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GENETIC GAINS FOR GRAIN YIELD IN TWO SELECTION PHASES OF A WHEAT BREEDING PROGRAM

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Abstract

Evaluation and selection of experimental lines over several environments is critical component of wheat breeding programs before release of cultivars to growers. Fifteen-year (1989-90 to 2004-05) data from three consecutive trials (A, B and Microplot) of the Cereal Crops Research Institute, Pirsabak (Nowshera) were analyzed as two independent selection phases to estimate selection differentials, genetic gains and realized heritability for grain yield. Wheat lines tested in A-trials ranged from 108 to 378 year^{-1} with selection intensity of 10 to 30% vs 72 to 198 year^{-1} in B-trials with selection intensity of 6 to 22%. Selection differentials and genetic gains were positive for each pair of years during the 15-year period. Averaged across 15-years, mean selection differential, genetic gain and realized heritability were 8.9 vs 5.3%, 6.0 vs 7.2%, and 0.63 vs 0.56 under Phase–I and Phase-II, respectively indicating more selection efficiency in Phase-I. The selected wheat lines out yielded the check cultivars throughout the 15-year period in A-trials, while the checks surpassed the selected lines in 12 of the 15-years in B-trials. An upward trend in grain yield ha^{-1} was generally followed by a decline both under A and B-trials. The statistical procedure used is effective for estimating genetic improvement for important traits in multi-stage crop breeding programs.

Introduction

Considerable increases have occurred in grain yield per hectare in almost all wheat producing countries of the world. The largest increase in wheat yields was noted in the mid 1950s to mid 1960s (Schmidt & Worral, 1983). Most researchers estimate, though not very precisely, that about one-half of the increase in wheat yields can be attributed to improvement in cultivars and one-half to improved management practices. Yield increase in the four largest wheat exporting countries (Argentina, Australia, Canada and USA) ranged from 220 kg ha^{-1} in Australia to 630 kg ha^{-1} in the USA. Similarly, an average increase of 32.0 to 72.1 kg ha^{-1} year^{-1} has been reported in China for wheat cultivars released since 1970 (Zhou *et al*., 2007). The recent wheat cultivars have been reported to be 30% high yielding than the traditional old cultivars (Donmez *et al*., 2001).

The Cereal Crops Research Institute (CCRI), Pirsabak, Nowshera has released several high yielding and disease resistant wheat cultivars. As such a major portion of the wheat acreage in NWFP is currently seeded to cultivars released by the CCRI. Testing of wheat lines at several locations and years is necessary before release as cultivars, but is expensive in terms of time and money. Therefore, we evaluated the effectiveness of wheat lines testing and selection procedures used at CCRI using the existing data following the statistical procedure developed by St. Martin & McClain (1991).

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Materials and Methods

Multi-location testing of wheat lines developed at CCRI or received from CIMMYT and ICARDA is undertaken as A-trials. The selected lines from A-trials are further tested and evaluated sequentially in the B-trials and Microplot-trials at several locations of NWFP till the most outstanding lines are submitted to the National Uniform Yield Trial (NUYT). Thus a complete cycle for a set of experimental lines consists of A-trial evaluation in year *n*, B-trial evaluation in year *n+1*, and Microplot-trial evaluation in year *n+2*. A randomized complete block design with 2 to 4 replications is mostly used in all trials at each location. Details about the number of A and B-trials conducted each year are given in Table 1.

The data of A-trials in year *'n'* were compared with those of B-trials in year '*n+1*' and similarly of B-trials with those of its successor Microplot-trial in year *'n+2'*. Sequential selection process from A to B-trials and B to Microplot-trials was considered as Phase-1 and Phase-II, respectively. For phase-I, means were calculated using A-trials data in year *n* and B-trials data in year *n+1*. The mean of all experimental lines evaluated in the A-trials in year *n* was designated as X. The mean of experimental lines selected from A-trials for testing in the successive B-trials (year *n+1*) was designated as X_s. The mean of only those check cultivars common to A-trials in year *n* and the B-trials in year *n+1* was designated as X_c when tested in A-trials and X'_c when tested in the successive B-trials. The mean of the experimental lines selected from the A-trials in year *n* and evaluated in the B-trials was designated as X'_s. Selection differential (S) and genetic gain (G) as percentage of respective checks were computed using the following formulas developed by St. Martin & McClain (1991);

Selection differential (S) = $[(X_s - X)/ X_c]*100$, and

Genetic gain (G) = $\{[(X'_s - X'_c)/ X'_c] - [(X - X_c)/ X_c]\}*100$

Or G = $[(X'_s / X'_c) - (X / X_c)]*100$

In analogous fashion, means were calculated from B-trials in year *n+1* and Microplot-trials data in year *n+2* to estimate selection differentials and genetic gains for Phase-II of the breeding program. Trials data for grain yield from 1989 to 2004 for Phase-I and 1990 to 2005 for Phase-II, thus, provided 15 estimates of selection differential and genetic gain in each phase. These estimates were averaged across 15-years to get the average selection differential and genetic gain for each phase of the breeding program. The 15 data points of genetic gain were regressed on respective selection differentials using no-intercept model to obtain realized heritability for grain yield in each phase (St. Martin & McClain, 1991).

A 3-year moving average of all lines, selected lines and common check cultivars was also calculated from 1989 to 2003 in A-trials and 1990 to 2004 in B-trials to examine yield trends over time. A 3-year moving average was employed to reduce potentially distorting individual year effects attributable to abnormal climatic factors. Because a single long-term standard check cultivar was not used in all years for any trial, one of the three check (Pak-81, Pirsabak-85, and Khyber-87) common in different years of 15-year period was used for estimating the 3-year moving average of the check.

Table 1. Experimental lines tested and selected in the A-trials and B-trials of the CCRI wheat breeding program from 1989 to 2004.

Harvest year	A-Trials			B-Trials		
	Lines tested	Lines selected[1]	Proportion selected	Lines tested	Lines selected[2]	Proportion selected
	--- no. ---		%	--- no. ---		%
2004	252	28	11	162	23	14
2003	198	30	15	126	10	8
2002	180	34	19	108	13	12
2001	162	32	20	90	8	9
2000	144	30	21	72	7	10
1999	216	35	16	144	17	12
1998	270	38	14	162	10	6
1997	126	35	28	90	20	22
1996	360	44	12	180	22	12
1995	378	45	12	126	14	11
1994	324	32	10	198	16	8
1993	306	35	11	144	13	9
1992	234	70	30	108	8	7
1991	108	17	16	126	17	13
1990	198	36	18	90	15	17
1989	162	25	15	--	--	--

[1]Evaluated the following year in the B-trials.

[2]Evaluated the following year in the Microplot-trials.

Results and Discussion

Total number of experimental lines evaluated and selected in A and B-trials of the CCRI wheat breeding program are presented in Table 1. Since A-trials constitute the first replicated evaluation of wheat lines, comparatively more lines were evaluated in A than B-trials. The number of line evaluated in a given year ranged from 108 to 378 in A-trials vs 72 to 198 in B-trials. Proportion of experimental lines selected for further evaluation in the respective successor trials ranged from 10 to 30% in A-trials compared to 7 to 23% in B-trials. Selection intensity averaged 17% under A-trials vs 11% in B-trials. Thus, selection pressure was comparatively more in B-trials in order to advance only the most high yielding wheat lines for further evaluation in the Microplot trials of the breeding program.

Selection differentials and genetic gains for grain yield as % of check cultivars in Phase-1 (A to B-trials) and Phase-II (B to Microplot-trials) of the breeding program are given in Table 2. The selection differentials were consistently positive throughout the period examined, ranging from 4.8 to 19.0% in Phase-I and 1.9 to 23.1% in Phase-II. The lowest selection differential of 4.8% was observed each during 1995-96 and 1997-98 in Phase-I. In contrast, the largest selection differential of 19.0% was recorded in 2002-03 followed by 2003-04 with selection differential of 14.1%. In Phase-II, the lowest selection differentials were recorded during three consecutive years; 2002-03 (1.9%), 2001-02 (2.3%) and 2000-01 (2.3%). Averaged over 15-year period, mean selection differential was 8.9% in Phase-I vs 5.3 in Phase-II of the wheat breeding program. This difference in magnitudes of selection differential was expected because selection is exercised from comparatively more lines in Phase-I than Phase-II and many of the poor yielders in the A-trials are not included in later B-trials. Khalil *et al*., (1995) have previously reported a difference of 4.3 units in mean selection differentials for grain yield computed in two phases of the Oklahoma Agricultural Experiment Station wheat breeding program. Similarly, selection differentials for yield were 5.2 and 2.8% computed from data of Uniform Preliminary Tests and Uniform Tests of the cooperative regional soybean breeding program from 1960 through 1988 (St.Martin & McClain, 1991).

Table 2. Selection differentials (S), genetic gains (G), as % of check, and realized heritability (h^2) for grain yield in Phase-I and Phase-II of the CCRI wheat breeding program, 1989 to 2005.

Pair of years	Phase-I (A→B-trial)		Phase-II (B→Microplot-trial)	
	S	G	S	G
1989-90[a]	7.2	9.7	--	--
1990-91	8.7	10.8	6.1	7.6
1991-92	8.1	4.6	3.5	3.8
1992-93	6.7	1.9	2.9	11.6
1993-94	6.1	4.4	23.1	1.7
1994-95	6.1	2.7	3.2	2.9
1995-96	4.8	4.1	2.4	8.4
1996-97	8.1	6.8	3.8	9.0
1997-98	4.8	0.3	6.2	1.0
1998-99	10.3	4.1	5.2	7.1
1999-00	13.9	9.7	3.2	11.0
2000-01	5.4	6.6	2.3	10.6
2001-02	10.2	6.3	2.3	7.5
2002-03	19.0	8.7	1.9	7.3
2003-04	14.1	8.6	8.9	8.7
2004-05[b]	--	--	4.7	9.7
Mean ± SE	8.9 ± 1.0	6.0 ± 0.8	5.3 ± 1.4	7.2 ± 0.9
Realized h^2 ± SE	0.63 ± 0.07		0.56 ± 0.24	

[a]S and G for Phase-II in 1989-90 not calculated due to lack of complete data about A-trials in the previous year.

[b]S and G for Phase-I in 2004-05 not computed due to non-availability of data from the successor trials making Phase-II.

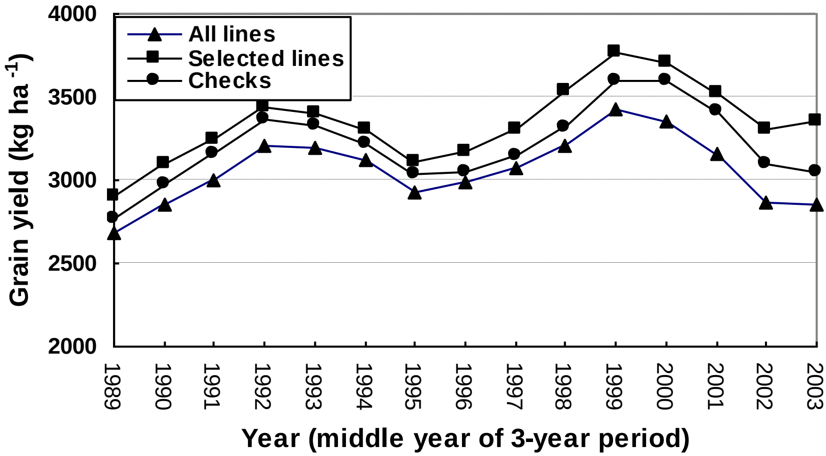

Fig. 1. Three-year moving average for grain yield of all lines, selected lines and check cultivars in the A-trials of CCRI wheat breeding program, 1989 to 2003.

Genetic gains computed during the consecutive 15-year period of the wheat breeding program were comparatively more variable in Phase-II than Phase-I. The lowest genetic gains for grain yield were observed during the same pair of years (1997-98) in the two phases; 0.3% in Phase-I and 1.0% in Phase-II. Similarly, genetic gains of greater magnitude either occurred during the same pair of years or were subsequently followed by each other in the two phases of the breeding program. For example, the greater genetic gain of 10.8% occurred during 1990-91 in Phase-I followed by the greatest gain of 11.6% during 1992-93 in Phase-II. Averaged over the 15-year period, genetic gains for yield were 6.0 and 7.2% in Phase-I and II, respectively. Genetic gains of 4.6 and 4.2% of the standard check cultivars have been reported by Khalil *et al*., (1995) in two phase of the hard red winter wheat breeding program at Oklahoma State University, USA. In contrast, genetic gains for soybean seed yield were about twice as large in the preliminary trials as in the advanced trials (St. Martin & McClain, 1991). Realized heritability, estimated as regression coefficient for genetic gain over selection differential, was slightly greater in Phase-I (0.63) than in Phase-II (0.56) for grain yield (Table 2). Low to medium heritability estimates for grain yield have also been reported previously by Laghari *et al*., (2010), Khan *et al*., (2007), Shah *et al*., (2007) and Singh *et al*., (1993) in wheat.

In addition to quantitative estimates, trends in yield improvement were also evaluated graphically based on 3-year moving averages of wheat lines and check cultivars in A and B-trials (Figs. 1 and 2). The 3-year moving average for grain yield of all lines was consistently lower than the checks mean throughout the 15-year period in A-trials. As expected, mean of the selected lines surpassed the checks mean during all years in A-trials. Following an initial increase in the first four years, grain yields have decreased since 1992 reaching the lowest levels in 1995. Since then the grain yields in A-trials have an upward trend attaining the optimum level in 1999 followed by another sharp decline (Fig. 1). Fig. 2 conveyed the most interesting feature about yield performance of experimental lines and checks under B-trials. Surprisingly, the checks consistently out yielded even the selected lines from 1990 to 2000 in B-trials. However, the selected lines have surpassed the checks in grain yield since 2001. Almost similar trend in long-term comparative performance of selected lines and check cultivars has been reported by Khalil *et al*., (2004).

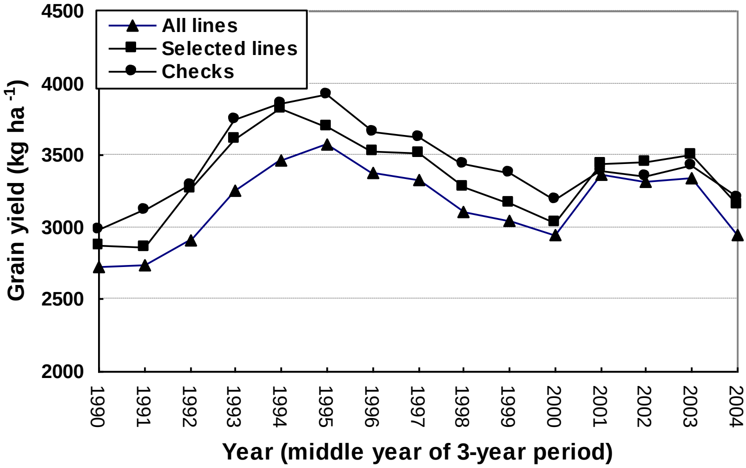

Fig. 2. Three-year moving average for grain yield of all lines, selected lines and check cultivars in the B-trials of CCRI wheat breeding program, 1990 to 2004.

We conclude that yield potential of new wheat cultivars released by CCRI has improved by >6% per year in the past 15-year period and selection efficiency is of equal magnitude in Phase-I and II. The release of wheat cultivars like Paseena-90, Pirsabak-91, Kaghan-93, Nowshera-96, Suleman-96, Saleem-2000, Haider-2000, Pirsabak-2004 and Pirsabak Barani-2005 over the past 15-years clearly reflects the payoffs from the CCRI wheat breeding program.

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