Research Article

Performance of Synthetically Developed Wheat (*Triticum aestivum* L.) Hybrids for Yield Traits under Normal and Late Planting

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Abstract | Five synthetic wheat lines and four cultivars were crossed in line × tester fashion in 2012-13 to develop 20 F_1 hybrids. Parents and F_1 hybrids were evaluated during 2013-14 wheat season at the University of Agriculture, Peshawar, Pakistan under normal (November, 10) and late (December, 15) planting environment using a triplicate Randomized Complete Block design. Genotype × environment interac tion across the two environments was significant for spikes plant^{-1}, spikelets spike^{-1}, grains spike^{-1}, spike density, 1000-grain weight and grain yield plant^{-1}. Line × tester interaction effect was also highly significant for all traits under both normal as well as late plantings. There was general reduction in mean performance of genotypes for important yield component traits due to late planting but the magnitude of reduction varied over genotypes and traits. Mean of 29 genotypes (9 parents and 20 F_1 hybrids) were 18.0 vs. 7.4 for spikes plant^{-1}, 23.4 vs. 20.5 for spikelets spike^{-1}, 70.2 vs. 51.6 for grains spike^{-1}, 47.7 vs. 40.4 g for 1000-grain weight and 35.6 vs.19.6 g for grain yield plant^{-1} under normal and late planting environment. Therefore, simultaneous evaluation and selection under both planting environments is more effective strategy for developing wheat cultivars with optimum performance under both normal and late environments.

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Introduction

Bread wheat (*Triticum aestivum* L.) is a major food grain and valuable staple crop in Pakistan and the world as well. Food challenges due to increasing population invite the attention of breeders, researchers and growers to raise the level of wheat production proportionally (Saeed et al., 2016). This could be achieved by combining together good attributes from available wheat germplasm into newly developed genotypes. Planting time plays important role especially in a country like Pakistan, where various agro-ecological climates are available throughout the country. Delayed wheat planting is amongst the major yield limiting constraints in rice-wheat, cotton-wheat and sugarcane-wheat cropping system of south Asia including Pakistan. Wheat growers suffer tremendous yield losses due to delayed in sowing (Fujisaka et al., 1994). For normal sowing of wheat, the time duration from 25th October to 20th November is recommended in Pakistan (Shah et al., 1994). Due to delay in sowing till December 5th, a yield loss of 42% has been recorded (Subhan et al., 2004). The late sown crop matures in shorter time as compared to the normal sown crop as the hot summer approaches. Seasonal changes in temperature, precipitation and growth periods have potential impacts on the phasic development as well as productivity of wheat crop (Hussain et al., 2014). Planting wheat crop at suitable time is one approach of realizing higher commercial yields as it allows the crop to fully express its yield potential. In the current era of climate change, considerable improvement in wheat production is inevitable to feed the ever increasing and burgeoning population and to maintain global food security (Deryngeet al., 2014). Synthetic hexaploid wheat possesses novel alleles and genes for biotic and abiotic stress tolerance as well as for grain quality traits, which are not currently available within the bread wheat gene pool. Hence, synthetic hexaploids act as a reservoir for introducing specific characters of interest from D-genome progenitors into bread wheat backgrounds (Kazi et al., 2007; Rasheed et al.,2012; Bibi et al., 2013) Some synthetic hexaploid wheat have also achieved yield similar to those of check cultivars under drought stress (Trethowan and Kazi, 2008). Therefore, our objective was to evaluate performance of 20 F1 hybrids derived from line×tester mating of five synthetic lines and four well adapted cultivars under normal and late environment.

Materials and Methods

This research was conducted at the University of Agriculture, Peshawar during wheat crop seasons 2012-14. Five synthetic wheat lines and four wheat cultivars (referred as testers) were crossed in line×tester fashion during 2012-13 to develop 20 F_1 populations for evaluation in next cropping season. The five synthetic lines were Syn L1, Syn L2, Syn L3, Syn L4 and Syn L5 and were obtained from the Wide Wheat Program at the National Agricultural Research Center (NARC), Islamabad, Pakistan. Among the four tester cultivars, Fakhre Sarhad and Atta Habib are full season cultivars and are recommended for early or normal planting (early to mid-November), while Khyber-87 and Saleem-2000 are short season cultivars and are recommended for late planting (early to late-December) in Khyber Pakhtunkhwa Province of Pakistan.

Field evaluation of parents and F_1 hybrids

The nine parental genotypes and the resultant 20 F_1 hybrid populations were evaluated as independent experiments under normal and late planting conditions during 2013-14 wheat season at Malkandher Research Farm, the University of Agriculture, Peshawar. A Randomized Complete Block (RCB) design with three replications was used under each test environment (normal and late planting) at same field to avoid environmental biasness. The normal experiment was planted on November 10, 2013 and late on December 15, 2013. A plot for each genotype (parents and F_1 hybrids) had 3 rows of 3 meter length. Row to row spacing was 30 cm, while plant to plant spacing was 10 cm. Nitrogen and phosphorous was applied at the rate of 120 and 60 kg ha^{-1} both to normal and late planted experiments in split doses (half at planting time and half at 3-4 leaf stage) in both normal and late planted experiment.

Table 1: *List of synthetic wheat lines and testers with their pedigree crossed in line×tester fashion to develop 20 F_1 hybrids.*

Genotypes	Pedigree
Synthetic Lines	
Syn L1	SNIPE/YAV79//DACK/TEAL/3/Ae.tauschii
Syn L2	ALTAR84/ Ae. Tauchii
Syn L3	ROK/KML// Ae. Tauchii
Syn L4	ACO89/ Ae. Tauchii
Syn L5	DOY1/ Ae. Tauchii
Testers	
Fakhr-e-Sarhad	PFAU"S"/SERI/BIW"S"
Khyber-87	KVZ/TRM//PTM/ANA(LIRA "S")
Saleem-2000	CHAM-6//KITE/PGO
Atta Habib	Inqalab91*2/Tukuru

Data recording and statistical analysis

Data was recorded on ten plants per genotype per replication for spikes $plant^{-1}$, spikelets $spike^{-1}$, grains $spike^{-1}$, spike density, 1000-grain weight and grain yield $plant^{-1}$. Data were statistically analyzed across the two environments to quantify performance of genotypes, parents and F_1s over two test environments using mixed effect model proposed by Annicchiarico (2002).

Results and Discussion

Spikes $plant^{-1}$

Combined analysis of variance (ANOVA) across two planting conditions (normal and late) indicated highly significant differences ($P \leq 0.01$) among the two environments and genotypes for spikes $plant^{-1}$ indicating presence of enough genetic variability for the given trait. Similarly, highly significant ($P \leq 0.01$)

Table 2: *Mean squares from ANOVA across two environments (normal and late planting) for Spikes plant^{-1}, spikelets spike^{-1}, spike density, grains spike^{-1}, 1000-grain weight and grain yield plant^{-1} of nine wheat parents and 20 F_1 hybrids at Peshawar.*

Source	df	Spikes plant^{-1}	Spikelets spike^{-1}	Spike density	Grains spike^{-1}	Th-grnWt	Grain yield plant^{-1}
Environment	1	4907.92 **	361.21**	2.72**	14902.68**	2284.65**	11184.05**
Reps w/n environment	4	0.37	0.61	0.01	0.67	1.82	2.09
Genotypes	28	30.33**	10.94**	0.11**	89.38**	87.49**	79.82**
Parents	8	22.03**	3.65*	0.07**	47.57**	105.37*	9.33*
F1s	19	14.40 **	10.60**	0.14**	74.02**	42.09**	30.30**
Parents vs F1s	1	399.29**	75.67**	0.10 NS	715.72**	807.35**	1584.40**
Genotypes × Environment	28	38.53**	9.75**	0.12**	55.03**	10.29**	7.80**
Parents × Environment	8	19.09**	3.27**	0.06**	17.43**	17.66**	3.16**
F1s × Environment	19	16.92 **	8.01**	0.14**	47.61**	2.77**	7.06**
Error	112	0.51	0.24	0.005	1.14	0.46	0.88

***,**:** *significant at 5% and 1% probability level, respectively;* **NS:** *Non-significant.*

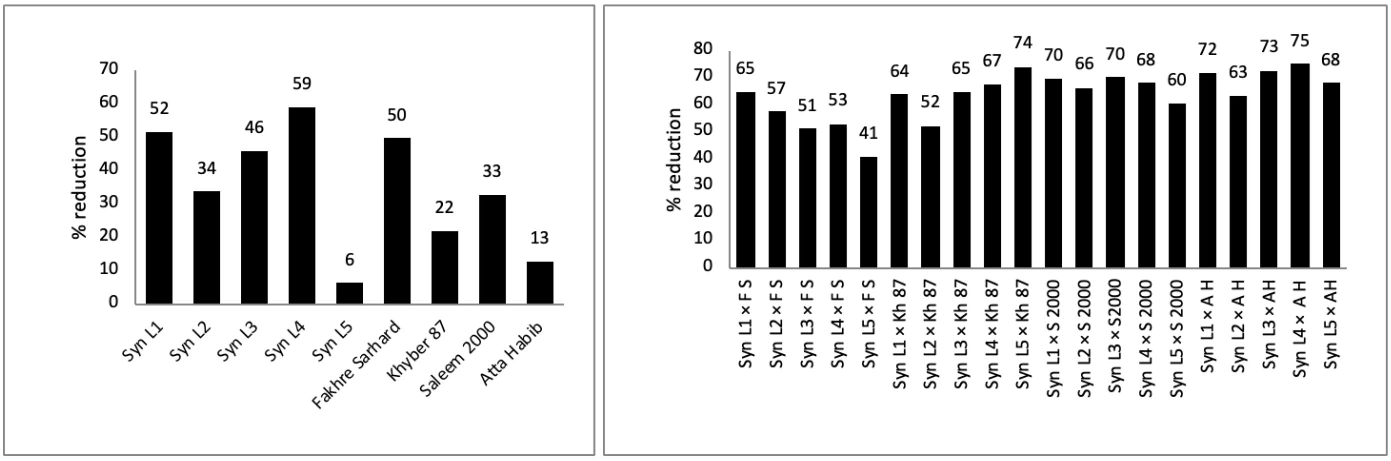

Figure 1: *Percent reduction in spikes per plant of 9 parents and 20 F_1 hybrids under late planting.*

genotype×environment interaction indicated differential response of genotypes for spikes plant^{-1} due to change in planting environment (Table 2). Independent analysis of variance showed significant differences ($P \leq 0.01$) among genotypes as well as their parents and F_1s for spikes plant^{-1} under each test environment. Similarly, parents vs. F_1 contrast was also highly significant ($P \leq 0.01$) both under normal as well as late planting. However, differences among lines were non-significant ($P \geq 0.05$) under both plantings. Differences among testers were highly significant under late planting. However, line×tester interactions for spike plant^{-1} were highly significant ($P \leq 0.01$) under each environment. Maximum spikes plant^{-1} under normal planting were produced by Syn L1×Fakhre Sarhad (24.0 spikes plant^{-1}), Syn L1×Saleem-2000 (23.6 spikes plant^{-1}) and Syn L4×Saleem-2000 (23.2 spikes plant^{-1}) among F_1s. Similarly under late planting, F_1 hybrid Syn L4×Fakhre Sarhad (9.6 spikes plant^{-1}), Syn L1×Fakhre Sarhad (8.5 spikes plant^{-1}) and Syn L3×Fakhre Sarhad (8.3 spikes plant^{-1}) produced maximum spikes. Averaged across two environments, Syn L1, Syn L3 and Syn L4 among parents and Syn L5×Khyber-87, Syn L3×Saleem-2000 and Syn L3×Fakhre Sarhad among F_1 hybrids produced maximum spikes plants^{-1} (Table 3). There was general reduction in spikes plant^{-1} ranging from 6% to 59% among parental genotypes, while 41% to 75% among F_1 hybrids due to late planting (Figure 1). Least reduction in spikes plant^{-1} was noticed in parental genotype Syn L5 and Syn L5×Fakhre Sarhad among F_1 hybrids. Moral et al. (2003) evaluated 10 wheat genotypes of CIMMYT and ICARDA origin at eight different locations for 2 years. Reduction due to late planting ranged from 34% to 37% in spikes m-2 due to moisture and terminal heat stress. Similarly, Baloch et al. (2012) investigated effect of planting time (Oct-20, Oct-30, Nov-10, Nov-20, Nov-30, Dec-10, Dec-20 and Dec-30) on yield components of wheat cultivars viz. Zam-04, Gomal-8, Hashim-8, and advanced lines DN-62 and DN-76 over different planting dates. Maximum spikes of 418 m^{-2} were observed for Nov-20, while least (372 spikes m^{-2}) for Dec-30 planting.

Spikelets spike^{-1}

Combined analysis of variance (ANOVA) across two planting environments (normal and late) for spikelets spike^{-1} revealed highly significant differences (P ≤ 0.01) among genotypes and genotype× environment

Table 3: *Means for spikes plant^{-1}, spikelets spike^{-1} and grains spike^{-1} of nine wheat parents and 20 F_1 hybrids tested under normal and late planting at Peshawar.*

Genotypes	Spikes plant^{-1} (no.)			Spikelets spike^{-1} (no.)			Grains spike^{-1} (no.)		
	Normal	Late	Mean	Normal	Late	Mean	Normal	Late	Mean
I. Parents									
Syn L1	18.0	8.7	13.4	23.2	20.7	22.0	71.7	53.6	62.6
Syn L2	12.2	8.1	10.2	19.5	20.7	20.1	63.1	52.2	57.7
Syn L3	16.1	8.7	12.4	20.9	20.2	20.5	66.9	48.7	57.8
Syn L4	17.5	7.2	12.3	21.6	20.5	21.1	65.1	53.2	59.2
Syn L5	9.2	8.7	9.0	22.6	20.2	21.4	61.7	51.4	56.5
FakhreSarhad	14.0	7.0	10.5	22.2	21.5	21.9	69.7	52.4	61.0
Khyber-87	9.6	7.5	8.5	22.1	20.5	21.3	63. 3	50.3	56.8
Saleem-2000	11.6	7.8	9.7	20.7	20.5	20.6	61.6	51.2	56.4
Atta Habib	8.3	7.3	7.8	18.7	20.5	19.6	58.5	47.4	53.0
Parents mean	13.0	7.9	10.4	21.3	20.6	20.9	64.6	51.2	57.9
II. F_1 hybrids									
Syn L1×Fakhre Sarhad	24.0	8.5	12.4	24.3	19.7	22.0	72.8	54.7	63.8
Syn L2×Fakhre Sarhad	17.4	7.4	12.7	24.2	18.5	21.4	75.4	49.5	62.5
Syn L3×Fakhre Sarhad	17.0	8.3	14.9	24.9	19.8	22.4	71.2	50.2	60.7
Syn L4×Fakhre Sarhad	20.3	9.6	10.7	24.2	19.5	21.9	70.2	53.2	61.7
Syn L5×Fakhre Sarhad	13.4	8.0	13.9	24.9	18.2	21.6	67.0	48.4	57.7
Syn L1×Khyber-87	20.3	7.4	10.3	24.2	17.7	21.0	64.0	53.0	58.5
Syn L2×Khyber-87	14.0	6.7	14.3	24.1	16.3	20.2	61.7	46.7	54.2
Syn L3×Khyber-87	21.2	7.5	14.0	23.6	17.3	20.5	76.4	51.6	64.0
Syn L4×Khyber-87	21.1	6.9	14.2	24.3	17.5	20.9	65.0	48.0	56.5
Syn L5×Khyber-87	22.5	5.8	15.4	23.9	19.2	21.6	81.1	49.0	65.1
Syn L1×Saleem-2000	23.6	7.2	14.7	22.6	19.7	21.2	74.6	53.7	64.2
Syn L2×Saleem-2000	21.9	7.4	14.7	22.6	22.6	22.6	76.4	52.8	64.6
Syn L3×Saleem-2000	22.7	6.8	15.3	24.5	22.5	23.5	77.1	51.3	64.2
Syn L4×Saleem-2000	23.2	7.4	11.9	23.7	23.3	23.5	75.5	52.8	64.1
Syn L5×Saleem-2000	17.1	6.8	14.1	24.9	22.2	23.6	72.0	52.0	62.0
Syn L1×Atta Habib	22.0	6.2	12.1	25.1	22.5	23.8	81.0	53.7	67.4
Syn L2×Atta Habib	17.7	6.5	13.7	25.2	23.6	24.4	69.7	56.3	63.0
Syn L3×Atta Habib	21.5	5.9	13.8	24.4	23.4	23.9	70.9	55.1	63.0
Syn L4×Atta Habib	22.1	5.5	14.5	25.2	22.7	24.0	83.1	53.5	68.4
Syn L5×Atta Habib	21.9	7.0	13.7	25.2	22.1	23.6	68.0	52.2	60.1
F1s mean	20.3	7.1	13.6	24.3	20.4	22.4	72.7	51.9	62.3
Env mean	18.0	7.4		23.4	20.5		70.2	51.6	
$LSD_{(0.05)}$ for Genotypes	0.8			0.6			1.2		
$LSD_{(0.05)}$ for Env	0.2			0.3			0.3		
$LSD_{(0.05)}$ for G × E	1.1			0.8			1.7		

Table 4: *Means for spike density, 1000-grain weight and grain yield plant^{-1} of nine wheat parents and 20 F_1 hybrids tested under normal and late planting at Peshawar.*

Genotypes	Spike density (spikelets cm^{-1})			1000-grain weight (g)			Grain yield (g plant^{-1})		
	Normal	Late	Mean	Normal	Late	Mean	Normal	Late	Mean
I.Parents									
Syn L1	1.7	2.1	1.9	41.7	36.7	39.2	32.6	15.6	24.1
Syn L2	1.6	1.8	1.7	36.7	34.3	35.5	28.6	14.9	21.8
Syn L3	1.6	2.1	1.8	40.1	37.1	38.6	31.6	18.3	25.0
Syn L4	1.9	2.2	2.1	39.8	37.5	38.7	31.2	16.9	24.0
Syn L5	1.7	2.4	2.0	36.7	35.2	35.9	30.7	16.0	23.4
FakhreSarhad	1.7	2.0	1.9	52.7	41.7	47.2	31.1	16.8	23.9
Khyber-87	1.8	1.9	1.9	50.1	40.1	45.1	29.2	13.9	21.5
Saleem-2000	1.9	2.1	2.0	47.6	41.3	44.4	28.0	16.3	22.2
Atta Habib	1.8	2.0	1.9	44.9	40.9	42.9	29.0	15.0	22.0
Parents mean	1.7	2.1	1.9	43.4	38.3	40.8	30.2	16.0	23.1
II. F_1 hybrids									
Syn L1×Fakhre Sarhad	1.9	2.2	2.1	48.7	40.7	44.7	36.0	19.0	27.5
Syn L2×Fakhre Sarhad	1.7	2.0	1.9	46.8	38.8	42.8	36.6	19.6	28.1
Syn L3×Fakhre Sarhad	2.0	1.9	1.9	49.8	41.8	45.8	39.6	21.3	30.5
Syn L4×Fakhre Sarhad	1.8	2.0	1.9	46.6	38.6	42.6	40.5	20.8	30.7
Syn L5×Fakhre Sarhad	2.1	1.8	1.9	47.6	39.6	43.6	38.2	20.2	29.2
Syn L1×Khyber-87	1.8	1.9	1.8	38.6	34.6	36.6	33.1	19.1	26.1
Syn L2×Khyber-87	2.1	1.7	1.9	48.9	40.9	44.9	33.6	19.2	26.4
Syn L3×Khyber-87	1.6	1.6	1.6	50.0	41.0	45.5	37.8	22.1	30.0
Syn L4×Khyber-87	2.1	1.9	2.0	50.3	41.7	46.0	37.2	22.2	29.7
Syn L5×Khyber-87	1.8	1.9	1.8	50.9	42.2	46.6	33.5	19.5	26.5
Syn L1×Saleem-2000	1.7	1.9	1.8	51.9	43.2	47.6	43.9	24.9	34.4
Syn L2×Saleem-2000	1.6	2.1	1.8	50.8	42.4	46.6	35.1	21.7	28.4
Syn L3×Saleem-2000	1.9	2.4	2.1	51.2	41.2	46.2	39.1	22.1	30.6
Syn L4×Saleem-2000	1.7	2.2	1.9	52.1	41.5	46.8	33.7	19.1	26.4
Syn L5×Saleem-2000	2.0	2.4	2.2	52.8	43.1	48.0	37.5	22.8	30.2
Syn L1×Atta Habib	1.8	2.6	2.2	49.1	42.8	45.9	41.2	21.5	31.4
Syn L2×Atta Habib	1.9	2.4	2.1	50.2	42.7	46.4	41.5	22.5	32.0
Syn L3×Atta Habib	1.8	2.1	2.0	52.5	44.1	48.3	41.6	22.6	32.1
Syn L4×Atta Habib	1.7	2.3	2.0	50.5	41.8	46.1	39.9	21.5	30.7
Syn L5×Atta Habib	2.0	2.2	2.1	52.8	44.4	48.6	41.0	22.0	31.5
F1s mean	1.8	2.1	2.0	49.6	41.4	45.5	38.0	21.2	29.6
Env mean	2.1	1.8		47.7	40.4		35.6	19.6	
$LSD_{(0.05)}$ for Genotypes	0.1			0.8			1.1		
$LSD_{(0.05)}$ for Env	0.1			0.8			0.6		
$LSD_{(0.05)}$ for G × E	0.1			1.1			1.5		

(Table 2). Independent analysis of variance under-normal and late planting showed that genotypes were significantly ($P \leq 0.01$) different for spikelets spike^{-1}. Parental genotypes and parents vs. F_1 contrast exhibited highly significant difference under normal planting. Similarly, genetic variation among F_1 hybrids was significant ($P \leq 0.01$) both under normal as well as late planting. However, lines showed non-significant ($P \geq 0.05$) differences under both planting, whereas differences among testers and line×tester interaction were significant under each test environment. Majeed et al. (2011) reported significant genetic variations among parents, F_1 hybrids and testers in spring wheat. Number of spikelets of parental genotypes ranged from 18.7 to 23.2 spike^{-1} under normal, while under late planting spikelets ranged from 20.2 to 21.5 spike^{-1} (Table 3). Syn L1 produced maximum spikelets spike^{-1} under normal planting, while Fakhre Sarhad under late planting. Among F_1 hybrids, maximum spikelets spike^{-1} (25.2 spikelets spike^{-1}) were produced by each cross combination Syn L2×Atta Habib, Syn L4×Atta Habib and Syn L5×Atta Habib under normal planting. Similarly, Syn L2×Atta Habib produced maximum spikelets spike^{-1} (23.6 spikelets) under late planting. Maximum reduction in spikelets spike^{-1} among parents was observed in Syn L1 and Syn L5 (11%) each due to late planting and Syn L2×Khyber-87 (32%) among F_1 hybrids. However, Syn L2×Saleem-2000 showed no reduction in spikelet spike^{-1} (Figure 2). Syn L1 (22.0 spikelets spike^{-1}) among parents and Syn L2×Atta Habib (24.4 spikelets spike^{-1}) among F_1 populations were top ranking wheat genotypes across two environments (Table 3).

Grains spike^{-1}

Combined analysis of variance (ANOVA) across two planting conditions (normal and late) indicated highly significant genetic differences ($P \leq 0.01$) among the wheat genotypes for grains spike^{-1}. Similarly total genetic variation partitioned into parental and F_1 hybrid components also depicted significant genetic differences among wheat parents and their resultant 20 F_1 hybrids for trait under study. Likewise, genotype×environments as well as its sub-component interaction effects were also highly significant ($P \leq 0.01$) (Table 2). Independent analysis of variance showed highly significant ($P \leq 0.01$) genetic differences among genotypes. Parents and F_1 hybrids under normal as well as late planting had enough genetic variability for number of grains spike^{-1}. Grains of wheat parents ranged from 58.5 to 71.7 grains spike^{-1} under normal, while 47.4 to 53.6 grains spike^{-1} under late planting (Table 3). Syn L1 among parental genotypes produced maximum grains spike^{-1} (71.7 grains spike^{-1}) under normal as well as late (53.6 grains spike^{-1}) planting. Maximum grains among F_1 populations were recorded in Syn L4×Atta Habib (83.1 grains spike^{-1}) under normal planting. Similarly under late planting, F_1 population Syn L2×Atta Habib produced maximum grains (56.3 spike^{-1}). Averaged over 9 parents, a net reduction of 13.4 grains spike^{-1} (21%), while among F_1 hybrids a net reduction of 20.8 grains spike^{-1} (29%) were observed due to late planting (Table 3). Least reduction due to late planting was observed in Syn L2, Syn L5 and Saleem-2000 (17% in each) among parents (Figure 3). Similarly among F_1 hybrids, least reduction due to late planting was observed in Syn L1×Khyber-87 (17%) (Figure 3). Average across two environments, Syn L1 among parents while, Syn L4×Atta Habib among F_1 hybrids were top ranking genotypes by producing maximum of 62.6 and 68.4 grains spike^{-1}, respectively (Table 3). Significant reduction up to 12% (Sial et al., 2005), 5-14% (Sial et al., 2010) and 33% (Yajam and Madani, 2013) in grains spike^{-1} due to late planting may occur mainly due to heat stresses at anthesis and grain development stages.

Spike density

Pool analysis of variance (ANOVA) across two planting environments (normal and late) indicated highly significant differences ($P \leq 0.01$) among the two environments for spike density. Similarly, genotypes and genotype×environment interaction was also highly significant ($P \leq 0.01$) for spike density (Table 2). Independent analysis of variance revealed that genotypes, parents and F_1 hybrids differed significantly ($P \leq 0.01$) for spike density under each test environment. Testers exhibited non-significant ($P \geq 0.05$) differences for spike density under normal planting but significant under late planting. Significant genetic differences for spike density in F_1 wheat populations and parental wheat lines were also observed by Kashif and Khaliq (2003). Spike density of wheat parents ranged from 1.6 to 1.9 spikelets cm^{-1} and 1.8 to 2.4 spikelets cm^{-1} under normal and late planting, respectively (Table 4). Parental genotypes Syn L4 and Saleem-2000 (each with 1.9 spikelets cm^{-1}) showed maximum spike density under normal planting and Syn L5 (2.4 spikelets cm^{-1}) under late planting. Spike density of F_1 hybrids ranged from 1.6 to 2.1 spikelets cm^{-1} under normal planting, while 1.6 to 2.6 spikelets cm^{-1} under late planting. Among F_1 hybrids, maximum spike density was recorded for Syn L5×Fakhre Sarhad, Syn L2×Khyber-87 and Syn L4×Khyber-87 (each with 2.1 spikelets cm^{-1}) under normal planting, while Syn L1×Atta Habib (2.6 spikelets cm^{-1}) produced maximum spike density under late planting. Syn L4 among parents, while Syn L5×Saleem-2000 and Syn L1×Atta Habib among F_1 hybrids had comparatively more dense spikes across the two planting conditions (Table 4).

1000-grain weight

Analysis of variance across the two environments exhibited highly significant differences ($P \leq 0.01$) among genotypes and environments for 1000-grain weight. Genotypes×environment interaction for 1000-grain weight was also significant ($P \leq 0.01$), indicating differential performance of wheat genotypes under two growing environments (Table 2). Independent analysis under normal as well as late plantings showed highly significant differences (P ≤ 0.01) among genotypes, parents and F_1 hybrids for 1000-grain weight. Parents vs. F_1 hybrid contrast was also significant (P ≤ 0.05) under each test environment (normal and late planting). Wheat lines showed no differences for 1000-grain weight under both test environments and testers under normal planting as well. However, line×tester interaction was significant (P ≤ 0.01) under each planting (normal and late) environment. Average 1000-grain weight of parental genotypes ranged from 36.7 to 52.7 g under normal planting vs. 34.3 to 41.7 g under late planting (Table 4). Tester Fakhre Sarhad produced maximum 1000-grain weight both under normal (52.7 g) as well as late (41.7 g) planting. Thousand grain weight of F_1 hybrids ranged from 38.6 to 52.8 g under normal vs. 34.6 to 44.4 g under late planting. Among F_1 hybrids, Syn L5×Saleem-2000 (52.8 g), Syn L5×Atta Habib (52.8 g) and Syn L3×Atta Habib (52.5 g) and Syn L4×Saleem-2000 (52.1 g) produced maximum 1000-grain weight under normal planting. Similarly under late planting, maximum 1000-grain weight was recorded for Syn L5×Atta Habib (44.4 g), Syn L3×Atta Habib (44.1 g), Syn L1×Saleem-2000 (43.2g) and Syn L5×Saleem-2000 (43.1g). Pooled over two environments, the highest 1000-grain weight was recorded for Fakhre Sarhad among parents, while Syn L5×Atta Habib among F_1 hybrids (Table 4). Thus, immense reduction in 1000-grain weight due late planting was observed both in parental genotypes (4-21%) as well as F_1 Hybrids (10-20%). Maximum reduction in 1000-grain weight due to late planting was observed for Fakhre Sarhad (21%) among parents, while minimum reduction was observed in parental genotype Syn L5 (4%). Similarly among F_1 hybrids, maximum reduction was observed for cross combinations Syn L3×Saleem-2000 and Syn L4×Saleem-2000 (20%), while minimum in Syn L1×Khyber-87 (10%) (Figure 4). Average 1000-grain weight of 20 F_1 hybrids was significantly greater than mean of 9 parents both under normal (49.6 vs. 43.4 g) as well as late planting (41.4 vs. 38.3 g), respectively (Table 4). Iqbal et al. (1999) observed reduction of 5 to 15 g per thousand grains may occur due to heat stress at grain development stage resulting in more proportion of shriveled grains. Moshatati et al. (2012) evaluated 20 spring wheat cultivars and observed that 1000-grain weight reduced from 44.07 g under optimum planting to 25.13 g under late planting showing net reduction of 43% using four sowing dates. Similarly, Bala et al. (2014) also reported reduction of 24.5, 25.7 and 31.6% in 1000-grain weight of cultivars PSW-550, PBW-343 and C-273 due to late sowing.

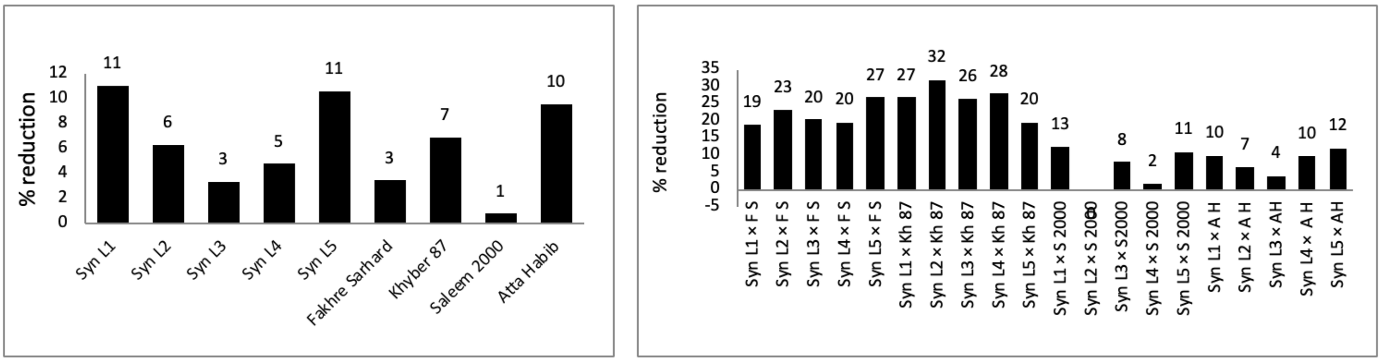

Figure 2: *Percent reduction in spikelets per spike of 9 parents and 20 F_1 hybrids under late planting.*

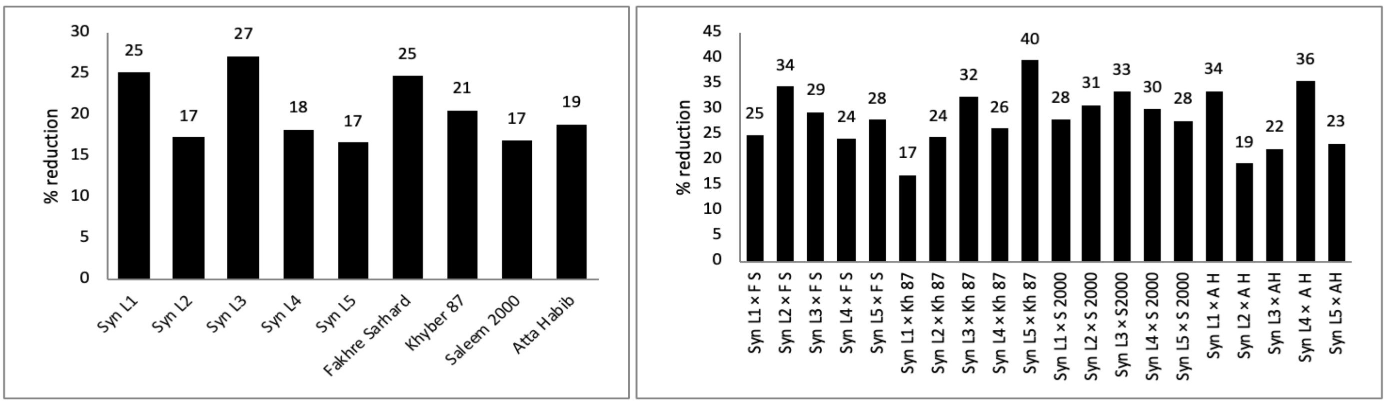

Figure 3: *Percent reduction in grains per spike of 9 parents and 20 F_1 hybrids under late planting.*

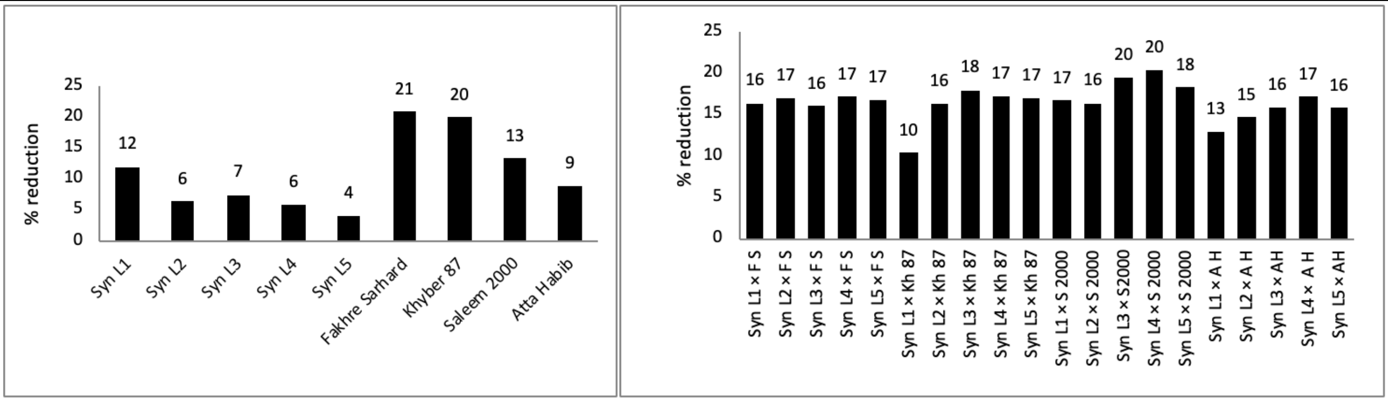

Figure 4: *Percent reduction in 1000-grain weight of 9 parents and 20 F_1 hybrids under late planting.*

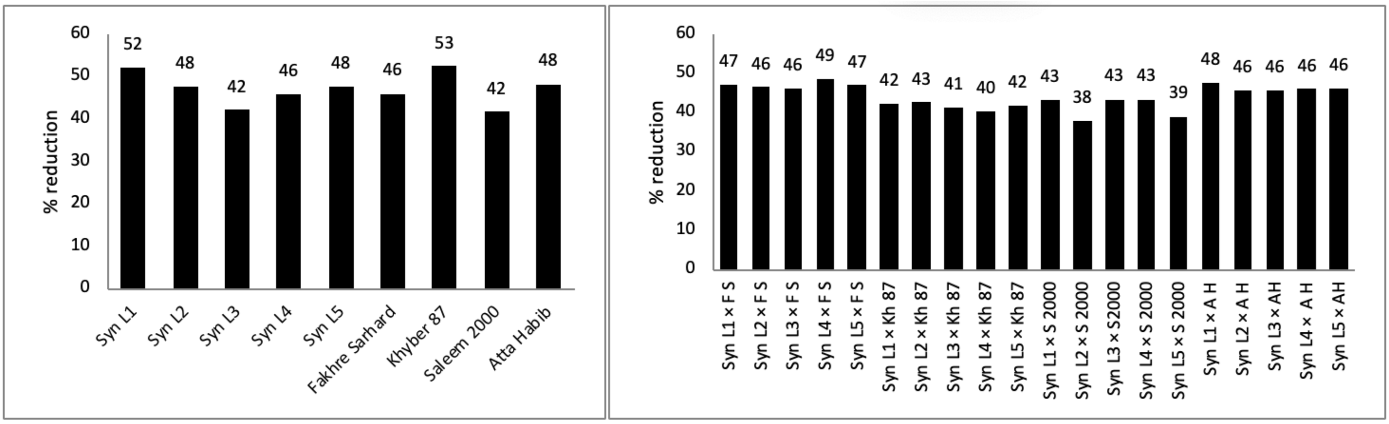

Figure 5: *Percent reduction in grain yield of 9 parents and 20 F_1 hybrids under late planting.*

Grain yield plant^{-1}

Combined analysis of variance across two environments revealed highly significant genetic differences ($p \leq 0.01$) among genotypes for grain yield plant^{-1} (Table 2). Similarly, differences among environments and genotypes × environment were also highly significant ($P \leq 0.01$) for grain yield plant^{-1} indicating variable performance of wheat genotypes under the two environments. Independent analysis exhibited significant differences ($P \leq 0.01$) among wheat genotypes for grain yield plant^{-1} under normal as well as late planting (Table 3). Similarly, parents, F_1hybridsand Parents vs. F_1s contrast also exhibited highly significant ($P \leq 0.01$) genetic variation under each test environment. Testers and Line×tester interaction effects were highly significant ($P \leq 0.01$), under each environment whereas lines did not show any variations for grain yield. Average grain yield of parental genotypes under normal planting ranged from 28.0 to 32.6 g plant^{-1} while 13.9 to 18.3 g plant^{-1} under late planting (Table 5). Maximum grain yield produced by parental genotype Syn L1 (32.6 g plant^{-1}) under normal planting, while highest yield under late planting was produced by genotype Syn L3 (18.3 g plant^{-1}). Grain yield of F_1 hybrids ranged from 33.1 to 43.9 g plant^{-1} under normal planting while, 19.0 to 24.9 g plant^{-1} under late planting. Maximum yield was produced by cross combinations Syn L1×Saleem-2000 (43.9 g plant^{-1}), Syn L3×Atta Habib (41.6 g plant^{-1}) and Syn L2×Atta Habib (41.5 g plant^{-1}) among F_1 hybrids, under normal planting. Similarly, maximum grain yield under late planting was produced by F_1 hybrid Syn L1×Saleem-2000 (24.9 g plant^{-1}),Syn L5×Saleem-2000 (22.8 g plant^{-1}), Syn L3× Atta Habib (22.6 g plant^{-1}) and Syn L2×Atta Habib (22.5 g plant^{-1}). Thus, general reduction was 42 to 52% among parental genotypes and 38 to 49% among F_1in grain yield plant^{-1} due to late planting. Least reduction in yield was noticed in genotypes Syn L3 and Saleem-2000 (each with 42% reduction) among parental genotypes, while maximum (52%) in Khyber-87 (Figure 5). Similarly, minimum reduction in grain yield due to late planting was observed in cross combination Syn L2×Saleem-2000 (38%), while maximum reduction in F_1 hybrids Syn L4×Fakhre Sarhad (49%) and Syn L1×Atta Habib (48%) (Figure 5). Average grain yield of 20 F_1 hybrids was significantly ($p \leq 0.01$) greater than nine parental genotypes both under normal (38.0 vs. 30.2 g plant^{-1}) as well as late (21.2 vs. 16.0 g plant^{-1}) planting indicating high potential of hybrid populations (Table 5). Averaged across two environments, parental genotypes Syn L3, Syn L1 and Syn L4 and F_1 hybrids

Syn L1×Saleem-2000, Syn L2×Atta Habib and Syn L3×Atta Habib were top ranking by producing maximum grain yield of 24.0 to 25.0 and 32.0 to 34.4 g plant^{-1}, respectively. Mukhtarullah et al. (2016) observed reduction in yield traits decreased overall grain yield from 2660 (Nov. 10) to 2330 kg ha^{-1} (Dec. 25), indicating 330 kg ha^{-1} or 13% reduction due to late planting. Similarly, yield reduction of 7.2 to 38.9% in five wheat cultivars (Zam-04, Gomal-08, Hashim-08, DN-62 and DN-76) evaluated using eight sowing dates commencing from Oct. 20 and ending Dec. 30 was observed by Baloch et al. (2012). Thus, grain yield was about 61% higher under normal planting condition. Similarly, Sattar et al. (2010) found that wheat grain yield of five wheat cultivars averaged 4.91 vs. 3.41 tons ha^{-1} under 10 Nov. and 10 Dec. planting. This reduction of 1.5 tons ha^{-1} or 31% was attributed to cumulative effect of reduced spikes m^{-2} (10.0%), spike length (10.4%), grains spike^{-1} (19.4%) and 1000-grain weight (12.6%) due to late planting.

Conclusions and Recommendations

Evaluation and selection under stress condition of newly developed wheat cultivars characterized by high yield potential and stability is of great importance in wheat breeding programs. Traits which maximize productivity in the absence of stress could still sustain a significant yield improvement under mild to moderate stress. In the current study, genotype×environment interaction were highly significant for all yield related traits indicating differential performance of wheat parents and their F_1 hybrid populations under normal (mid-Nov.) and late (mid-Dec.) plantings. General reduction was observed in mean performance of parental genotypes as well as F_1 hybrids for most yield traits due to late planting but the magnitude of reduction varied over genotypes and traits. Syn L1, Syn L3, and Syn L4 among lines and Fakhre Sarhad and Khyber-87 among testers had best performance for most traits like spikes plant^{-1}, spikelets spike^{-1}, grains spike^{-1}, 1000-grain weight, and grain yield under one or both environments. Similarly, F_1 hybrid Syn L1×Saleem-2000, Syn L2×Atta Habib, Syn L3×Atta Habib and Syn L5×Atta Habib were best for most of the yield traits under one or both test environments.

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Novelty Statement

The current research helps in identifying yield component traits, which maximize wheat productivity under normal and late sowing conditions encountered in majority of wheat growing regions of Pakistan and world as well.

Author's Contribution

Durr e Nayab conducted the research and Iftikhar Hussain Khalil supervised the research work as well as assisted in data analysis. Fida Mohammad and Shad Khan Khalil provided technical guidance during research.

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