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RESEARCH ARTICLE

Morphological Characterization for Identification of Drought Adapted Genotypes in Wheat (*Triticum aestivum* L.) under Drought Stress

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Drought is one of the major limitations to wheat production worldwide. This study was designed to identify the drought adapted genotypes among 160 wheat genotypes. Five morphological traits namely leaf morphology, leaf angle, leaf rolling, waxiness on leaf, spike fertility and nine yield traits namely days to heading, days to anthesis, days to maturity, grain filling duration, spikelets per spike, grains per spike, grain weight per spike (g), 1000-grain weight (g), and grain yield per plant (g). Grain yield per plant exhibited highly significant and positive correlation with 1000-grain weight, grain weight per spike, waxiness score, indicating dependency of yield on these traits. Based on path analysis, maximum positive direct effect on grain yield per plant was contributed mostly by days to maturity, followed by 1000 grain weight, waxiness score, number of grains per spike, grain weight per spike and leaf rolling score. From our results, waxiness score and leaf rolling score showed strong association with grain yield per plant. We have selected 18 genotypes based on high morphological score as-well-as high grain yield per plant namely; DBW50, HD2985, HD3043, HD2687, HD3059, HD3076, HD3093, HI1531, HW1105, PBN142, PBW502, WH1080, WH730, AUS30354, AUS30518, DRYSDALE, SB187, SSRT17. These genotypes can be utilized in drought breeding programme for development of mapping population, as well as drought resilience varieties for rainfed areas.

Key Words: Drought stress, Morphological traits, Wheat (*Triticum aestivum* L), Yield traits

Introduction

Wheat (*Triticum aestivum* L.) is one of the most important food crops across the globe. It is grown under broad range of environmental conditions in terms of water regimes, climates and soil types. At present, changes in global climate and increased variability in precipitation giving insistence to drought stress (Trenberth, 2011). Wheat production in semiarid and arid regions is increasingly constrained due to drought stresses (Gregersen *et al.*, 2013). Therefore improvement in drought tolerance as-well-as grain yield is very important in the selection of wheat cultivars for rainfed condition. The International Maize and Wheat Improvement Centre (CIMMYT) contributed to the worldwide adoption of modern wheat varieties through multi-environmental testing and collaboration with national breeding programmes (Manes *et al.*, 2012).

In wheat greater genetic variability can be explore with germplasm from its centres of origin and diversity (Dvorak *et al.*, 2011). In addition to cultivated wheat varieties and breeding lines, extensive variability for drought tolerance remains within wild relatives and landraces (Nevo and Chen, 2010; Dodig *et al.*, 2012). Manipulation of this diversity to improve drought tolerance among genotypes may be achieved through genetic modification and selection for adaptive mechanisms including drought escape, dehydration avoidance, and dehydration tolerance (Blum, 2010).

There are several approaches to investigate morphological traits for the purpose of increasing yield under moisture deficit conditions. Leaf rolling induced by loss of turgor and poor osmotic adjustment represents as an important drought avoidance mechanism (Richards, 1996). The erectophile leaf canopy has been proposed

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as a trait that could increase crop yield potential by improving radiation use efficiency in high radiation environments (Reynolds *et al.,* 1999).

Therefore, the grain yield and its contributing traits are two important selection criteria in moisture deficit conditions (Plaut *et al.,* 2004). Drought stress reduces the grain yield and an average yield loss of 17-70% has been estimated due to drought stress (Nouri-Ganbalani *et al.,* 2009). An understanding of yield components of a wheat crop in a particular environment is the key for a successful breeding program. Yield component traits, such as days to heading, days to anthesis, days to maturity, grain filling duration, spikelets per spike, grains per spike, grain weight per spike (g), 1000-grain weight (g), grain yield per plant (g) influence the tolerance to drought in wheat (Passioura, 1977).

Material and Methods

Experimental Site

The experiment was conducted in the experimental area of NE Borlaug Crop Research Centre (NEBCRC), G.B. Pant University of Agriculture and Technology. Pantnagar, Distt. US Nagar, Uttarakhand during 2014-15 and 2015-16 *Rabi* seasons. The Crop Research Centre is situated at 29ºN latitude, 79º29' E longitude and at an altitude of 243.84 m above the mean sea level.

Experimental Design

The experiment was conducted in Alpha lattice design (Patterson and Williams, 1976). The randomization of 160 cultivars was done with Crop Stat v7.2 software. The design constitutes of 8 × 20 i.e. eight blocks each of 20 genotypes, planted in rainfed (RF) condition with two replications. The each entry was planted two meter long rows, with three rows per plot. The plants were spaced 10 cm from each other and rows were 20 cm apart.

Water Deficit Environment

The experimental materials were evaluated in rainfed (RF) environment with two replications for 2 years 2014-15 and 2015-16. No irrigation was done to create the water deficit environment during the crop season.

Morphological Parameters

The data were recorded on five morphological traits namely morphology of leaves, leaf angle, leaf rolling, waxiness on leaves and spike fertility. The morphology of leaves was observed visually using 1 to 3 scale (1 = broad, 2 = medium and 3 = narrow). Leaf angle was observed visually using 1 to 3 scale (1 = droopy, 2 = semi-erect and 3 = erect). Leaf rolling of leaves was observed visually using 1 to 4 scale (1 = no rolling, 2 = weak rolling, 3 = semi-rolling and 4 = full rolling). Waxiness on leaves was observed visually using 1 to 4 scale (1 = absence, 2 = weak 3 = medium and 4 = strong). Spike fertility was also observed through hand detection using 1 to 3 scale (1 = sterile, 2 = semi-sterile, 3 = sterile) (Kundu, 2007).

Yield and Yield Components Traits

The data were recorded on nine yield and yield contributing traits namely days to heading, days to anthesis, days to maturity, grain filling duration, number of spikelets per spike, number of grains per spike, grains weight per spike (g), 1000 grain weight (g) and grain yield per plant (g).

Statistical Data Analysis

The data were subjected to analysis of variance using SAS GLM procedure release 9.3. Pearson correlation analyses were used to determine the association between morphological and yields traits. Path coefficient analyses were used for the causal relationship between these traits, with the degree of such relationship.

Results and Discussion

Leaf morphology is also associated with drought stress, plants having narrow leaves are more adapted for drought stress, because less loss of water through transpiration (Kumar *et al*., 2016). Leaf angle is one of the most important parameters used to describe the structure of horizontal vegetation canopies of field crops, and affects how incident photosynthetically active radiation is distributed on plant leaves, thus directly affecting plant productivity (Zou *et al.,* 2014). Leaf rolling may be associated with improved grain yield under drought stress, rolled leaf loss less water through transpiration as compared to unrolled leaf (Rebetzke *et al.,* 2001). Waxiness on leaf may be well suited for drought condition because waxiness restricts transpiration in plant (Borrell *et al*., 2006). Some spike may be sterile or semi-fertile under drought stress due to metabolic imbalance (Shitsukawa *et al.,* 2009). Five morphological characters were recorded for characterization with respect to drought adaptation of wheat genotypes, the details of these traits are given below (Fig. 1a-e).

Leaf Morphology (Narrow/Medium/Broad): Leaves are the main organ for photosynthesis, providing major assimilate source required for plant growth and panicle development. Under favourable conditions, wheat flag leaf contributes 45-58 % of photosynthate and 41-43 % of assimilates used in grain filling. Broad leaved plants had greener biomass, more chlorophyll content indicating suitable for green forage. On the other hand plants having narrow leaves become tolerant to abiotic stresses like drought, salinity, alkalinity and rainfed situation.

Leaf Angle (Erect/Semi-erect/Droopy): Leaf angle of leaves affect the extent to which a crop canopy intercepts solar radiation and light penetration through the canopy. Developmentally leaf angle is affected by temperature, light intensity, wavelength and growth regulators. The leaf erectness has been used to optimize plant architecture since erect leaves can enhance photosynthesis and dry matter production by greater sunlight capture. Brassinosteroid is a recent class of phytohormones that is related to erect leaf angle.

Leaf Rolling (Full/Semi/Weak/No-rolling): Leaf rolling may be associated with improved grain yield in some drought situations. The flag leaf of wheat plant rolls up into a cylinder in response to drought conditions. This is a desirable trait improving grain size particularly under drought. It may lead to a delay in the onset of leaf senescence and thus lead to greater water-use efficiency. The trait is mainly expressed in the flag leaf, which is one of the main organs contributing to grain yield.

Waxiness on Leaf (Strong/Medium/Weak/Absence): Epicuticular wax which imparts a bluish green cast, referred to as glaucousness has been associated with drought tolerance in several crop species. Genetic variation in epicuticular wax has an importance in breeding for drought tolerance. Genetic variation in epicuticular wax in wheat has been previously reported, but only in a limited range of genotypes. The present paper explores epicuticular waxiness in the large number genotypes and its relationship with yield and yield component traits of spring wheat cultivars.

Spike Fertility (Fertile/Semi-fertile/Sterile): Grain number per spike, which is greatly affected by floret fertility, is an important trait of wheat grain yield. Maximum floret primordia, fertile floret, and grain number per spikelet are three important factors of floret fertility. Floral degradation plays an important role in determining these three floret fertility-related traits. Spike is produced on the top of the main stem of each of the tiller that are fertile in a normal wheat cultivar, and those tillers that do not produce spike are referred to sterile tillers.

Adjusted Mean and Drought Adaptation Score: Adjusted mean of all the yield traits and adaptation score of all morphological traits given in the Table (1). For adjusted mean, we have taken from polled data of both the year 2014-15 and 2015-16, and for drought adaptation score, we have prepared based on sum of score value of all morphological traits for each genotype. We have selected 18 genotypes based on highest drought adaptation score and high grain yield per plant mentioned by bold figures (Table 1; Fig. 2).

Analysis of Variance

The data of analysis of variance (ANOVA) alpha lattice design both studied years and pooled are presented in Tables (2, 3, and 4). Results of these tables revealed that mean square of the replications had highly significantly differences for days to heading, days to anthesis, days to maturity, no. of spikelets per spike, 1000-grain weight (g) in both years and pooled data, remaining traits in the first year, second year and pooled data were non-significant. Mean square of the blocks had highly significantly differences for days to heading, days to anthesis, days to maturity, grain filling duration, grain weight per spike (g), 1000-grain weight (g), grain yield per plant (g) in the first year, days to heading, days to anthesis, days to maturity, grain filling duration, 1000-grain weight (g) in second year, days to heading, days to anthesis, days to maturity, grain filling duration, no. of spikelets per spike, no. of grains per spike, grain weight per spike (g), 1000-grains weight (g), grain yield per plant (g) in the pooled data. No. of spikelets per spike in the first year was significant only. Grain weight per spike (g) and grain yield per plant (g) in the second year were significant only. No. of grains per spike in the first year was non-significant. No. of spikelets per spike and no. of grains per spike were non-significant only in the second year. Mean square of the treatments had highly significantly differences for all the studied traits in both the years and pooled data. Mean square of replication x block were highly significant differences for days to anthesis, no. of spikelets per spike, no. of grains per spike in the first year, days to anthesis, no. of spikelets per spike, no. of grains per spike in second year, days to anthesis, grain filling duration, no. of spikelets per spike, no. of grains per spike, grain weight per spike (g) in the pooled data. Grain filling duration in the second year

Table 1. Adjusted mean of yield data and drought adaptation score of 160 wheat genotypes studied under rainfed condition

Sl. No.	Genotypes	Pedigree	DH	DA	DM	GFD	SLS	GS	GW (g)	TGW (g)	GY (g)	DTS
1	C 306	RGN/CSK3//2*C591/3/C217/N14//C281	86	92	127	34	16	43	2.41	41.17	11.74	4
2	Chirya 7	*	88	93	127	35	17	51	2.99	43.31	9.25	5
3	DBW 14	RAJ3765/PBW343	86	93	127	34	18	54	2.33	36.43	9.35	10
4	DBW 28	MILAN/PBW343	87	92	125	33	16	48	2.42	39.98	9.63	13
5	DBW 39	ATTILA/HUI	86	91	126	35	19	60	3.35	42.32	10.52	9
6	**DBW 50**	KAUZ//ALTAR84/AOS/3/MILAN/KAUZ/4/HUITES	**87**	**92**	**126**	**34**	**19**	**57**	**2.83**	**43.07**	**12.26**	**12**
7	DBW 58	ATTILA/3*BCN//BAV92/3/TILHI	86	91	125	34	18	50	2.61	40.75	7.12	13
8	DBW 77	*	87	90	125	34	20	58	3.21	39.76	10.95	11
9	DBW 88	KAUZ//ALTAR84/AOS/3/MILAN/KAUZ/4/HUITES	87	92	127	35	19	56	2.83	43.50	9.11	12
10	FLW 12	UP2338/Mega	85	90	125	34	18	52	1.78	40.64	7.27	7
11	FLW 13	WH542*/Yr15(CH25087)	90	94	127	33	18	52	2.21	42.04	8.02	7
12	FLW 3	UP2338/CHINA84	89	92	126	34	17	51	2.28	35.36	10.31	7
13	FLW 7	*	88	93	126	32	17	46	1.73	37.16	6.12	6
14	HALNA	HD1982/K816	84	88	124	35	19	53	2.18	41.89	12.90	8
15	HD 2643	VEE"S"/HD2407//HD2329	84	88	123	35	17	51	2.77	46.53	10.14	8
16	HD 2733	ATTILA/3/TUI/CARC//CHEN/CHTO/4/ATTILA	87	93	125	32	19	52	1.38	28.63	6.68	11
17	HD 2824	PTO-1/CNO79/PRL/GAA/3/HD1951	88	93	126	33	17	52	2.60	41.04	10.92	6
18	HD 2833	PBW226/HW1042//HD2285	82	88	123	35	18	55	2.52	35.90	8.12	6
19	HD 2864	DL509-2/DL377-8	85	91	127	36	17	47	1.84	39.79	10.45	5
20	HD 2877	CDWR9549/HD2347//HD2402	86	90	124	34	18	46	2.16	37.89	10.33	6
21	HD 2932	KAUZ/STAR//HD2643	86	93	124	32	18	53	2.38	39.19	11.39	9
22	HD 2967	ALD/COC//URES/HD2160M/HD2278	88	94	126	32	20	62	1.61	28.68	6.70	13
23	**HD 2985**	PBW343/PASTOR	86	92	125	33	19	57	2.57	41.12	12.88	11
24	HD 2987	HI1011/HD2348//MENDOS//IWP72/DL153-2	84	89	127	38	17	47	2.48	43.46	12.87	9
25	**HD 3043**	PJN/BOW//OPATA*2/3/CROC_1/Ae. squarrosa (224)//OPA	86	91	125	34	17	43	1.97	39.14	11.04	11
26	HD 2687	CPAN2009/HD2329	89	94	125	31	17	51	2.27	37.72	10.40	13
27	HD 3059	KAUZ//ALTAR84/AOS/3/MILAN/KAUZ/4/HUITES	**88**	**93**	**127**	**34**	**18**	**55**	**2.72**	**40.81**	**11.59**	**14**
28	HD 3070	TAM 200/TUI/3/URES/JUN//KAUZ	88	91	126	35	17	49	2.10	35.38	5.15	12
29	**HD 3076**	BL2064//SW89.5124*2/FASAN/3/TILHI	**91**	**94**	**127**	**33**	**19**	**52**	**2.18**	**39.44**	**12.66**	**12**
30	HD 3086	DBW14/HD2733//HUW468	84	89	123	34	17	50	2.47	39.95	12.20	8
31	HD 3090	SFW/VAISHALI//UP2425	86	91	126	35	18	52	2.54	39.71	7.74	6
32	HD 3091	PICUS/3/KAUZ*2/BOW//KAUZ/4/TILHI	84	91	125	35	15	38	1.71	34.96	9.25	7
33	**HD 3093**	NW1012/HUW453	**88**	**91**	**127**	**36**	**16**	**44**	**2.35**	**41.68**	**11.07**	**11**
34	HD 3118	ATTILA*2/PBW65//WBLL1*2/TUKURU	86	90	125	35	16	51	2.91	38.74	11.31	10
35	HD 3121	MILAN//PRL/2*PASTOR/4/CROC_1/Ae. Squarrosa(213)//PGO/3/BAV92	85	90	125	35	18	54	2.78	40.27	10.72	10
36	HD 3122	W15.92/4/PASTOR//HXL7573/2*BAU/3/WBLL1	86	90	124	34	18	47	3.56	45.17	12.84	11
37	HD 3123	PASTOR//HXL7573/2*BAU/3/CMH82.575/CMH82.801	88	92	125	33	17	47	1.91	37.95	9.46	13
38	HI 1500	HW2002*2//STREMPALLI/PNC 5	86	91	128	37	18	53	3.10	41.11	12.20	6
39	**HI 1531**	HI1182/CPAN1990	88	93	**125**	**32**	**18**	**56**	**2.61**	**35.06**	**12.38**	**12**
40	HI 1544	HINDI 62/BOBWHITE/CPAN 2099	86	92	128	36	16	42	2.11	44.54	10.07	9
41	HI 1563	MACS 2496*2/MC10	84	89	127	38	18	53	2.69	41.08	7.62	4
42	HI 617	SELECTION FROM C 306	85	91	127	36	16	46	2.81	43.49	8.11	6
43	HUW 510	HD 2278/HUW234//DL230-16	85	89	126	37	17	52	2.12	35.89	8.84	7
44	HW 1105	C 306 *7//TR 380-14 #7/3AG14	**87**	**92**	**127**	**34**	**18**	**45**	**1.90**	**39.04**	**11.25**	**11**
45	HW 2004	*	87	91	126	35	18	52	2.73	46.25	10.46	6
46	HW 2005	*	86	91	126	35	16	48	1.67	35.13	9.49	6
47	HW 2009	*	80	86	123	37	17	50	2.24	31.13	6.57	8
48	HW 2036	*	86	91	126	35	18	55	2.83	41.66	10.09	10
49	HW 2039	*	83	87	125	38	16	49	2.28	41.02	11.09	6

Sl. No.	Genotypes	Pedigree	DH	DA	DM	GFD	SLS	GS	GW (g)	TGW (g)	GY (g)	DTS
50	HW 2066	MACS 2496*2//COOK*6/C80-1	86	91	125	34	18	56	2.62	28.84	6.92	11
51	HW 3620	*	88	91	125	34	17	49	1.89	30.42	6.00	5
52	HW 4002	*	82	88	127	40	17	49	2.77	43.24	10.58	5
53	HW 4008	*	82	87	123	37	16	49	2.04	40.86	8.96	6
54	HW 4009	HD2285*5/THATCHER*8/VPM	87	92	126	34	17	47	1.98	33.31	6.58	6
55	HW 4022	*	85	90	124	34	16	46	2.37	35.62	9.20	4
56	HW 4029	*	80	86	123	38	15	48	2.10	38.13	5.61	6
57	HW 4202	*	87	92	125	33	17	49	1.61	25.41	6.94	8
58	HW 4209	*	87	92	125	33	15	48	1.95	34.98	9.57	9
59	HW 4213	*	86	90	127	37	17	47	1.86	34.62	10.51	5
60	HW 4215	*	87	92	126	34	19	52	2.72	43.86	12.14	8
61	HW 4218	*	88	93	127	34	18	53	2.53	41.45	11.39	5
62	HW 4219	*	89	93	126	33	18	46	1.94	31.83	6.14	10
63	HW 5209	C 306 *7//TR 380-14 #7/3AG14	85	91	124	33	17	48	2.49	42.39	10.00	5
64	K 1016	PBW373/UP2338	81	92	121	29	17	53	2.49	40.17	8.27	12
65	Lok 1	S308/S331	85	88	126	38	15	44	2.08	47.97	12.75	6
66	Lok 45	CPAN 3066/K.SONA "S"/LOK 1/CNO 79/CPAN2081/J 24/SS-1063/CPAN 1907/CC 493//HD 2385	82	88	121	34	19	56	2.98	39.26	4.87	4
67	Lok 65	Lok1/J.24/SONALIKA"S"//HW2006/HD2358/HW2002	87	92	128	35	18	52	2.95	46.86	11.13	6
68	MACS 2496	SERI"S"	89	93	128	35	17	50	3.25	43.64	11.55	5
69	NI 5439	REMP80/3*NP710	87	93	125	32	18	54	2.46	33.43	6.35	9
70	NP 846	NP760/RIONEGRO	90	95	128	33	18	47	1.83	35.34	6.69	5
71	NW 1014	HAHN "S"	85	91	125	34	19	60	2.76	41.05	12.28	10
72	NW 2036	BOW/CROW/BUC/PVN	84	90	123	33	17	50	3.00	41.89	11.99	5
73	**PBN 142**	HD2189/NI917//AGANTHA	**87**	**92**	**125**	**33**	**18**	**52**	**2.39**	**39.20**	**10.55**	**14**
74	PBN 51	BUC'S'/FLK'S'	87	91	126	34	16	46	2.08	29.22	4.12	6
75	PBW 175	HD2160/WG1025	82	88	121	34	18	51	2.75	37.34	7.41	4
76	PBW 343	ND/VG9144//KAL/BB/3/YCO"S"/4/VEE#S "S"	90	95	126	31	18	53	2.37	35.84	10.06	10
77	PBW 373	ND/VG9144//KAL/BB/3/YCO"S"/4/VEE#5 "S"	87	91	125	34	16	51	2.25	35.90	9.50	9
78	**PBW 502**	W 485/PBW343//RAJ1482	**83**	**89**	**123**	**34**	**16**	**50**	**2.60**	**38.60**	**10.51**	**12**
79	PBW 550	WH 594/RAJ 3858//W485	85	89	126	37	17	53	2.52	37.04	10.55	8
80	RAJ 3765	HD2402/VL639	85	90	126	36	17	47	1.94	38.41	12.60	7
81	RAJ 4037	DL788-2/RAJ3717	87	91	124	33	15	42	1.94	35.43	6.37	6
82	RAJ 4083	PBW343/UP2442//WR258/UP2425	88	93	127	34	18	50	2.12	36.75	9.78	7
83	RAJ 4120	PBW343/V1	85	91	126	34	17	52	2.63	37.67	8.49	13
84	TEPOKO	*	87	91	125	34	16	48	2.57	34.65	7.66	7
85	UP 2691	UP2377/HW1085	90	95	127	32	18	49	2.54	44.80	10.21	9
86	UP 2828	CH01 X M95/ HUW562	87	91	124	33	19	53	2.33	40.45	9.22	11
87	WH 1021	NYOT95/SONAK	86	92	126	34	19	54	2.87	39.86	6.14	9
88	**WH 1080**	21STSAWSN151	87	92	127	35	17	**48**	**2.78**	**39.63**	**11.20**	**12**
89	WH 147	E 4870/C286/C273/4/S339/PV18	87	90	123	33	17	52	2.53	32.18	5.52	4
90	WH 157	NP876/S308//CNO/8156	88	93	127	34	19	47	2.05	42.07	7.20	8
91	WH 542	JUP /BJY"S"//URES	88	93	124	31	20	57	2.20	30.66	6.73	13
92	WH 711	ALD 'S' HUAC//HD2285/3/HFW-17	85	89	124	35	17	47	1.75	36.87	9.45	8
93	**WH 730**	*	**82**	**87**	**126**	**39**	**18**	**52**	**2.87**	**41.60**	**12.81**	**11**
94	ATTILA	CM85836-50Y-0M-0Y-3M-0Y	93	96	134	39	18	48	2.01	38.17	5.13	6
95	**AUS30354**	CMSS96Y02555S-040Y-020M-050SY-020SY-21M-0Y-0AUS	**90**	**93**	**127**	**34**	**19**	**51**	**2.16**	**45.01**	**10.44**	**13**
96	AUS30355	CMSS96Y02555S-040Y-020M-050SY-020SY-34M-0Y-0AUS	87	92	125	33	17	47	2.21	46.68	9.61	12
97	**AUS30518**	CMSA00M00114S-3M-2Y-0AUS	87	92	127	34	18	55	3.10	39.73	**10.43**	**12**
98	AUS30523	CMSA00M00114S-39M-3Y-0AUS	88	92	125	33	18	48	2.08	31.18	8.10	6
99	BABAX	CM92066	87	91	123	32	19	55	2.41	34.88	5.21	13
100	BACANORA 88	*	87	92	126	34	19	57	2.65	33.16	7.20	14

Sl. No.	Genotypes	Pedigree	DH	DA	DM	GFD	SLS	GS	GW (g)	TGW (g)	GY (g)	DTS
101	BARKARE	*	87	92	126	34	17	50	2.80	38.44	7.65	8
102	BAVIACORA M 92	CM92066-J-0Y-0M-0Y-4M-0Y-0MEX-48BBB-0Y	83	88	124	36	17	50	1.78	32.10	7.58	6
103	BAW898	CM92354-33M-0Y-0M-6Y-0B-0BGD-0Y	82	88	122	35	19	51	2.35	38.32	6.32	12
104	BERKUT	CMSS96M05638T	85	90	125	35	17	50	2.20	36.47	9.84	10
105	BWL 0814	*	87	92	126	34	15	47	2.12	36.53	10.81	8
106	BWL 0924	*	87	91	125	34	17	41	1.74	36.97	7.28	9
107	BWL 1771	*	86	88	125	37	19	54	2.17	39.65	10.32	6
108	BWL 1793	*	84	91	124	33	16	42	1.73	36.22	9.61	6
109	BWL 9022	*	88	94	126	31	19	44	1.30	35.64	7.69	12
110	CETTIA	CM92313-19Y-0H-0SY-5M-0RES-0HUA-0Y	87	92	126	34	17	50	2.23	34.40	10.05	6
111	DHARWAR DRY	*	87	93	127	34	21	59	2.66	40.01	12.89	7
112	**DRYSDALE**	-0AUS	**86**	**91**	**126**	**35**	**18**	**53**	**2.41**	**41.11**	**12.93**	**11**
113	EXCALIBUR	-DH_E165-0Y	89	94	127	33	19	50	2.00	33.49	7.21	6
114	GLADIUS	-0AUS	88	93	127	34	16	45	1.51	37.86	8.73	10
115	GRANERO INTA	CM49641-9Y-1M-2Y-3Y-0M-1P-0P-0ARG-0Y	87	90	126	36	18	52	2.24	35.76	8.01	12
116	HARTOG	CM8399-D-4M-4Y-2M-2Y-0M	86	89	125	36	16	38	1.79	30.00	9.29	6
117	IC 252803 CK9	*	87	92	125	32	18	52	2.38	40.89	8.82	5
118	IC 532653	*	95	98	131	33	19	53	2.40	32.69	7.60	7
119	IEPACA RABBE	*	89	92	126	34	19	57	3.07	38.88	11.57	8
120	JANZ	QT3685	88	93	126	34	18	48	1.75	30.44	7.57	5
121	KRICHAUFF	-0AUS	87	91	124	33	15	45	2.49	36.20	11.25	7
122	KUKRI	-0Y-0Y	89	93	127	34	18	49	2.30	35.04	8.49	6
123	LOVE-HH-129	-0Y	87	91	125	35	16	48	1.95	39.09	9.87	12
124	MACS 6272	*	88	93	127	34	18	52	2.23	33.68	9.45	14
125	MACS 6273	*	86	90	125	35	16	45	2.15	38.64	10.42	5
126	NACOZARI F 76	CM5287-J-1Y-2M-2Y-3M-0Y-0MEX-0Y	89	94	126	32	19	58	2.26	33.41	9.95	11
127	OTHERY EGYPT	*	88	93	128	35	16	48	1.85	42.06	8.63	5
128	PASTOR	CM85295	85	89	125	35	19	57	2.87	29.77	9.01	8
129	RAC875	-0Y-0Y	87	92	125	33	18	53	2.62	39.03	9.92	13
130	SB003	CMSS96Y04084S-0Y-1B-4TLA-0B-0Y-3B-0Y-0AUS	88	94	125	31	16	46	1.65	32.89	8.71	6
131	SB010	CMSS96Y04084S-0Y-1B-11TLA-0B-0Y-10B-0Y-0AUS	90	94	130	35	17	41	1.27	35.99	8.97	5
132	SB025	CMSS96Y04084S-0Y-1B-31TLA-0B-0Y-25B-0Y-0AUS	88	91	125	33	18	46	1.91	39.35	9.75	6
133	SB044	CMSS96Y04084S-0Y-1B-52TLA-0B-0Y-44B-0Y-0AUS	86	91	126	35	18	48	1.34	27.63	9.66	6
134	SB053	CMSS96Y04084S-0Y-1B-52TLA-0B-0Y-53B-0Y-0AUS	87	93	124	31	19	52	1.84	37.84	8.29	8
135	SB057	CMSS96Y04084S-0Y-1B-67TLA-0B-0Y-57B-0Y-0AUS	85	90	125	34	19	52	2.45	37.97	8.04	11
136	SB062	CMSS96Y04084S-0Y-1B-72TLA-0B-0Y-62B-0Y-0AUS	87	90	124	34	18	55	2.49	33.79	7.67	8
137	SB069	CMSS96Y04084S-0Y-1B-80TLA-0B-0Y-69B-0AUS	86	90	128	38	17	42	1.70	37.34	5.50	4
138	SB109	CMSS96Y04084S-0Y-1B-93TLA-0B-0Y-109B-0Y-0AUS	89	94	125	31	18	52	2.64	41.53	7.71	10
139	SB165	CMSS96Y04051S-0Y-1B-16TLA-0B-0Y-5B-0Y-0AUS	88	92	124	33	18	50	2.71	36.98	5.58	11
140	SB169	CMSS96Y04051S-0Y-1B-22TLA-0B-0Y-9B-0Y-0AUS	88	93	126	34	19	53	2.49	33.62	8.73	8
141	**SB187**	CMSS96Y04051S-0Y-1B-52TLA-0B-0Y-27B-0Y-0AUS	**85**	**90**	**125**	**34**	**19**	**49**	**2.75**	**36.74**	**10.54**	**13**
142	SERI M 82	CM33027-F-15M-500Y-0M-87B-0Y-0MEX	85	92	126	34	17	50	2.12	31.94	9.73	12
143	SILVERSTAR	*	86	90	125	35	18	52	2.10	32.04	10.00	9
144	SITTELLA	*	87	92	126	33	18	47	1.56	32.73	4.61	9
145	SOKOLL	CMSS97M00316S-0P20M-0P20Y-60M-010Y	92	95	129	35	20	50	1.78	38.07	4.20	5
146	SSRT02	*	85	90	125	35	20	56	2.33	34.76	7.35	10
147	SSRT09	*	83	90	123	33	18	48	1.49	29.68	4.25	6
148	SSRT14	*	81	87	124	37	16	47	1.67	35.09	5.41	6
149	SSRT16	*	89	92	126	34	18	53	2.77	38.75	6.62	9
150	**SSRT17**	*	**87**	**90**	**126**	**36**	**19**	**55**	**3.02**	**36.25**	**10.17**	**12**
151	SSRT65	*	87	93	126	34	18	54	2.79	37.21	8.01	11

Sl. No.	Genotypes	Pedigree	DH	DA	DM	GFD	SLS	GS	GW (g)	TGW (g)	GY (g)	DTS
152	SSRW35	*	88	91	125	34	17	63	3.31	41.96	9.70	9
153	SSRW47	*	83	88	120	32	17	48	1.99	31.14	6.51	5
154	TACUPETO F2001	CGSS95B00016F-099Y-099B-099Y-099B-15Y-0B-0MEX	89	93	124	31	19	55	2.30	35.59	5.56	9
155	VJ01	*	84	89	123	34	18	47	2.04	37.73	8.35	12
156	VJ10	*	88	92	126	34	19	54	3.25	42.34	11.42	10
157	VJ30	*	82	87	120	33	17	42	1.83	33.44	5.87	6
158	VJ99	*	85	90	129	39	18	40	2.09	39.32	6.83	4
159	VOROBEY	CMSS96Y02555S-040Y-020M-050SY-020SY-34M-0Y	90	95	127	33	19	54	2.06	30.62	7.71	11
160	WYALKATCHEM	-0AUS	88	92	128	36	17	46	1.74	30.04	4.11	8

*= Pedigrees not available

DH=Days to heading, DA=Days to anthesis, DM=Days to maturity, GFD=Grain filling duration, SLS=no. of spikelets per main spike, GS=no. of grains per spike, GW=Grains weight per spike, TGW=Thousand grain weight, GY=Grain yield per plant, DTS=Drought tolerance score

Table 2. Analysis of variance of different yield traits studied in wheat genotypes during 2014-15 under rainfed condition

Sources of variation	d.f.	DH	DA	DM	GFD	SLS	GS	GW (g)	TGW (g)	GY (g)
Replication	1	87.15**	52.81**	28.80**	3.61^{ns}	80.00**	2.62^{ns}	0.01^{ns}	206.08**	0.26^{ns}
Blocks	7	49.46**	22.22**	10.41**	11.67**	3.47*	54.22^{ns}	0.58**	52.71**	3.79**
Treatments	159	10.36**	7.51**	5.60**	5.44**	2.47**	36.14*	0.40**	36.35**	9.63**
Rep. x Blocks	7	3.28^{ns}	3.88^{ns}	1.55^{ns}	3.94^{ns}	4.10**	83.88**	0.22^{ns}	2.93^{ns}	0.70^{ns}
Error	145	2.74	2.23	2.33	2.83	1.45	26.27	0.14	10.12	1.10

** = Significant at 1 % level, * =Significant at 5 % probability level, ns = Non-Significant

Table 3. Analysis of variance of different yield traits studied in wheat genotypes during 2015-16 under rainfed condition

Sources of variation	d.f.	DH	DA	DM	GFD	SLS	GS	GW (g)	TGW (g)	GY (g)
Replication	1	29.40**	69.37**	75.07**	0.11^{ns}	72.20**	3.20^{ns}	0.12^{ns}	223.22**	2.02^{ns}
Blocks	7	48.96**	26.94**	16.16**	13.28**	2.30^{ns}	56.30^{ns}	0.41*	72.11**	2.39*
Treatments	159	10.99**	8.57**	7.25**	6.04**	2.77**	38.21*	0.39**	41.99**	10.35**
Rep. x Blocks	7	3.15^{ns}	6.25**	3.46^{ns}	6.51*	4.18**		0.26^{ns}	2.37^{ns}	0.39^{ns}
Error	145	2.51	2.21	2.48	2.53	1.43	27.94	0.17	9.40	1.02

** = Significant at 1 % level, * =Significant at 5 % probability level, ns = Non-Significant

Table 4: Pooled analysis of variance of different yield traits studied in wheat genotypes during 2014-15 and 2015-16 under rainfed condition

Sources of variation	d.f.	DH	DA	DM	GFD	SLS	GS	GW (g)	TGW (g)	GY (g)
Year	1	697.22**	741.75**	1758.93**	216.22**	72.90**	690.97**	10.52**	179.73**	86.17**
Replication	1	108.90**	121.62**	98.43**	1.22^{ns}	152.10**	5.81^{ns}	0.02^{ns}	429.14**	0.40^{ns}
Blocks	7	98.02**	48.78**	26.06**	24.01**	4.24**	109.15**	0.96**	122.76**	5.93**
Treatments	159	20.92**	15.88**	12.49**	10.87**	5.10**	74.01**	0.78**	75.78**	19.84**
Rep. x Blocks	7	6.10*	9.83**	4.54^{ns}	10.15**	8.06**	188.13**	0.46**	3.16^{ns}	1.02^{ns}
Year x Treat.	159	0.43^{ns}	0.21^{ns}	0.35^{ns}	0.61^{ns}	0.17^{ns}	0.36^{ns}	0.01^{ns}	2.56^{ns}	0.14^{ns}
Error	305	2.54	2.13	2.32	2.58	1.39	25.80	0.15	9.37	1.02

** = Significant at 1 % level, * =Significant at 5 % probability level, ns = Non-Significant

and days to heading in the pooled data were significant only, remaining traits in the first year, second year and pooled data were non-significant. Mean square of the year had highly significantly differences for all the traits in pooled data. Mean square of the year × treatment had non-significantly differences for all the traits in pooled data. These results indicated that considerable amount of genetic variation present in this material. These results are in agreement with those obtained by (Zarea-Fizabady and Ghodsi, 2004; Sajjad *et al.,* 2011; Abd EI-Mohsen and Abo-Hegazy, 2013).

Simple Correlation Coefficient Analysis: Correlation analysis is widely used in statistical evaluations and it shows efficiency of relationship between two variables. Correlation coefficient in the present study was estimated by taking the pooled mean of quantitative traits and correlated with the scores of morphological traits. According to the data presented in Table 5, grain yield per plant exhibited highly significant and positive correlation with 1000 grain weight (0.536), grain weight per spike (0.391), waxiness score (0.247), indicating dependency of yield on these traits. Other traits including, No. of grains per spike (0.131), grain filling duration (0.127), leaf rolling score (0.115), days to maturity (0.102), leaf angle score (0.086), spike fertility score (0.017), showed non-significant positive correlation with grain yield per plant; and days to anthesis (-0.051), No. of spikelets per spike (-0.043), days to heading (-0.039), leaf morphology score (-0.017) showed non-significant negative correlation with grain yield per plant, indicating that Non-dependency of yield on these traits. The results of present investigation show that waxiness score and leaf rolling score have strong association with grain yield per plant. The findings are in agreement with the results of (Rebetzke *et al.,* 2001; Sirault, 2007)

Path Coefficient Analysis: The knowledge of correlation alone is often misleading as the correlation observed may not be always true. Two characters might be show correlation just because they are correlated with a common third one. In such cases, it is necessary to use a method by which we can show the causal relationship between the variables, with the degree of such relationship. Path coefficient analysis measure the direct influence of one variable upon the other, and separate the correlation coefficients into components of direct and indirect effects. Portion of total correlation into direct and indirect effects provide actual information on contribution of characters and thus form the basis for selection to improve the grain yield. The results of correlation coefficient was partitioned into direct and indirect effects through various yield contributing characters. The estimates of direct and indirect effects of the thirteen attributes on grain yield are presented in Table (6).

Based on path analysis, maximum positive direct effect on grain yield per plant was contributed mostly by days to maturity (0.603), followed by 1000 grain weight (0.439), waxiness score (0.179), No. of grains per spike (0.147), grain weight per spike (0.094) and leaf rolling score (0.045). This means that a slight increase in one of these traits may directly contribute to grain yield. Similar results were reported by (Dhonde, 2000; Satya, 2002; Khan and Dar, 2010). The positive direct effects of spikes number, grains number and thousand-kernel weight were previously reported in wheat (Fellahi, 2013; Pirdashti, 2012). On the other hand, the maximum negative direct effect was exhibited by days to anthesis (-0.577), followed by grain filling duration (-0.483), No. of spikelet per spike (-0.201), days to heading (-0.050), leaf angle score (-0.049), spike fertility score (-0.035) and leaf morphology score (-0.007). Residual effects (0.078) indicated that thirteen characters included in this study explained high percentage of variation in grain yield.

The effect of leaf angle on the canopy-reflected spectrum have an importance, cannot be ignored in the inversion of leaf area index. Leaf angle affects light interception (Utsugi, 1999) which influences canopy reflectance (Roberts). Leaf rolling may be associated with improved grain yield in some drought conditions. Evidence of varietal differences for leaf rolling in wheat (*Triticum aestivum* L.) has been reported (Rebetzke *et al.,* 2001) but studies investigating the amount and nature of genotypic variation in leaf rolling of wheat are rare (Sirault, 2007). Leaf waxes are composed of cutins that form the cuticular matrix and waxes (Samuels *et al.,* 2008). The waxes embedded in the matrix are known as intracuticular wax, while waxes deposited on the leaf surface are known as epicuticular waxes, also referred to as glaucousness. Ishag (2003) suggested that the leaf waxes may reduce heat input, thereby lowering leaf temperatures. Leaf waxiness or glaucousness has been associated with cooler canopies under water limiting conditions (Bennett *et al.,* 2012). Grain number per spike, which is greatly influenced by floret fertility, is an important trait of wheat (*Triticum aestivum* L.) yield. Maximum floret primordia, fertile floret, and final grain number per spikelet are three crucial factors of floret fertility. Floral degradation plays a critical role in determining these three floret fertility-related traits (Guo and Schnurbusch, 2015). The results of present investigation showed that waxiness score and leaf rolling score have strong association with grain yield per plant. We have selected 18 genotypes based on high morphological score as-well-as high grain yield per plant namely; DBW50, HD2985, HD3043, HD2687, HD3059, HD3076, HD3093, HI1531, HW1105, PBN142,

Table 5. Simple correlation coefficients analysis between different morphological and yield traits studied under rainfed condition

Characters	LM	LA	LR	WX	SF	DH	DA	DM	GFD	SLS	GS	GW (g)	TGW (g)	GY (g)
Leaf morphology score	**1.000**	0.300**	0.418**	0.205*	-0.090	-0.001	0.094	-0.136	-0.246**	0.145	0.145	-0.081	-0.052	-0.017
Leaf angle score		**1.000**	0.484**	0.475**	-0.091	0.152	0.176*	0.041	-0.190*	0.200*	0.246**	0.111	0.028	0.086
Leaf rolling score			**1.000**	0.608**	0.000	0.057	0.113	-0.131	-0.263**	0.235**	0.290**	0.200*	-0.016	0.115
Waxiness score				**1.000**	0.013	0.187*	0.198*	0.034	-0.225**	0.306**	0.356**	0.259**	0.100	0.247**
Spike fertility score					**1.000**	-0.015	-0.069	-0.077	-0.001	0.165*	0.236**	0.186*	0.070	0.017
Days to heading						**1.000**	0.874**	0.642**	-0.359**	0.271**	0.094	-0.061	-0.064	-0.039
Days to anthesis							**1.000**	0.588**	-0.544**	0.282**	0.116	-0.096	-0.075	-0.051
Days to maturity								**1.000**	0.325**	0.111	-0.069	-0.047	0.143	0.102
Grain filling duration									**1.000**	-0.228*	-0.194*	0.073	0.227*	0.127
No. of spikelets per spike										**1.000**	0.642**	0.238**	-0.021	-0.043
No. of grains per spike											**1.000**	0.563**	0.054	0.131
Grain weight per spike (g)												**1.000**	0.506**	0.391**
1000-Grains weight (g)													**1.000**	0.536**
Grain yield per plant (g)														1.000

** = Significant at 1 % probability level, r=0.230, * = Significant at 5 % probability level, r=0.164

Table 6. Direct and indirect effects of different morphological and yield contributing traits on grain yield under rainfed condition

Characters	LM	LA	LR	WX	SF	DH	DA	DM	GFD	SLS	GS	GW (g)	TGW (g)	GY (g)
Leaf morphology score	**-0.007**	-0.015	0.019	0.037	0.003	0.000	-0.054	-0.082	0.119	-0.029	0.021	-0.008	-0.023	-0.017
Leaf angle score	-0.002	**-0.049**	0.022	0.085	0.003	-0.008	-0.102	0.025	0.092	-0.040	0.036	0.010	0.012	0.086
Leaf rolling score	-0.003	-0.024	**0.045**	0.109	0.000	-0.003	-0.065	-0.079	0.127	-0.047	0.043	0.019	-0.007	0.115
Waxiness score	-0.001	-0.023	0.028	**0.179**	0.000	-0.009	-0.114	0.020	0.109	-0.061	0.052	0.024	0.044	0.247**
Spike fertility score	0.001	0.004	0.000	0.002	**-0.035**	0.001	0.040	-0.047	0.000	-0.033	0.035	0.018	0.031	0.017
Days to heading	0.000	-0.007	0.003	0.033	0.001	**-0.050**	-0.504	0.387	0.173	-0.054	0.014	-0.006	-0.028	-0.039
Days to anthesis	-0.001	-0.009	0.005	0.036	0.002	-0.044	**-0.577**	0.355	0.263	-0.057	0.017	-0.009	-0.033	-0.051
Days to maturity	0.001	-0.002	-0.006	0.006	0.003	-0.032	-0.339	**0.603**	-0.157	-0.022	-0.010	-0.004	0.063	0.102
Grain filling duration	0.002	0.009	-0.012	-0.040	0.000	0.018	0.314	0.196	**-0.483**	0.046	-0.029	0.007	0.100	0.127
No. of spikelets per spike	-0.001	-0.010	0.011	0.055	-0.006	-0.014	-0.163	0.067	0.110	**-0.201**	0.094	0.022	-0.009	-0.043
No. of grains per spike	-0.001	-0.012	0.013	0.064	-0.008	-0.005	-0.067	-0.041	0.094	-0.129	**0.147**	0.053	0.024	0.131
Grain weight per spike (g)	0.001	-0.005	0.009	0.046	-0.006	0.003	0.056	-0.028	-0.035	-0.048	0.083	**0.094**	0.222	0.391**
1000-Grains weight (g)	0.000	-0.001	-0.001	0.018	-0.002	0.003	0.043	0.086	-0.110	0.004	0.008	0.048	**0.439**	0.536**

LM=Leaf morphology score, LA=Leaf angle score, LA=Leaf rolling score, WX=Waxiness score, SF=Spike fertility score, DH=Days to heading, DA=Days to anthesis, DM=Days to maturity, GFD=Grain filling duration, SLS=no. of spikelets per main spike, GS=no. of grains per spike, GW=Grains weight per spike (g), TGW=Thousand grain weight (g), GY=Grain yield per plant (g)

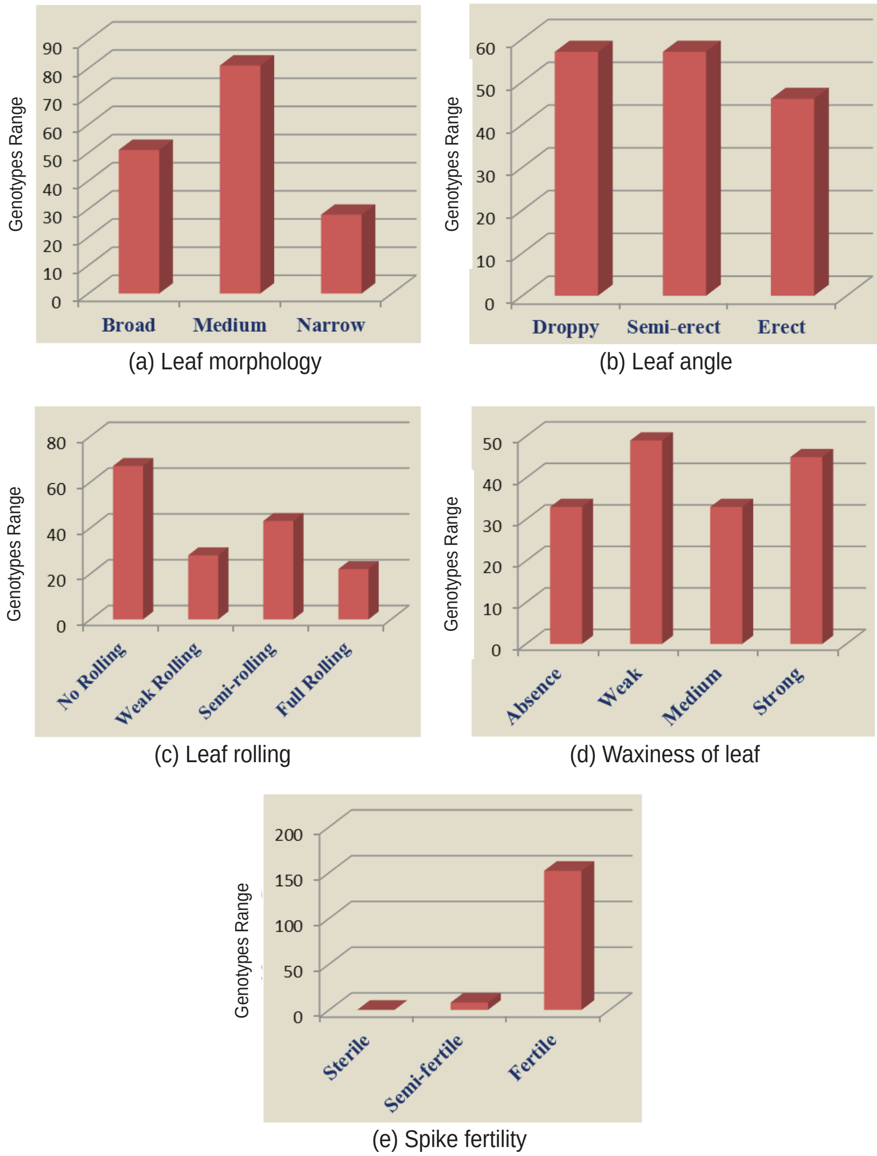

Fig. 1a-e. Frequency histograms of morphological characters recorded in 160 wheat genotypes studied under rainfed conditions.

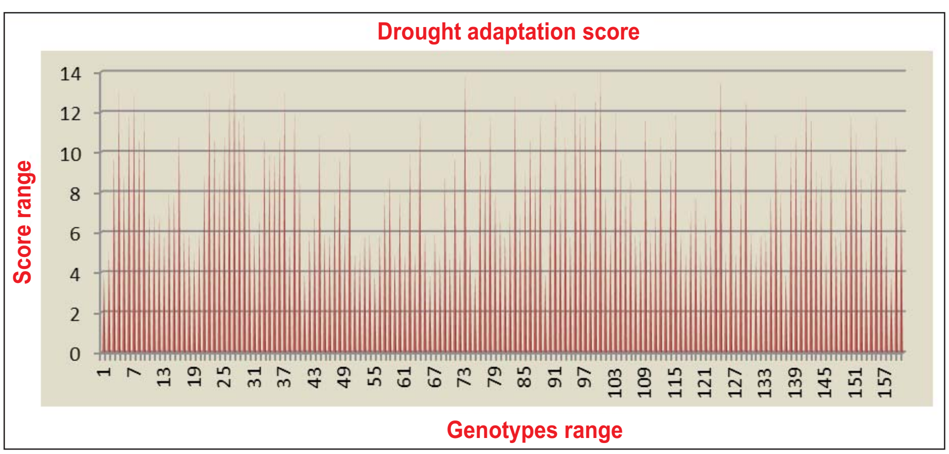

Fig. 2. Drought adaptation score studied in 160 wheat genotypes evaluated under rainfed condition.

PBW502, WH1080, WH730, AUS30354, AUS30518, DRYSDALE, SB187, SSRT17. These genotypes can be utilized in drought breeding programme for development of mapping population, as well as drought resilience varieties for rainfed areas.

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