Research Article

Impact of Selection on Distribution of Crop Duration Parameters in Chinese Wheat Hybrids

Zainab Iftikhar[1], Muhammad Arif[2], Iqbal Munir[1] and Sajid Ali[1*]

[1]Institute of Biotechnology and Genetic Engineering, The University of Agriculture, Peshawar, Pakistan; [2]Department of Agronomy, The University of Agriculture, Peshawar, Pakistan.

Abstract | Changes in climatic conditions would strongly influence the crop duration of many crops including wheat, which necessitates exploration of diversity in crop duration parameters in wheat with particular emphasis on novel sources of genetic variation, including hybrid wheat. The present work was designed to assess the potential of Chinese wheat hybrid germplasm for cultivation across Pakistan. For this purpose, 416 hybrids were assessed for diversity in crop duration parameters in the year 2017-18 and a subset of better performing 108 hybrids were selected and assessed for subsequent assessment. During the first experiment of preliminary testing of 416 Chinese wheat hybrids along with 5 local checks tested during 2017-18, significant variability (P<0.01) was observed for days to jointing and booting, the parameters related to crop duration. The overall impact was negative on the crop duration, resulting in selection of earlier lines. Although selection increased the mean value, the variability decreased for most of the parameters. Variability in Chinese hybrids reflects on the potential of selection for candidate hybrids to be released in Pakistan after proper testing. The variability could also be exploited for generation of further variability in Pakistani wheat germplasm for normal varietal development as a novel source of germplasm to reduce genetic homogeneity.

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***Correspondence** | Sajid Ali, Institute of Biotechnology and Genetic Engineering, The University of Agriculture, Peshawar, Pakistan; **Email:** bioscientist122@yahoo.com
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Introduction

Wheat crop production has enormously increased in the post Green Revolution decades due to the use of semi dwarf varieties of wheat in Pakistan and India like Mexi-Pak, Sonalika and Kalyan Sona (Ziska *et al*., 2012). Green Revolution, however, has resulted in exploitation of limited crop diversity in countries like Pakistan, where most of the wheat germplasm is based on CIMMYT introduced material (Ali *et al*., 2014c). Further increase in yield is relatively slow due to its narrow genetic background, particularly in semiarid areas, especially in the context of changing climate. The crop duration is strongly influenced by the changes in climatic conditions, especially temperature and rainfall. The available diversity in Pakistani germplasm provides limited variability to carry out breeding for earliness and other crop duration parameters. It becomes more complicated while considering diseases, where many varieties have been shown to be overcome by the highly adaptive rust pathogens (Ali *et al*., 2014a), mainly due to limited diversity in sources of genetic resistance (Ali *et al*., 2014c). Thus, an efficient genetic improvement programme necessitates exploitation of novel/exotic sources of diversity, ranging from sources in wild rel-

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atives to hybrid wheat.

For the exotic germplasm, the performance of lines may vary when introduced into a novel area and thus, testing of exotic germplasm is a pre-requisite for further breeding (Qasim *et al*., 2008). However, a large number of lines are introduced at the first point to capture the maximum diversity, thus, thorough phenotyping is quite difficult. Preliminary testing is, thus, the first step to characterize a large set of germplasm (Fufa *et al*., 2005; Perween *et al*., 2020). After preliminary testing, selection could be made to proceed with cultivars or hybrids with desirable trait, though passing through a risk of genetic drift, where some desirable lines could be lost due to limited information about the germplasm during the preliminary testing (Aycicek and Yildirim 2006; Singh *et al*., 2016). The effectiveness of the selection for both, quantitative and qualitative traits, depend on the genetic variability and heritability (Khan and Hassan 2018). Field based preliminary testing in various parameters is essential in order to quantify the phenotypic variation, while exploring genetic resources not exploited in the past in Pakistan, like the ones from Chinese wheat germplasm, including Chinese wheat hybrids.

The hybrid breeding seems to be an effective process employed in removing the obstacles in higher wheat yield, when approached a stagnancy in the varietal development. Greater profit from heterosis and a large return on investment could be attained because of an in-built varietal phytoprotection which makes hybrid breeding recommendable in comparison to line breeding. The gain from hybrid vigour is a routine process in cross pollinated crops like maize, and regular hybrids are registered on annual basis for subsequent dissipation to the farmers. These hybrids have been shown to increase the yields of various crops in different parts of the world. However, reduction of inbred lines and subsequent production of hybrid seed is a limiting factor in many crops. A prominent gain in selection, an inexpensive production and availability of hybrid seed and enough heterosis levels are needed for success of a hybrid wheat breeding program (Longin *et al*. 2012). The hybrid vigour needs to be used commercially through developing hybrid wheat varieties which could likely overcome the food shortcomings due to yield heterosis (Singh *et al*. 2004). The additional hybrid seed expenditures, comparatively lower seed multiplying rate and complex hybridizing systems are the limiting factors to produce hybrid wheat's growth and sales of seeds along with insufficient amount of heterosis in a number of ecological conditions (Edwards 2001). Exploration of the potential of hybrid wheat varieties is under intensive assessment to improve wheat yield in China. Chinese wheat represents a diverse source of wheat gene pool, which could potentially be exploited in Pakistan for wheat genetic improvement. Additionally, the potential of Hybrid wheat remains unexplored in Pakistan.

Our work is designed with an aim to explore diversity among Chinese hybrids for their suitability in the wheat production in Pakistan, based on preliminary testing and their response to selection. Comparison of the performance of hybrid lines with local checks will enable to estimate commercial heterosis. The information in the preliminary trial is not only important for selection of parents with better performance to be crossed, but is also important for selection of better performing F_1 hybrids, which could be directly recommended for cultivation after thorough testing. These studies on Chinese hybrids could enable to explore useful genes in the rich allelic stock of hybrids, which have been developed from Chinese landraces and wheat cultivars (Peleg *et al*., 2009; Dresselhaus and Hu¨ckelhoven 2018). The hybrids studied in the current study are based on the male sterility traits and considering their Chinese origin, these are well suited to be considered under Pakistani wheat production system.

The present study was, thus, designed to explore diversity for crop duration parameters in Chinese hybrids and the impact of selection in terms of changes in the distribution of these parameters. The performance of selected hybrids was, further, assessed based on field testing while estimating selection differential and genetic advance.

Materials and Methods

A set of 416 Chinese Hybrids, received from Beijing Engineering Research Centre for Hybrid Wheat (BERCHW), China, was assessed for its phenotypic diversity along with five checks in the first year, whereas a subset of selected 108 Chinese Hybrids was assessed during the second year for evaluation. Both the preliminary testing and evaluation of selected material was carried out at the experimental field of Sheerin Khan Research Farm, the University of Agriculture, Peshawar, Pakistan (34°1′21″N, 71°28′5″E).

The experimental site had subtropical climate, with semi-arid conditions, receiving annual rainfall of 360 mm.

Preliminary field testing of 416 Chinese wheat hybrids

The preliminary trial comprised of 416 Chinese wheat hybrids and 5 check varieties *viz.,* Atta Habib, Shahkar-13, PirSabak-15, Ghanimat-e-IBGE and PirSabak-13 (Table 1). The aim of this experiment was to assess the preliminary field-based diversity among these Chinese hybrids in comparison with the local checks. Data was collected on crop duration parameters i.e., days to emergence, jointing, booting, heading, anthesis and maturity (Maqbool *et al*., 2010; Khan and Hassan, 2018). The field experimentation and crop husbandry were followed as per routine wheat production technology at the research farm.

The trial was carried out in an augmented design, which consisted of 8 blocks, 25 plots and 22 subplots. The sub-plots consisted of two rows of 1.5 meter length with 25 cm row spacing. Each block was divided into a plot and then, subplot, having seventeen hybrids and five check varieties, which was repeated to calculate the error mean square and block effect, as per standard procedure of augmented design. Wheat hybrids were sown on a well-prepared seedbed during November in winter with hand hoe, maintaining row to row distance of 25 cm. Crop husbandry was done as per recommended practices. Planting was done at the seeding rate of 50 seeds plot^{-1}. A basal dose of phosphorus and potassium each at the rate of 90 and 50 kg ha^{-1} was applied in the form of DAP (Di-ammonium Phosphate) and Sulphate of potash (SOP), respectively. Nitrogen at the rate of 150 kg ha^{-1} was applied in two splits; half was applied with first irrigation while remaining half was applied at jointing stage. First irrigation was applied four weeks after sowing the crop while subsequent irrigations were applied as and when needed. Affinity 50WP (Isoproturon + Carfentrazone) @ 2 kg ha^{-1} (800 g a.i. acre^{-1})/ Puma super 75 FW @ 1.25 L ha^{-1} + Buctril super EC @ 750 ml ha^{-1} herbicide was sprayed with the help of knapsack sprayer to control broad and narrow leaf weeds to avoid weed crop competition.

Data collection for crop duration parameters

Data on crop duration parameters was collected using Zadok's Cereal Growth Stages key (Zadoks *et al*., 1974). These included days to emergence, jointing, booting, heading, anthesis and maturity. Data regarding days to emergence was recorded by counting the days taken from the date of sowing to the date when 75% emergence occurred in each plot. Data regarding days to jointing was recorded by counting the days taken from the date of sowing to the date when 75% plants reached the jointing stage in each plot. Days to booting were recorded by counting number of days taken from date of sowing to the date when 75% plants reached the boot stage in each plot. Days to heading were recorded by counting the days taken by crop from sowing until 75% plants reached the heading stage in each plot. Days to anthesis were recorded by counting the days from planting to the date when 75% plants reached the anthesis stage in each plot. Days to maturity were recorded by counting the number of days from sowing till 75% plants reached the physiological maturity in each plot indicated by yellow color of the spikes (Mohsin *et al*., 2012).

Field testing of selected 108 Chinese wheat hybrids

A subset of approximately 108 hybrids from the 416 Chinese wheat hybrids was selected and tested for crop duration parameters to assess the impact of selection and estimate selection differential and genetic advance. The performance of selected hybrids and commercial heterosis was also described in comparison with five promising local check varieties over two years (2017-18 and 2018-19).

For the field testing of the selected 108 Chinese wheat hybrids, the augmented design was applied with 8 blocks and 20 subplots (15 hybrids and 5 check varieties), except for the last block which contained 8 subplots consisting of 3 hybrids and 5 check varieties, which were included to calculate the error mean square and block effect, as per standard practice. The remaining crop husbandry was maintained as that in the preliminary field testing (described above). The data was collected on crop duration parameters i.e., days to emergence, jointing, booting, heading, anthesis and maturity as described above (Maqbool *et al*., 2010; Khan and Hassan, 2018).

Data analyses for assessment of selection impact

The collected data was subjected to analysis of variance (ANOVA), by using the model to determine whether the genotypic differences were significant for the characters under consideration. The distributions of overall population (416 Chinese hybrids) and selected hybrids (during 2017-18 and 2018-19) were represented as Boxplots, generated through

Table 1: *List of tested Chinese wheat hybrids and five local check varieties along with their distribution into cluster groups, based on crop duration parameters.*

S. No.	Genotype	Group[a]	S. No.	Genotype	Group	S. No.	Genotype	Group	S. No.	Genotype	Group
1	17BH001	G4	106	17BH106	G1	211	17BH211	G1	316	17BH316	G1
2	17BH002	G1	107	17BH107	G4	212	17BH212	G1	317	17BH317	G4
3	17BH003	G1	108	17BH108	G1	213	17BH213	G2	318	17BH318	G4
4	17BH004	G4	109	17BH109	G2	214	17BH214	G4	319	17BH319	G1
5	17BH005	G2	110	17BH110	G1	215	17BH215	G4	320	17BH320	G4
6	17BH006	G1	111	17BH111	G2	216	17BH216	G4	321	17BH321	G4
7	17BH007	G2	112	17BH112	G1	217	17BH217	G1	322	17BH322	G1
8	17BH008	G1	113	17BH113	G4	218	17BH218	G2	323	17BH323	G4
9	17BH009	G1	114	17BH114	G4	219	17BH219	G1	324	17BH324	G4
10	17BH010	G2	115	17BH115	G1	220	17BH220	G4	325	17BH325	G3
11	17BH011	G2	116	17BH116	G2	221	17BH221	G3	326	17BH326	G1
12	17BH012	G1	117	17BH117	G2	222	17BH222	G3	327	17BH327	G1
13	17BH013	G2	118	17BH118	G4	223	17BH223	G4	328	17BH328	G4
14	17BH014	G1	119	17BH119	G4	224	17BH224	G2	329	17BH329	G4
15	17BH015	G2	120	17BH120	G4	225	17BH225	G4	330	17BH330	G1
16	17BH016	G4	121	17BH121	G4	226	17BH226	G4	331	17BH331	G4
17	17BH017	G1	122	17BH122	G2	227	17BH227	G4	332	17BH332	G4
18	17BH018	G1	123	17BH123	G2	228	17BH228	G4	333	17BH333	G2
19	17BH019	G4	124	17BH124	G1	229	17BH229	G1	334	17BH334	G4
20	17BH020	G2	125	17BH125	G4	230	17BH230	G1	335	17BH335	G4
21	17BH021	G1	126	17BH126	G3	231	17BH231	G1	336	17BH336	G4
22	17BH022	G1	127	17BH127	G4	232	17BH232	G4	337	17BH337	G4
23	17BH023	G1	128	17BH128	G1	233	17BH233	G3	338	17BH338	G1
24	17BH024	G1	129	17BH129	G2	234	17BH234	G4	339	17BH339	G4
25	17BH025	G4	130	17BH130	G4	235	17BH235	G1	340	17BH340	G4
26	17BH026	G2	131	17BH131	G2	236	17BH236	G4	341	17BH342	G4
27	17BH027	G1	132	17BH132	G1	237	17BH237	G4	342	17BH343	G4
28	17BH028	G4	133	17BH133	G1	238	17BH238	G4	343	17BH344	G3
29	17BH029	G1	134	17BH134	G4	239	17BH239	G4	344	17BH345	G4
30	17BH030	G4	135	17BH135	G1	240	17BH240	G4	345	17BH346	G1
31	17BH031	G1	136	17BH136	G4	241	17BH241	G4	346	17BH347	G4
32	17BH032	G1	137	17BH137	G1	242	17BH242	G4	347	17BH348	G4
33	17BH033	G2	138	17BH138	G1	243	17BH243	G3	348	17BH349	G3
34	17BH034	G1	139	17BH139	G1	244	17BH244	G4	349	17BH350	G4
35	17BH035	G1	140	17BH140	G4	245	17BH245	G4	350	17BH351	G3
36	17BH036	G2	141	17BH141	G4	246	17BH246	G4	351	17BH352	G4
37	17BH037	G1	142	17BH142	G4	247	17BH247	G1	352	17BH353	G4
38	17BH038	G1	143	17BH143	G4	248	17BH248	G4	353	17BH354	G4
39	17BH039	G1	144	17BH144	G4	249	17BH249	G1	354	17BH355	G4
40	17BH040	G1	145	17BH145	G4	250	17BH250	G1	355	17BH356	G4
41	17BH041	G1	146	17BH146	G4	251	17BH251	G4	356	17BH357	G3
42	17BH042	G2	147	17BH147	G4	252	17BH252	G4	357	17BH358	G1
43	17BH043	G2	148	17BH148	G2	253	17BH253	G4	358	17BH359	G1
44	17BH044	G2	149	17BH149	G1	254	17BH254	G4	359	17BH360	G4

45	17BH045	G4	150	17BH150	G4	255	17BH255	G4	360	17BH361	G4
46	17BH046	G1	151	17BH151	G4	256	17BH256	G4	361	17BH362	G3
47	17BH047	G2	152	17BH152	G4	257	17BH257	G4	362	17BH363	G4
48	17BH048	G2	153	17BH153	G4	258	17BH258	G4	363	17BH364	G4
49	17BH049	G2	154	17BH154	G1	259	17BH259	G4	364	17BH365	G4
50	17BH050	G1	155	17BH155	G2	260	17BH260	G1	365	17BH366	G4
51	17BH051	G1	156	17BH156	G2	261	17BH261	G4	366	17BH367	G4
52	17BH052	G4	157	17BH157	G4	262	17BH262	G4	367	17BH368	G4
53	17BH053	G1	158	17BH158	G4	263	17BH263	G1	368	17BH369	G4
54	17BH054	G2	159	17BH159	G4	264	17BH264	G4	369	17BH370	G4
55	17BH055	G1	160	17BH160	G1	265	17BH265	G4	370	17BH371	G4
56	17BH056	G4	161	17BH161	G1	266	17BH266	G1	371	17BH372	G4
57	17BH057	G1	162	17BH162	G2	267	17BH267	G1	372	17BH373	G4
58	17BH058	G1	163	17BH163	G1	268	17BH268	G4	373	17BH374	G4
59	17BH059	G1	164	17BH164	G4	269	17BH269	G4	374	17BH375	G4
60	17BH060	G1	165	17BH165	G4	270	17BH270	G1	375	17BH376	G1
61	17BH061	G1	166	17BH166	G4	271	17BH271	G4	376	17BH377	G1
62	17BH062	G1	167	17BH167	G4	272	17BH272	G4	377	17BH378	G3
63	17BH063	G1	168	17BH168	G4	273	17BH273	G4	378	17BH379	G4
64	17BH064	G1	169	17BH169	G1	274	17BH274	G4	379	17BH380	G3
65	17BH065	G1	170	17BH170	G4	275	17BH275	G4	380	17BH381	G4
66	17BH066	G1	171	17BH171	G4	276	17BH276	G4	381	17BH382	G4
67	17BH067	G1	172	17BH172	G1	277	17BH277	G4	382	17BH383	G4
68	17BH068	G1	173	17BH173	G4	278	17BH278	G4	383	17BH384	G4
69	17BH069	G4	174	17BH174	G1	279	17BH279	G1	384	17BH385	G4
70	17BH070	G1	175	17BH175	G4	280	17BH280	G4	385	17BH386	G4
71	17BH071	G2	176	17BH176	G4	281	17BH281	G1	386	17BH387	G4
72	17BH072	G2	177	17BH177	G4	282	17BH282	G4	387	17BH388	G3
73	17BH073	G1	178	17BH178	G1	283	17BH283	G4	388	17BH389	G4
74	17BH074	G2	179	17BH179	G1	284	17BH284	G4	389	17BH390	G4
75	17BH075	G1	180	17BH180	G4	285	17BH285	G4	390	17BH391	G3
76	17BH076	G1	181	17BH181	G4	286	17BH286	G1	391	17BH392	G3
77	17BH077	G1	182	17BH182	G1	287	17BH287	G3	392	17BH393	G4
78	17BH078	G1	183	17BH183	G1	288	17BH288	G1	393	17BH394	G3
79	17BH079	G2	184	17BH184	G2	289	17BH289	G4	394	17BH395	G4
80	17BH080	G1	185	17BH185	G1	290	17BH290	G4	395	17BH396	G4
81	17BH081	G1	186	17BH186	G4	291	17BH291	G4	396	17BH397	G4
82	17BH082	G4	187	17BH187	G3	292	17BH292	G4	397	17BH398	G3
83	17BH083	G2	188	17BH188	G4	293	17BH293	G2	398	17BH399	G3
84	17BH084	G2	189	17BH189	G4	294	17BH294	G1	399	17BH400	G4
85	17BH085	G1	190	17BH190	G1	295	17BH295	G4	400	17BH401	G3
86	17BH086	G4	191	17BH191	G2	296	17BH296	G4	401	17BH402	G4
87	17BH087	G1	192	17BH192	G1	297	17BH297	G4	402	17BH403	G4
88	17BH088	G4	193	17BH193	G4	298	17BH298	G1	403	17BH404	G4
89	17BH089	G4	194	17BH194	G1	299	17BH299	G4	404	17BH405	G4
90	17BH090	G1	195	17BH195	G4	300	17BH300	G4	405	17BH406	G4
91	17BH091	G1	196	17BH196	G1	301	17BH301	G4	406	17BH407	G1

92	17BH092	G1	197	17BH197	G4	302	17BH302	G4	407	17BH408	G4
93	17BH093	G4	198	17BH198	G2	303	17BH303	G4	408	17BH409	G4
94	17BH094	G4	199	17BH199	G4	304	17BH304	G3	409	17BH410	G4
95	17BH095	G1	200	17BH200	G4	305	17BH305	G1	410	17BH411	G4
96	17BH096	G1	201	17BH201	G4	306	17BH306	G1	411	17BH412	G4
97	17BH097	G1	202	17BH202	G4	307	17BH307	G4	412	17BH413	G4
98	17BH098	G1	203	17BH203	G2	308	17BH308	G4	413	17BH414	G4
99	17BH099	G4	204	17BH204	G4	309	17BH309	G4	414	17BH415	G4
100	17BH100	G2	205	17BH205	G1	310	17BH310	G4	415	17BH416	G4
101	17BH101	G1	206	17BH206	G1	311	17BH311	G3	416	17BH417	G4
102	17BH102	G4	207	17BH207	G4	312	17BH312	G4	3 Local checks	Ghanimat-e-IBGE, Shahkar-13, PS-13	G3
103	17BH103	G3	208	17BH208	G4	313	17BH313	G1			
104	17BH104	G4	209	17BH209	G4	314	17BH314	G4			
105	17BH105	G2	210	17BH210	G1	315	17BH315	G1	2 Local checks	PS-15 & Atta-Habib	G4

Note: [a]*refers to clustering group assigned based on crop duration parameters.*

Table 2: *Mean square values and their significance for various crop duration parameters tested during 2017-18.*

Studied Parameter	Mean square values						LSD (0.05) values	
	Check varieties		Hybrids		Hybrid vs. check		Among Checks	Among hybrids
Days to emergence	6.57	NS	2.06	NS	20.86	**	NS	NS
Days to jointing	86.93	*	47.98	**	50.96	NS	2.99	14.93
Days to booting	101.49	**	25.45	*	249.49	**	2.42	12.10
Days to heading	131.34	**	13	*	25	NS	1.76	8.8
Days to anthesis	83	NS	8	NS	425	**	NA	NA
Days to maturity	10	NS	4	NS	1	NS	NA	NA
Degree of freedom	4		415		1		4	415

Note: * *refers to significance at less than 5%,* ** *refers to significance at less than 1%; NS refers to "non-significant".*

R-statistical software, to assess the role of selection in changing the distribution of these parameters. Selection differential and genetic advance was estimated through comparing the difference in performance of overall population and selected hybrids during the same year (for selection differential) and over the subsequent year (for genetic advance).

Results and Discussion

Our results revealed a highly significant variability among the tested wheat hybrids for various crop duration parameters (Table 1), revealing a very high and significant variability among the Chinese hybrids, reflected by the mean square values and their significance. The selected hybrids performance showed significant variability, with better performance for certain hybrids than the local checks. This variability in performance was further confirmed by the subsequent year performance of the selected hybrids. The work enabled to identify the hybrids with better performance than local checks.

Preliminary assessment of 416 Chinese wheat hybrids for crop duration parameter

During the preliminary testing of 416 Chinese hybrids, the differences for days to emergence were non-significant between varieties and hybrids, while these were significant for hybrids versus varieties (Table 2). Significant differences were observed for days to jointing between hybrids (LSD: 14.93) and between varieties (LSD: 2.99). However, no significant differences were found between varieties vs. hybrids. Significant differences for days to booting between hybrids (LSD: 12.10), varieties (LSD: 2.42) and hybrids vs varieties were observed. Significant differences were observed for the hybrids (LSD: 8.8) and varieties (LSD: 1.76) for days to booting. The mean square values revealed higher variability among the hybrids compared to the local checks. The analysis of variance for the days to anthesis revealed non-significant results for both, the hybrids and check varieties, whereas the hybrid vs. check probability was shown to be significant. The days to maturity showed non-significant results for all, hybrids, varieties and hybrids versus check varieties. The Chinese hybrids exhibited higher diversity compared to the local checks (Figure 1).

The days to emergence for the Chinese hybrids ranged from 10 to 15, with a mean value of 12 and standard deviation of 1.44 (Figure 1a). This range included the range for days to emergence of the local check varieties, which ranged from 11 days (for Ghanimat-e-IBGE) to 13 days (observed for Shahkar-13 and Atta-Habib) with a mean value of 12 and standard deviation of 0.84. The values mentioned clearly indicated that the hybrids had higher variability than the local checks and could be exploited for subsequent selection.

The genetic diversity in terms of days to jointing was assessed for Chinese hybrids and local checks, as plotted through the boxplots. The boxplots clearly indicated greater variations of the hybrids against the check varieties (Figure 1b). The days to jointing for the hybrids ranged between 50 and 73, with a mean value of 62 and S.D of 6.93. The range for the hybrids included even the range of the check varieties which was 60 (observed for Ghanimat-e-IBGE) to 65 (observed for Atta Habib) with mean value of 62 and S.D of 1.82. These values clearly hint towards higher variability of the hybrids compared to the local checks.

The days to booting also exhibited higher diversity in the Chinese hybrids than the local checks (Figure 1c). The range of days to booting between the hybrids was 82 to 100 with a mean value of 93 and standard deviation of 5.05. The values for the days to booting among the check varieties were 89 (recorded for PirSabak-15) to 94 (recorded for Atta Habib) which was included in the range of the hybrids. The mean value for the checks was 91 with standard deviation of 1.92. This showed higher diversity in the hybrids opposing to the checks.

Days to heading for both, the hybrids and the checks, were recorded for assessing the genetic diversity for crop duration, considering the importance of this parameter to crop production (Figure 1d). The values for the days to heading for the hybrids ranged between 102-118 with a mean value of 110 and standard deviation of 3.64. These values included the values of the local checks which ranged between 107 (observed for PirSabak-15) and 113 (observed for Atta Habib) with a mean value of 109 and S.D. of 2.30. The higher variation for days to heading for the hybrids than local checks could be useful for further selection.

The hybrids had larger range of the days to anthesis values between 119 and 130 with mean value of 124 and standard deviation of 2.80 (Figure 1e). The values for the checks ranged between 121 (observed for Ghanimat-e-IBGE, PirSabak-13 and PirSabak-15) to 125 (observed for Atta Habib) with mean value of 122 and standard deviation of 1.79. The values clearly indicated higher variability of the Chinese hybrids compared to the local checks.

Genetic diversity for days to maturity was assessed for the 416 hybrids along with the check varieties, where the values ranged between 151 and 159 with a mean value of 154 and S.D of 1.90 for hybrids (Figure 1f). This revealed higher variability compared to the values of the check varieties, which ranged between 153 (recorded for Shahkar-13) and 155 (observed for PirSabak-15 and Atta Habib) having mean of 154 and S.D of 0.84.

Clustering of 416 Chinese wheat hybrids based on field parameters

The clustering of 416 Chinese wheat hybrids in the preliminary assessment for crop duration parameters, grouped these into four major clusters, which could be subdivided to further sub-groups (Figure 2). Group G1 contained 118 Chinese hybrids, while group G2 contained 136 Chinese hybrids. Group G3 and group G4 contained 102 and 63 Chinese hybrids, respectively. Group G2 could be said to have maximum hybrids for crop duration parameters.

The hybrids of group G1 took maximum number of days to emerge as evident from the clustering figure. Maximum number of days to jointing, booting, heading, anthesis and maturity were taken by the lines present in clustering group G2, thus, representing the group with long crop duration parameters among the tested lines.

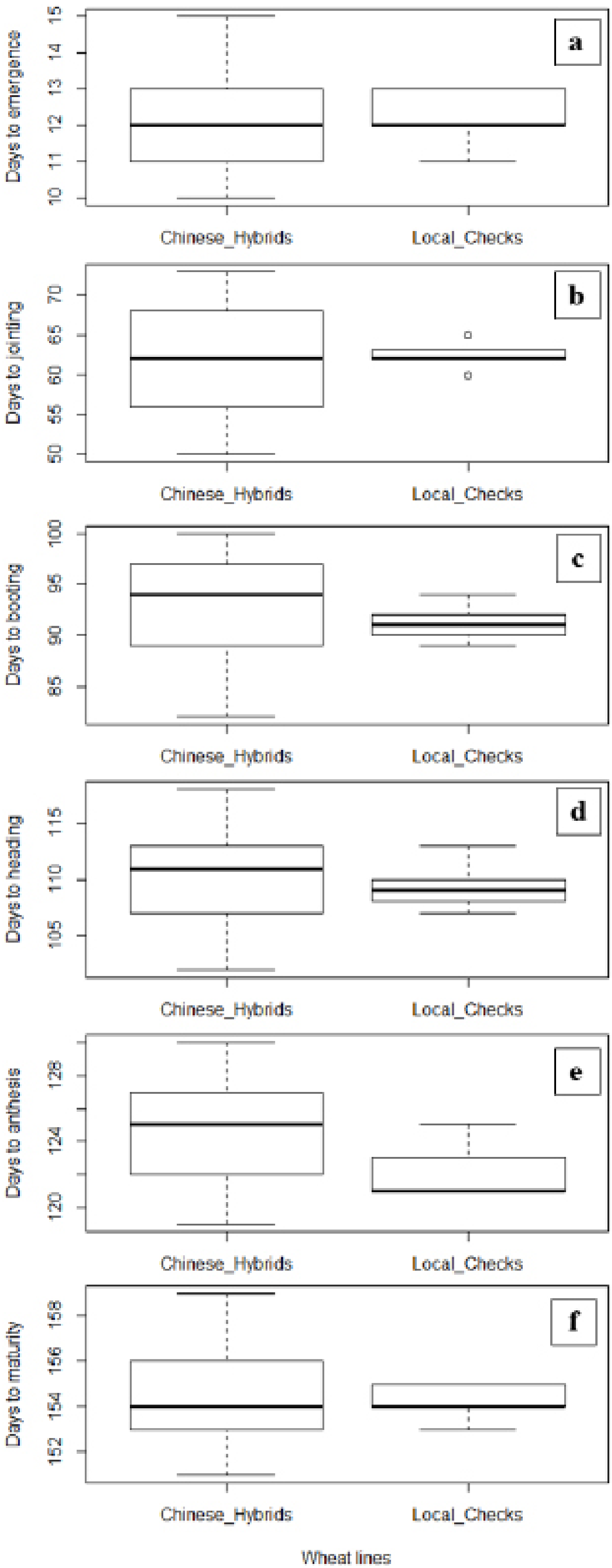

Figure 1: *Diversity for crop duration parameters in a set of 416 exotic Chinese hybrid lines, tested during 2017-18.*

Impact of selection and estimation of selection differential

A subset of 108 wheat hybrids was selected from these 416 Chinese wheat hybrids to estimate the selection differential and genetic advance, in terms of the performance of selected hybrids over the second year. An overall high diversity was observed among the selected genotypes and the impact of selection was positive on almost all the studied parameters as reflected by the mean value, while the level of variation decreased as revealed by the standard deviation values (Table 4).

Field testing of selected 108 hybrids during 2018-19, revealed varying level of differences between varieties, hybrids and hybrids versus varieties which were found to be non-significant for days to emergence (Table 3). The analysis of variance for days to emergence revealed non-significant differences for hybrids, check varieties and hybrids vs check varieties. Hence, the variability for the hybrids was low. Days to jointing revealed highly significant differences between hybrids (LSD: 6.98) and check varieties (LSD: 2.47). The significant differences between hybrids revealed the higher variability between the hybrids. The hybrids vs check varieties also had significant differences. The analysis of variance for the days to booting revealed highly significant differences between hybrids (LSD: 5.5) and the local check varieties (LSD: 1.94). The hybrid vs check varieties also showed significant variation. This showed high variability among the hybrids. When subjected to analysis of variance for measuring the variation, the hybrids showed high level of significance (LSD: 6.76), along with check varieties (LSD: 2.39) for days to heading. Likewise, the hybrids vs check varieties also had significant differences. The variability for days to maturity between hybrids and varieties was lower as evident from the analysis of variance which revealed non-significant differences between hybrids and checks, while the differences were significant for hybrids vs. check varieties.

For the crop duration parameters, selection resulted in an overall increase in the mean value for crop duration, though an overall decrease in the variability (Table 4). The mean value for days to emergence was the same among the overall population, selected hybrids and the progeny of selected hybrids (12), while the standard deviations were 1.41, 1.47 and 1.22, respectively. The mean value for days to jointing increased from 62 in the overall population to 63 in selected hybrids and 69 in the progeny of the selected hybrids, while the standard deviation decreased from 6.98 to 6.56 and 3.14, respectively. There was also an increase in days to booting from 93 in the overall population and selected hybrids to 106 in the progeny of the selected

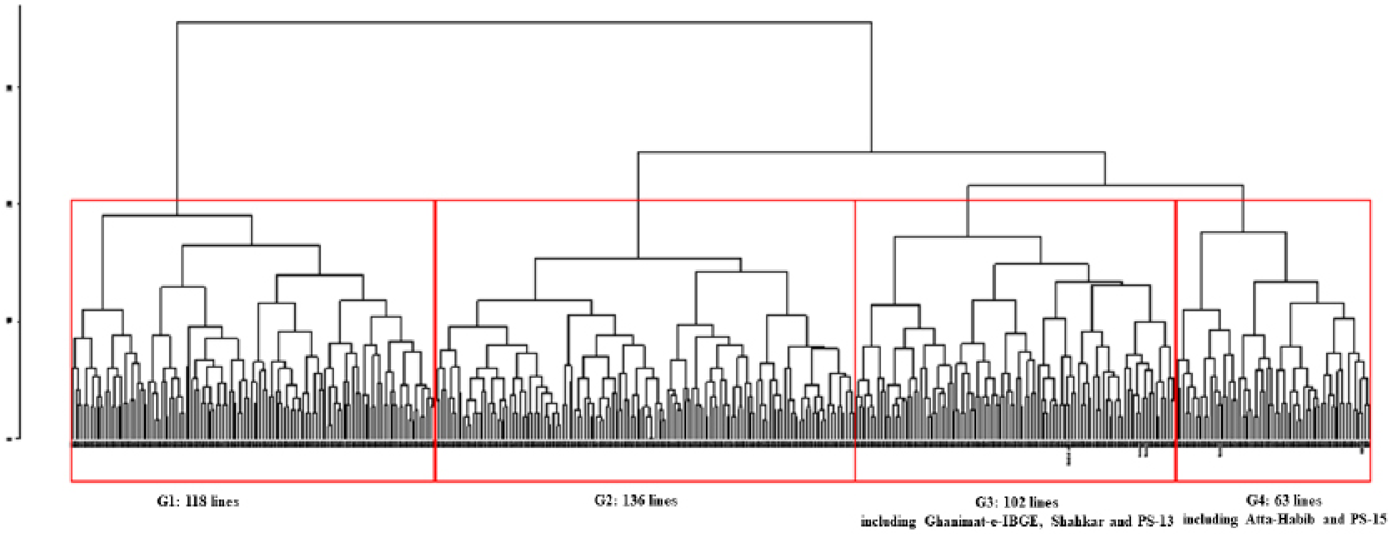

Figure 2: *Clustering of 416 Chinese wheat hybrids and local check varieties based on various field characteristics. The information on various lines is given in* **Table 1**.

Table 3: *Mean square values and their significance for various crop duration parameters for the selected hybrids tested during 2018-19.*

Studied Parameter	Mean square values						LSD (0.05) values	
	Hybrids		Check varieties		Hybrid vs. check		Among hybrids	Among checks
Days to emergence	5.615	NS	1.511	NS	0.158	NS	NS	NS
Days to jointing	16.51	*	9.86	*	194.00	**	2.47	6.98
Days to booting	36	**	6	*	396	**	1.94	5.5
Days to heading	65	**	10	*	455	**	2.39	6.76
Days to anthesis	37	**	4	*	296	**	1.59	4.49
Days to maturity	18	NS	2	NS	181	**	NS	NS

Note: ** refers to significance at less than 5%, ** refers to significance at less than 1%; NS refers to "non-significant".*

hybrids, though the standard deviation decreased from 5.03 to 5.01 and 2.59, respectively. The days to heading increased from 110 in the overall populations and selected hybrids to 124 for the progeny of the selected hybrids; while the standard deviation decreased from 3.71 to 3.40 and 3.25, respectively. The days to anthesis increased from 124 in the overall populations and selected hybrids to 137 for the progeny of the selected hybrids; while the standard deviation decreased from 2.86 to 2.66 and 2.11, respectively. For the last and most important crop duration parameter, days to maturity, the mean value increased from 154 in the overall population and selected hybrids to 164 in the progeny population, whereas the standard deviation was reduced from 1.95 to 1.73 and 1.66, respectively.

Distribution of crop duration parameters post-selection

The distribution of crop duration parameters was plotted as boxplots for overall population, the selected hybrids during 2017-18 and the second year (2018-19) performance of the selected hybrids, to assess how the selection has influenced these parameters. The changes in distribution of crop duration parameters i.e., days to emergence, days to jointing, days to booting, days to heading, days to anthesis and days to maturity are shown in the boxplots (Figure 3). There was a decrease for all of the six crop duration parameters in the selected hybrids during 2017-18, though an overall increase was observed for the selected hybrids during the subsequent year (2018-19).

Days to emergence ranged from 10 days to 15 days in the overall population and the selected hybrids during 2018-19, though it was in the range of 10 days to 14 days for the selected hybrids, the same as that of the year 2017-18 (Figure 3a). There were no substantial changes in the distribution of days to emergence due to selection with a mean value of 12 days in all the populations, with limited impact on the variability (Table 4).

Table 4: *Descriptive parameters for the overall 416 Chinese wheat hybrids population, the selected hybrids and the progeny of selected hybrids.*

Studied Parameter	Overall population		Selected hybrids (2017-18)		Selected hybrids (2018-19)	
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
Days to emergence	12	1.41	12	1.47	12	1.22
Days to jointing	62	6.98	63	6.56	69	3.14
Days to booting	93	5.03	93	5.01	106	2.59
Days to heading	110	3.71	110	3.40	124	3.25
Days to anthesis	124	2.86	124	2.66	137	2.11
Days to maturity	154	1.95	154	1.73	164	1.66

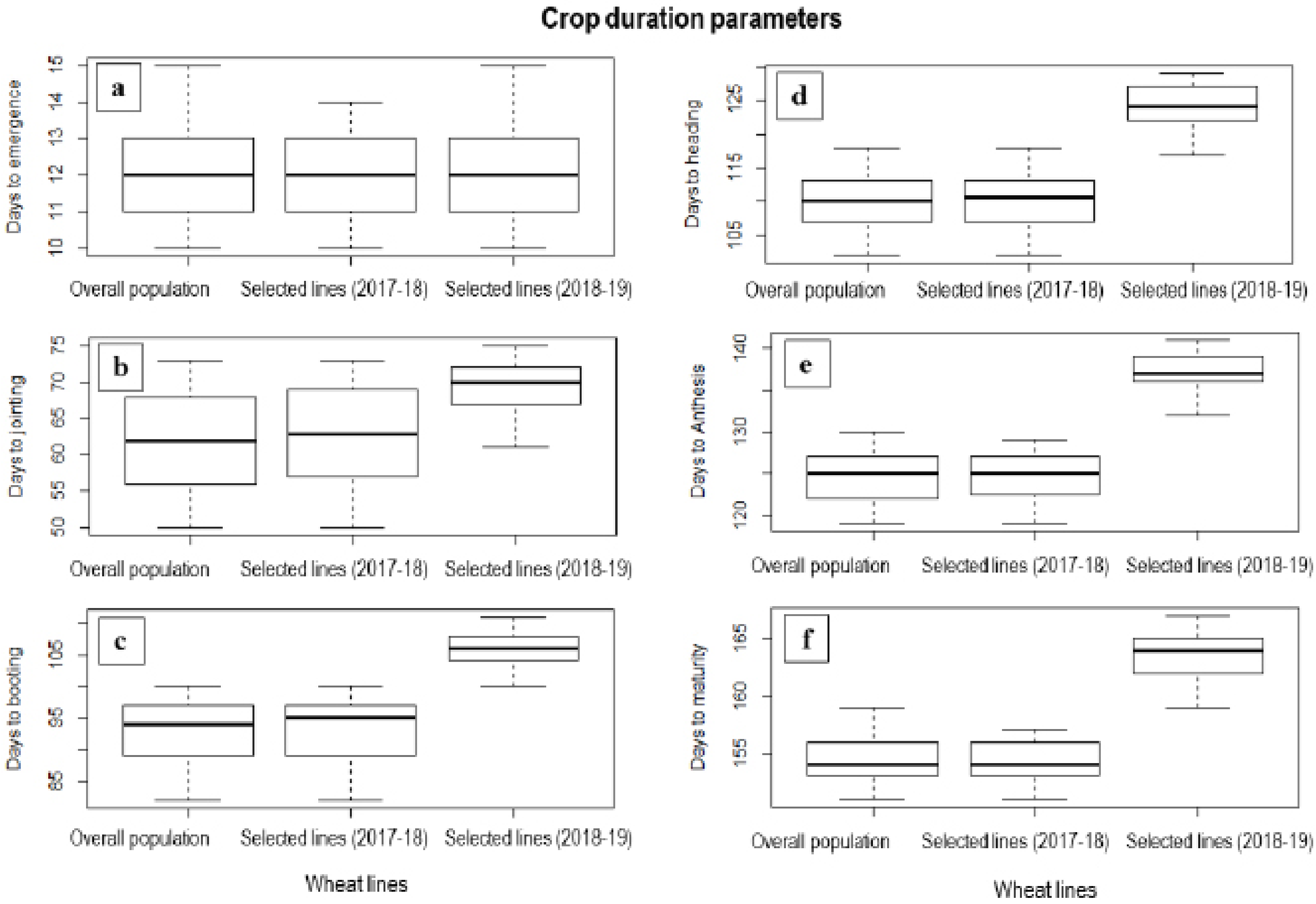

Figure 3: *Distribution of crop duration parameters for various set of Chinese wheat hybrids as subjected to selection. The upper line represents the maximum, the lower line represents the minimum, which the middle bold line represents the average values. The dots represent the outlier values, if any.*

Days to jointing was clearly impacted by the selection, as the data ranged from 50 days to 73 days in the overall population and selected hybrids during same year (2017-18), while it was shifted upward with a range of 61 days to 75 days in the subsequent year (2018-19) performance of the selected hybrids (Figure 3b). The mean value also shifted upward from 62 days (in the overall population) and 63 days (in the selected hybrids) to 69 days (in the subsequent year (2018-19)) performance of the selected hybrids (Table 4).

Selection from the overall population had a clear impact on days to booting (Figure 3c). Its range was 83-100 for the overall population, with a mean value of 93 and 82-100 for the selected hybrids, with a mean value of 93. The values substantially increased for the subsequent year (2018-19) performance of the selected hybrids, which were 100-111, with a mean of 106.

Days to heading was the same for the both, the overall population and the selected hybrids. The values for overall population ranged from 102-117, with mean of 110 (Figure 3d). The range of the selected hybrids was 102-118, with a mean of 110. The performance of the selected hybrids during the subsequent year (2018-19) clearly improved in that the values for the days to heading for the subsequent year (2018-19) performance of selected hybrids were 117-129 with a mean of 124.

Both the overall population and the selected hybrids shared the same range for the days to anthesis, i.e., 119-130 and 119-129, respectively, along with same mean value of 124, for both, the overall population and selected hybrids (Figure 3e). The subsequent year (2018-19) performance of the selected hybrids, on the other hand, showed much elevated and improved performance with a range of 132-141 and mean value of 137.

Just like the other crop duration parameters, the days to maturity was increasingly impacted in the subsequent year (2018-19) performance of the selected hybrids (range=159-167 and mean=164) compared to the overall population (range=151-159) and selected hybrids during the same (2017-18) year (range=151-157), both of which also shared the same mean of 154, revealing increase in crop duration (Figure 3f).

Estimation of selection differential and genetic advance
Selection differential and genetic advance (in terms of the 2nd year performance of the selected hybrids) were estimated to assess the impact of selection on the exotic Chinese wheat hybrids which revealed an overall improvement in various parameters in desired direction (Figure 4). Among the crop duration parameters, maximum selection differential was observed for the days to jointing which was 2.25 and minimum of -0.03 for days to maturity. The maximum genetic advance was observed for the days to heading which was 12.89 whereas it was minimum for days to emergence which was 4.86.

The present study revealed a high diversity among Chinese hybrids for various characteristics, which enabled to carry out selection with subsequent testing of the selected hybrids. These hybrids were engineered at Beijing Engineering Research Centre for Hybrid Wheat (BERCHW), China, representing a novel source of germplasm, not previously tested in Pakistan. Efficient germplasm management and genotype selection is very useful for different breeding purposes (Fufa *et al*., 2005). The genetic variations between individuals in a population is the genetic variability which could be the heart of plant breeding as diversity management can yield permanent gain in plant production and protect against climatic changes. The limited gain achieved in yield across various wheat growing regions have been shown to be associated with the limited variability in wheat germplasm unable to overcome the pathogen changing races and limited consideration of crop duration parameters (Ali *et al*., 2017; Ray *et al*., 2013). This necessitates to widen the sources of crop germplasm and testing the non-traditional sources. Our results revealed a highly significant variability among the tested wheat hybrids for crop duration parameters. The preliminary trial revealed better performance of certain hybrids when compared with the recently recommended best performing Pakistani wheat check varieties. Performance of the selected lines revealed the impact of selection exerted on the 416 hybrids in terms of change in distribution and estimation of selection differential and genetic advance.

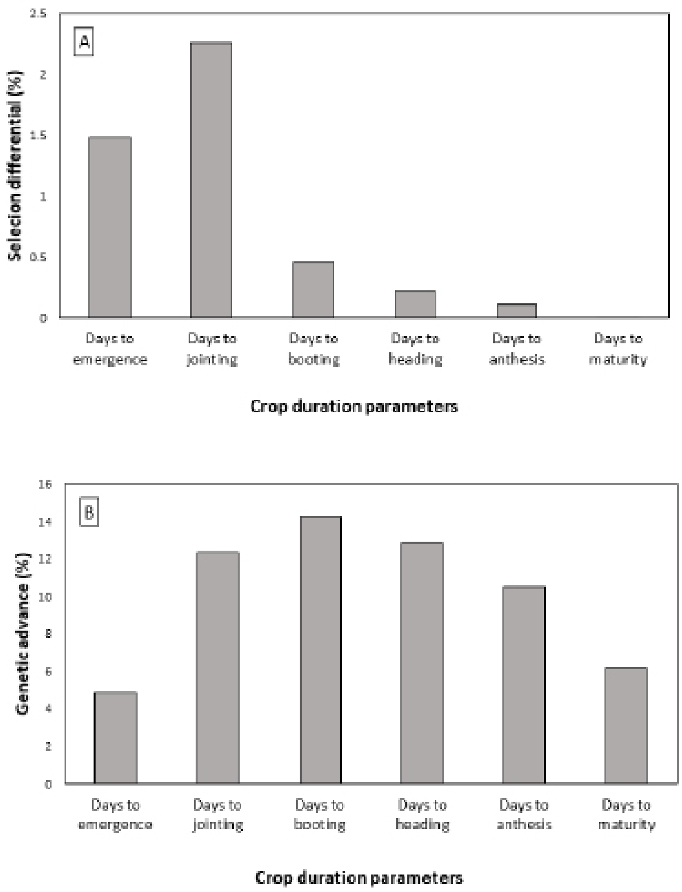

Figure 4: *Impact of selection in a set of 416 Chinese wheat hybrids, as assessed by selection differential (A) and genetic advance (B).*

Preliminary testing of the Chinese hybrids during the first experiment revealed a wide range of variability in all parameters in comparison with the improved local checks i.e., Shahkar, Pirsabak-2013, Pirsabak-2015, Atta-Habib and Ghanimat-e-IBGE, which are widely grown better performing wheat varieties (Khan *et al*., 2020a). The performance of a hybrid may vary when introduced into a novel area and thus, testing of exotic germplasm is a pre-requisite for further breeding (Qasim *et al*., 2008). Preliminary testing is the first step in many field crops like wheat to characterize a large set of germplasm for subsequent selection (Fufa *et al*., 2005; Perween *et al*., 2020). The effectiveness of the selection for both quantitative and qualitative traits depend on the genetic variability and heritability (Khan and Hassan, 2018). Field based preliminary testing in various parameters is essential in order to quantify the phenotypic variation for the prediction of genetic gain (Aycicek and Yildirim 2006).

The information in the preliminary trial is not only important for selection of parents with better performance to be crossed, but is also important for selection of better performing F_1 hybrids, particularly while introducing exotic hybrids, as in the current case. Such studies could also provide information on the useful genes in the rich allelic stock of hybrids, which have been developed from Chinese landraces and wheat cultivars (Peleg *et al*., 2009; Dresselhaus and Hu¨ckelhoven 2018). Better performance was shown by hybrid varieties in many crops including maize (Duvick 1997; Li *et al*., 2013).

Looking at the crop duration characters in the preliminary testing, hybrids were proven to provide substantial diversity both for early and late maturing lines, when compared with the local high yielding and better performing varieties. The growth rate, reflected by the crop duration parameters, during the period from emergence to the grain filling is the crucial period for determining the overall yield potential in wheat (Dreccer *et al*., 2018). For maximum yield and stability, the time of heading, among the phenological stages of wheat plant, is crucial (Raza *et al*., 2018). For optimum utilization of the genetic material for plant breeding and associated procedures, consideration of crop duration parameters is important (Uddin and Boerner 2008).

The overall grouping of the 416 Chinese hybrids based on the field-based parameters recorded during the preliminary testing revealed the existence of very high diversity. The clustering analyses have been shown to be very useful for assessing diversity and grouping of variability based on phenotypic traits (Ali *et al*., 2009). Clustering based on important agronomic and primary traits would account for subsequent selection (Nepolean *et al*., 2018). The exotic genotypes under study needs to be exposed to different agro-ecological conditions, which may lead to different performance of various genetic parameters and their knowledge could help to decide breeding strategies. Field based screening with subsequent selection for the required traits in different genetic stocks is the preconditions for improving wheat. Various phenotypic and physiological traits are being studied as selection objectives for wheat breeding programs (Casadesús *et al*., 2007; Naghavi *et al*., 2007). Phenotypic performance can be based for criteria of selection of the parents. Additionally, the genotype into environment interaction results in determining the phenotype of an individual. The resultant phenotype may be due to environmental conditions which may vary at different locations (Najaphy *et al*., 2012). Development of better varieties and selection with better chances result from high genetic diversity which could be evaluated utilizing pedigree analysis, morphological and physiological characters and molecular markers (Habash *et al*., 2009).

Selection of a subset of 108 promising wheat hybrids from these 416 Chinese wheat hybrids showed a clear impact of selection on the distribution of crop duration parameters, with an overall decrease in standard deviation values, which revealed declining variation among the selected hybrids. Considering the performance of the selected Chinese hybrids tested during 2017-18 and 2018-19, a high variability and better performance for various parameters was observed, when compared with the most promising local wheat cultivars. High genetic advance as percent of mean for days to heading, grain filling period, whereas moderate genetic advance as percent of mean for days to maturity was reported by Demelash *et al*. (2013). The distribution of the overall hybrids compared to the selected hybrids during the same year and the subsequent year varied significantly. This was further evident by selection differential and genetic advance. The genetic advance here should be considered carefully as the progeny of the selected hybrids is not the F_2 progeny of the F_1 hybrids, but merely the second-year testing of selected hybrids. It is important to point out that the selection gain in hybrids must be higher compared to line breeding, in terms of yield, its stability and biotic and abiotic resistance to stress to overcome the associated cost of hybrid breeding (Mette *et al*., 2015). The distribution of crop duration parameters (days to emergence, jointing, booting, heading, anthesis and maturity) revealed an overall increase due to selection. The variation, on the other hand, was comparatively lower among the crop duration parameters especially for days to jointing and booting where it decreased by two folds. Considering the performance of selected hybrids in terms of crop duration/crop duration parameters, 65 hybrids (both years combined) were earlier than the local checks, while 67 hybrids were late than the latest local check. This emphasized that a few elite hybrids could be selected from these selected 108 Chinese hybrids. The crop duration parameters are important for attaining better crop yield, as both early crop duration and delayed crop duration have their pros and cons (Dreccer *et al*., 2018).

Crop duration would ensure a short duration of crop in wheat, avoiding terminal heat stress and enable a timely sowing of the next crop (Raza *et al*., 2018). A longer crop duration would provide more degree days for production and accumulation of photosynthates in the grain, resulting in a higher grain yield. A longer duration could also be useful in context of dual-purpose wheat providing both, fodder and grain yields (Arif *et al*., 2006; Naveed *et al*., 2015). The variability in the Chinese germplasm could provide, both, short and long duration wheat hybrids. The reduction in yield due to radiation levels lower than optimum and damage to reproductive parts resulting from frost prevents flowering in winter (Dreccer *et al*., 2018). Late flowering due to warm and dry conditions can result in water scarcity and damage by heat and ultimately, result in reduced yield (Flohr *et al*., 2017). Winter hardiness and plant morphology is essential for adaptation, among other significant aspects of development, which should be paralleled with seasonal development. Crop breeding strategies can be improved by having thorough knowledge about the genetic base of crop duration characters which can even add to prediction of risks related to yield, like drought, frost and heat (Dreccer *et al*., 2018).

This work is one of the few studies to characterize the Chinese hybrid wheat lines in Pakistan. Better performance and adaptability to diverse conditions and environments have been shown as characteristics of hybrid wheat (Lang, 1989). However, hybrid production is quite complicated due to its flowering characteristics and large and hexaploid wheat genome, yet its potential is considered as one of the promising avenue for commercial exploitation of hybrid vigor for increasing wheat productivity (Reynolds *et al*., 1996). A larger extent of exchange of genetic material was required for extracting transgressive segregants from crosses among complementary parents for breeding pure line cultivars in self-pollinated crops (Heisey *et al*., 2002). The acceptability of cross-pollinated traits along with the male sterility introduction have been shown to possess a potential for hybrid wheat development (Pickett, 1993). The hybrids studied in the current study are based on the male sterility traits, and considering their Chinese origin, these are well suited to be considered under Pakistani wheat production system.

Observed variability in the Chinese hybrids could be utilized as additional diversity in wheat germplasm. A direct exploitation of our results would be to further test and release the promising Hybrids in Pakistan. However, the hybrids need evaluation and examination at different levels for multiple years in order to properly evaluate their feasibility, while considering the limitation of the cost of hybrid production. Crossing these hybrids with local lines could also diversify the germplasm of wheat. Varieties and lines need to be further evaluated for resistance to all the rusts specifically yellow and leaf rust (Ali and Hodson, 2017).

Conclusions and Recommendations

The current study revealed a high diversity among Chinese hybrids, an overall positive impact of selection along with the identification of desirable hybrids based on two-year performance. The hybrids possessed high variability and even better performance than local checks in some cases. There is a huge potential for exploitation of wheat hybrid in Pakistan, subject to subsequent testing in multilocation trials and farmer fields. The Chinese hybrids showed higher variation than the check varieties. The better performing hybrids during preliminary testing and second year testing "should undergo proper testing in national testing system". Various group of hybrids identified through boxplots and cluster analyses could be used in crossing blocks for resistance and high yield to diversify the germplasm of wheat.

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Novelty statement

The work is the first-ever attempt to assess the impact of selection on variability in crop duration parameters for Chinese hybrids under the field conditions. The work is one of the few studies to explore the potential of Chinese wheat hybrids in Pakistan, which should contribute to improvement of wheat production in Pakistan.

Authors' contribution

MA and SA designed the study. ZI, MA and SA conducted the study and analyzed the data. MA, IM and SA provided resources for the study. ZA, IM, MA and SA wrote and revised the manuscript.

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