1	17.0	13.9	0.4	1.0	1.3	6.4	4.3	4.0	1.6	2.3	3.1
BD-522	20.3	29.2	21.8	0.4	0.9	1.2	8.3	3.3	6.4	1.7	3.4	2.3
BD-524	8.6	16.6	16.3	0.6	0.9	1.0	12.4	7.6	4.2	1.0	1.2	3.3
BD-525	10.6	12.8	10.0	0.5	1.0	1.0	5.6	2.3	4.0	1.3	3.8	2.4
BD-527	13.5	19.8	18.6	0.5	0.9	1.0	10.6	5.4	6.1	0.9	1.5	1.4
BD-529	9.7	16.9	13.4	0.9	1.1	1.3	11.1	9.7	9.5	1.2	0.8	1.2

Genotypes	Remaining seed dry weight (mg)			Root:Shoot			Amount of respiration			Seed metabolic efficiency (g/g)		
	Control	PEG 15%	PEG 25%	Control	PEG 15%	PEG 25%	Control	PEG 15%	PEG 25%	Control	PEG 15%	PEG 25%
BD-531	4.2	12.1	19.5	0.8	1.3	1.1	14.6	10.0	7.7	1.1	1.2	0.9
BD-533	5.3	12.7	16.4	0.4	1.4	1.0	13.6	7.6	5.4	0.9	1.5	1.8
BD-534	5.6	14.0	18.6	0.9	1.2	0.9	11.9	7.2	4.6	1.2	1.5	1.9
BD-535	3.9	12.9	17.0	0.7	1.1	1.1	15.2	12.4	7.9	1.0	0.8	2.5
BD-536	4.0	11.8	15.5	1.0	0.8	1.4	14.9	14.9	10.1	1.2	0.7	1.1
BD-537	4.7	12.4	19.1	1.0	1.6	1.3	17.6	17.3	8.5	0.9	0.5	1.2
BD-539	5.1	16.6	25.0	0.9	1.2	1.0	14.6	12.7	7.2	1.3	0.7	0.9
BD-540	5.9	15.1	15.3	0.7	1.0	1.2	16.8	13.2	8.1	1.0	0.8	3.2
BD-541	5.1	15.3	21.4	0.8	1.2	0.8	13.8	10.7	5.7	1.2	0.9	1.6
BD-542	4.0	14.7	19.4	0.7	1.4	0.7	14.8	6.0	6.6	0.9	1.8	0.9
BD-545	4.3	15.0	22.0	0.9	1.5	1.1	15.7	14.1	6.6	1.2	0.6	1.4
BD-546	8.0	21.7	16.5	0.7	1.1	0.8	16.6	12.6	19.3	0.9	0.5	0.2
BD-547	5.1	17.1	18.6	0.8	1.2	0.8	14.0	8.5	6.6	1.1	1.1	1.5
BD-551	7.3	10.1	10.8	0.6	0.8	2.7	7.8	9.7	9.1	1.4	0.7	0.8
BD-552	4.6	13.9	17.7	0.7	1.0	1.0	14.4	6.7	7.2	1.0	1.8	1.1
BD-560	5.2	14.8	20.5	0.8	1.0	0.9	13.0	6.5	3.6	1.1	1.7	2.3
BD-562	5.0	15.4	19.4	0.8	1.2	1.1	14.7	8.5	7.1	1.1	1.5	1.4
BD-563	7.4	22.0	29.2	0.8	1.2	1.3	16.8	8.7	5.2	1.1	1.5	1.8
BD-567	5.1	17.1	20.9	1.0	1.0	0.9	14.8	5.6	4.0	0.9	1.9	2.1
BD-568	3.5	15.6	17.6	0.9	1.4	1.0	11.8	5.4	4.2	1.3	1.8	2.1
BD-569	5.0	19.1	24.3	0.8	1.1	1.1	17.2	7.6	4.6	0.9	1.5	2.0
BD-570	4.1	15.9	18.8	0.7	1.1	1.2	10.3	3.7	2.9	1.4	2.6	2.5
BD-574	4.0	12.9	17.0	0.7	1.2	0.9	13.4	5.8	5.1	1.0	2.1	1.7
BD-576	4.6	13.3	18.2	0.7	1.0	0.8	11.8	5.0	3.7	1.2	2.5	2.3
BD-579	5.4	15.3	24.4	0.9	1.0	1.0	15.7	10.0	6.3	1.1	1.3	2.8
BD-581	4.9	14.9	20.5	0.6	1.2	1.4	14.1	8.4	5.0	1.1	1.3	1.7
BD-582	4.2	15.3	21.3	0.8	1.3	1.4	16.0	8.3	5.0	1.1	1.7	2.3
BD-583	6.1	16.7	25.1	1.0	0.9	1.1	15.6	9.1	3.2	1.1	1.4	3.1
BD-584	4.8	13.6	20.0	0.7	0.9	0.9	15.2	8.7	7.5	1.0	1.5	1.0
BD-590	3.3	15.1	16.2	0.7	0.9	1.1	12.2	6.1	5.7	1.1	1.3	1.3
BD-592	5.4	8.3	13.3	0.7	1.1	1.2	8.2	5.4	4.1	1.9	3.0	3.3
BD-593	6.6	8.3	13.8	0.6	0.9	1.0	8.5	7.2	3.3	1.4	1.7	3.4
BD-598	5.4	12.1	16.0	0.6	1.3	1.5	9.7	4.5	3.8	1.6	3.1	2.9
BD-599	6.5	12.9	19.9	0.9	1.2	1.1	12.1	5.5	3.1	1.3	2.9	3.7
BD-600	5.2	14.2	19.5	0.7	1.1	0.9	15.1	7.7	6.8	1.2	2.1	1.8
BD-601	5.7	16.2	20.6	0.7	1.2	1.1	11.4	4.4	4.0	1.5	3.5	2.9
BD-602	5.1	8.9	17.7	0.6	0.8	0.8	12.7	9.0	3.6	1.2	1.7	3.3
BD-603	7.1	13.6	16.7	0.8	1.0	0.9	10.7	4.5	4.4	1.6	3.6	3.1
BD-604	5.5	12.3	15.6	0.4	0.9	0.8	8.5	4.4	3.0	1.7	3.1	3.6

Genotypes	Remaining seed dry weight (mg)			Root:Shoot			Amount of respiration			Seed metabolic efficiency (g/g)		
	Control	PEG 15%	PEG 25%	Control	PEG 15%	PEG 25%	Control	PEG 15%	PEG 25%	Control	PEG 15%	PEG 25%
BD-605	7.4	16.0	19.8	0.6	1.0	1.0	7.8	3.9	4.1	2.1	3.5	2.7
BD-607	5.4	13.3	17.3	0.6	1.1	0.9	9.0	3.7	3.3	1.7	3.8	3.1
BD-608	7.8	14.3	20.9	0.7	1.0	1.0	15.0	9.0	6.5	1.1	1.7	1.8
BD-610	10.6	23.7	25.2	0.5	0.7	0.7	11.9	3.9	2.5	1.1	2.9	3.5
BD-611	6.2	12.5	16.9	0.5	1.1	0.8	9.3	4.1	4.1	1.6	3.3	2.2
BD-612	5.0	12.7	17.9	0.6	1.0	1.4	16.0	10.2	4.6	1.0	1.3	3.0
BD-613	4.5	11.8	17.1	0.7	1.0	1.2	11.7	8.2	4.5	1.5	1.6	2.6
BD-614	6.4	9.1	22.3	0.7	0.9	0.6	13.5	10.0	3.7	1.1	1.5	3.0
BD-616	8.0	10.4	15.4	0.7	1.0	1.1	5.7	5.4	2.4	2.4	2.1	4.0
BD-617	5.1	9.9	18.2	0.6	1.0	1.2	16.4	11.5	7.7	0.9	1.3	1.4
BD-618	7.6	11.6	17.3	0.4	1.0	1.1	16.4	9.5	5.6	0.7	1.6	2.3
BD-622	5.4	12.5	24.0	0.5	0.8	0.4	15.2	8.3	2.0	0.9	1.6	3.9
BD-628	6.6	9.1	15.5	0.7	0.9	1.2	16.6	15.9	12.0	0.8	0.7	0.8
BD-629	4.4	11.6	17.0	0.4	1.2	1.4	12.6	5.4	3.1	1.0	2.4	3.4
BD-632	4.2	11.3	15.7	0.6	1.3	1.4	9.1	3.3	3.2	1.5	3.8	3.2
BD-633	6.5	14.9	20.2	0.6	0.8	1.0	18.6	7.6	6.3	0.7	2.1	2.0
BD-634	5.2	12.6	16.6	0.5	0.9	1.3	13.4	6.9	4.8	1.2	2.1	2.7
BD-635	5.2	14.6	18.1	0.5	0.8	1.0	17.0	10.5	9.8	0.9	1.2	1.0
BD-636	4.1	6.5	14.5	0.6	0.9	1.2	13.9	14.4	6.9	1.0	0.8	1.5
BD-638	5.3	18.5	24.8	0.5	0.5	1.1	15.3	6.7	3.9	1.1	1.7	2.6
BD-641	5.5	13.9	18.4	0.5	1.0	0.9	10.8	4.4	2.6	1.1	2.3	2.8
BD-642	13.0	18.4	23.5	0.5	1.1	0.6	16.2	11.9	9.1	0.8	0.9	1.0
BD-643	7.8	18.2	24.3	0.6	1.0	0.8	16.9	9.6	5.8	0.9	1.3	1.7
BD-644	8.2	16.7	16.9	0.5	0.8	1.0	13.9	7.5	6.8	1.0	1.5	1.3
BD-645	5.2	14.8	20.5	0.8	1.0	0.9	17.0	11.5	8.4	0.8	1.0	1.2
LSD (0.05)		2.59			0.34			0.45			0.53	
CV (%)		10.14			19.45			2.58			15.66	

Table 3. Effect of drought stress through polyethylene glycol (PEG-6000) solution on vigour index and relative vigour index of wheat genotypes.

	Vigour index			Relative vigour index	
Genotypes	Control	15%PEG	25% PEG	15%PEG	25% PEG
BD-466	848	579	182	-32	-79
BD-470	1265	686	350	-46	-72
BD-473	1048	701	479	-33	-54
BD-476	1163	662	300	-43	-74
BD-479	1118	661	302	-41	-73
BD-480	1195	1006	734	-16	-28
BD-481	932	670	494	-28	-47
BD-483	943	626	513	-34	-46
BD-487	1083	770	261	-29	-76
BD-488	1028	551	278	-46	-73
BD-489	1188	805	485	-32	-59
BD-491	1158	755	629	-35	-46
BD-493	1302	916	554	-30	-57
BD-496	1769	1191	926	-33	-48
BD-497	1472	984	686	-33	-53
BD-498	1169	944	838	-19	-28
BD-499	1584	1340	1064	-15	-33
BD-500	1415	808	840	-43	-41
BD-501	1493	1352	1053	-9	-29
BD-505	1434	1102	982	-23	-32
BD-507	1399	802	945	-43	-32
BD-508	1525	1139	966	-25	-37
BD-509	1490	766	762	-49	-49
BD-510	1737	1084	920	-38	-47
BD-511	1406	824	889	-41	-37
BD-512	1276	742	796	-42	-38
BD-513	984	878	795	-11	-19
BD-514	952	869	770	-9	-19
BD-516	1485	859	897	-42	-40
BD-517	1062	777	780	-27	-27
BD-519	944	817	832	-13	-12
BD-522	1217	895	843	-26	-31
BD-524	1178	801	767	-32	-35
BD-525	704	604	444	-14	-37
BD-527	822	588	437	-28	-47

	Vigour index			Relative vigour index	
Genotypes	Control	15%PEG	25% PEG	15%PEG	25% PEG
BD-529	1306	605	792	-54	-39
BD-531	1494	990	500	-34	-67
BD-533	1231	906	611	-26	-50
BD-534	1443	855	508	-41	-65
BD-535	1355	646	397	-52	-71
BD-536	1743	868	761	-50	-56
BD-537	1500	686	563	-54	-62
BD-539	1663	720	227	-57	-86
BD-540	1411	733	323	-48	-77
BD-541	1679	800	451	-52	-73
BD-542	1062	746	334	-30	-69
BD-545	1682	729	563	-57	-66
BD-546	722	153	32	-79	-96
BD-547	1556	792	660	-49	-58
BD-551	937	249	20	-73	-98
BD-552	1255	830	530	-34	-58
BD-560	1337	899	452	-33	-66
BD-562	1655	1041	703	-37	-58
BD-563	1747	1128	672	-35	-62
BD-567	1337	912	624	-32	-53
BD-568	1538	716	587	-53	-62
BD-569	1608	1029	543	-36	-66
BD-570	1323	803	234	-39	-82
BD-574	1278	949	269	-26	-79
BD-576	1360	1041	512	-23	-62
BD-579	1693	1118	388	-34	-77
BD-581	1338	827	495	-38	-63
BD-582	1632	1084	768	-34	-53
BD-583	1627	1037	671	-36	-59
BD-584	1462	1002	527	-31	-64
BD-590	1295	618	496	-52	-62
BD-592	1353	1232	970	-9	-28
BD-593	1196	938	670	-22	-44
BD-598	1554	1221	654	-21	-58
BD-599	1527	1345	751	-12	-51
BD-600	1725	1414	856	-18	-50
BD-601	1593	1201	629	-25	-61

Genotypes	Vigour index			Relative vigour index	
	Control	15%PEG	25% PEG	15%PEG	25% PEG
BD-602	1439	1196	843	-17	-41
BD-603	1588	1318	889	-17	-44
BD-604	1343	1116	760	-17	-43
BD-605	1633	1208	811	-26	-50
BD-607	1317	1037	610	-21	-54
BD-608	1507	1190	719	-21	-52
BD-610	1154	379	89	-67	-92
BD-611	1332	1098	587	-18	-56
BD-612	1433	1115	922	-22	-36
BD-613	1562	1047	761	-33	-51
BD-614	1313	1227	674	-7	-49
BD-616	1283	963	621	-25	-52
BD-617	1430	1137	624	-20	-56
BD-618	1060	981	725	-7	-30
BD-622	1302	1109	596	-15	-54
BD-628	1190	825	461	-31	-61
BD-629	1095	899	540	-18	-51
BD-632	1308	1031	662	-21	-49
BD-633	1230	1192	831	-3	-29
BD-634	1433	1125	851	-22	-41
BD-635	1593	998	701	-37	-56
BD-636	1252	855	726	-32	-42
BD-638	1532	965	491	-37	-68
BD-641	972	719	435	-26	-55
BD-642	940	788	521	-16	-45
BD-643	1532	990	540	-35	-65
BD-644	1118	781	437	-30	-61
BD-645	1217	864	661	-29	-46
LSD (0.05)		143.50		-	-
CV (%)		7.65		-	-