African Journal of Biotechnology Vol. 11(22), pp. 5970-5981, 15 March, 2012
Available online at http://www.academicjournals.org/AJB
DOI: 10.5897/AJB11.2914
ISSN 1684–5315 © 2012 Academic Journals

Full Length Research Paper

Patterns of trait associations in various wheat populations under different growth environments

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Accepted 16 December, 2011

Five wheat populations were investigated for two years to explore the pattern of trait associations and their contribution to grain yield. The correlation pattern between two traits and their association with grain yield was similar in CIMMYT and Pakistani germplasm. Indian germplasm had different pattern of trait association from those of CIMMYT and Pakistani germplasm. The number of kernels per plant, number of spikes per plant, spike length and spike dry weight were the major yield contributing traits in CIMMYT, Pakistani and ICARDA genotypes. In Indian and miscellaneous genotypes, the number of kernels per plant and number of spikes per plant were the only traits with a positive effect on grain yield. Furthermore, three traits, the number of kernels per plant, the number of spikes per plant and the spike dry weight appeared to have positive effect on grain yield and other major yield traits. Spike density had a negative effect on grain yield in CIMMYT germplasm in dry season. Chlorophyll contents showed no correlation with grain yield in all populations.

Key words: Pakistani, CIMMYT, genotypes, wheat, ICARDA, populations.

INTRODUCTION

Wheat is an important cereal crop world wide in terms of production and utilization. Maximizing yield potential is the primary objective of wheat breeders. Grain yield in wheat is a complex quantitative trait and is the outcome of various yield attributes (Sajjad et al., 2011). Knowledge of the correlation of a yield trait is very important to assess the expected response of other traits and grain yield when the selection is applied to that trait in a breeding program (Waitt and Levin, 1998). Since the correlation between the different traits is the result of underlying genetic cause(s); epistasis, linkage, population structure , linkage disequilibrium and growth environment, therefore, it changes with the genetic constitution of a population and the growth environment.

Previous studies showed that the patterns of correlation of a trait with other traits varies in different sets of genotypes and growth environments. Thousand grain weight was reported as positively correlated with grain yield by Aycecik and Yildirim (2006), Kashif and Khaliq (2004), Chowdhry et al. (2000), Subhani and Chowdhry (2000), but negatively correlated by Tamam et al. (2000) in different sets of genotypes and environments. The number of spikes per plant were investigated as positivity correlated with plant height by Gulnaz et al. (2011), Maqbool et al. (2010), and Richards et al. (2002) but negatively correlated with plant height by Khan et al. (2010) and Khan and Dar (2009). Spike length was reported as negatively correlated with grain yield by Khan et al. (2010) and positivity associated by Shahid et al. (2002) and Saleem et al. (2006). Plant height was found to be positively correlated with grain yield by Khaliq et al. (2004), Jedynski (2001), Narwal et al. (1999) and Uddin et al. (1997) but negatively correlated with grain yield by Khan et al. (2010), Akram et al. (2008) and Okuyama et al.(2004).

All previous studies for correlations among yield traits were conducted only for one season and in one type

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Table 1. Correlation coefficient among various yield traits in CIMMYT germplasm.

Yield trait	GY	K/P	KS	S/P	NSpt/S	MFFl/Spt	SDW	PH	SL	AL	SD	CC
GY	1.00	0.86*	0.37**	0.45**	0.21**	0.33**	0.54**	0.30**	0.30**	0.27**	-0.16**	0.08
K/P	0.84**	1.00	-0.14*	0.49**	0.27**	0.31**	0.33**	0.19**	0.16**	0.17**	-0.04	0.07
KS	0.33**	-0.14	1.00	0.01	-0.07	0.09	0.45**	0.28**	0.29**	0.20**	-0.24**	0.04
S/P	0.49**	0.49**	0.01	1.00	0.06	0.01	0.05	0.04	0.05	0.08	-0.05	0.08
NSpt/S	0.24**	0.27**	-0.07	0.06	1.00	0.13*	0.22**	0.12	0.28**	0.05	0.25**	-0.08
MFFl/Spt	0.31**	0.31**	0.08	0.01	0.13*	1.00	0.51**	0.12	0.23**	0.13*	-0.11	0.05
SDW	0.52**	0.32**	0.45**	0.05	0.22**	0.51**	1.00	0.33**	0.50**	0.35**	-0.25**	0.03
PH	0.27**	0.19**	0.28**	0.04	0.12	0.12	0.33**	1.00	0.27**	0.25**	-0.17**	-0.02
SL	0.31**	0.16*	0.29**	0.05	0.28**	0.23**	0.50**	0.27**	1.00	0.30**	-0.70**	0.06
AL	0.31**	0.17**	0.20**	0.08	0.05	0.13*	0.35**	0.25**	0.30**	1.00	-0.17**	0.08
SD	-0.06	-0.02	-0.14*	-0.07	0.28**	-0.13*	-0.18**	0.02	-0.35**	-0.15*	1.00	-0.07
CC	0.09	0.07	0.04	0.08	-0.08	0.05	0.03	-0.02	0.06	0.08	-0.06	1.00

Values below diagonal are for the year 2008-2009 (rainy season) and values above diagonal are for the year 2009-2010 (dry season). * Significant at 0.05; ** Significant at 0.01; GY: grain yield; K/P: number of kernels per plant; KS: kernel size as 100 grain weight; S/P: number of spikes per plant; NSpt/S: number of spikelets per spike; MFFL/Spt: maximum fertile florets per spikelet; SDW: spike dry weight; PH: plant height (cm); SL: spike length (cm); AL: awn length (cm); SD: spike density (number of spikelets/spike length); CC: chlorophyll contents

breeding population of relatively smaller size. The variations and contradictions in these results confused breeders in selection criteria. Therefore, various breeding populations were needed to be studied simultaneously for at least two years to obtain a clear picture of traits correlation patterns and to help the wheat breeders in their selection decisions for improving yield potential. Keeping in view the deficieny in the exploration of traits correlation patterns, we designed an experiment to investigate the patterns of correlation comprehensively in five wheat populations for two years. Luckily, the year 2008 to 2009 received heavy precipitation and the second year 2009 to 2010 remained dry. This natural environmental difference made this study more interesting and informative.

MATERIALS AND METHODS

Five wheat populations were used for this study at the department of Plant Breeding and Genetics, University of Agriculture, Faisalabad (Latitude = 31°, 26' N, Longitude = 73°, 06' E, Altitude = 184.4 m). The first population was of 260 CIMMYT genotypes. The second population consisted of 165 Pakistani varieties, land races and advanced lines. The third population had 22 Indian lines. The fourth population was of 43 ICARDA genotypes, and fifth population was a mixture of ten genotypes from different origins. These sets of wheat genotypes were planted during the years 2008 to 2009 and 2009 to 2010 according to alpha lattice design with two replications. The first growth season was rainy in the years 2008 to 2009, receiving 83.4 mm of rain and the second crop season was dry in the years 2009 to 2010 receiving only 22.8 mm rain (http://www.uaf.edu.pk/faculties/agri/depts/crop_physiology/agri_met_cell/met_bulletin.html).

The recommended package of agronomic practices was followed to raise the crop. For data recording, 10 randomly selected plants from each plot were tagged. Twelve quantitative traits, grain yield, kernels per plant, kernal size (1000-grain weight), number of spikes per plant, number of fertile spikelets per spike, maximum fertile floret per spikelet, spike dry weight (g), plant height (cm), spike length (cm), awn length (cm), spike density and chlorophyll contents were all phenotyped. The correlation and principal component analysis were performed using Statistica (v7.1) software.

RESULTS

In wheat breeding, the knowledge about correlation among traits contributing to yield is one of the prerequisites for varietal development. Correlation between two traits varies with breeding populations and growth environments. Our work presents a comprehensive study of the patterns of traits relationship in five different wheat populations grown for two years.

In the CIMMYT population, all yield traits except spike density and chlorophyll contents included in this study were positively correlated with grain yield per plant under both rainy and dry seasons (Table 1). Spike density was the only trait that showed negative correlation with yield in the dry season. The number of kernels per plant had positive correlation with the number of spikes per plant, number of spikelets per spike, maximum fertile floret per spikelet, spike dry weight, plant height, spike length, and awn length in rainy as well as dry seasons. The number of kernels per plant was negatively correlated with only kernel size in both seasons. Kernel size had positive correlation with spike dry weight, plant height, spike length, and awn length but negative correlation with spike density in both seasons. The number of spikelets was also positively correlated with maximum fertile floret, spike dry weight, spike length and spike density in dry as well as rainy season. Spike dry weight was positively correlated with all studied traits with the exception of the number of spikes per plant and chlorophyll contents. Plant height had also positive correlation with spike

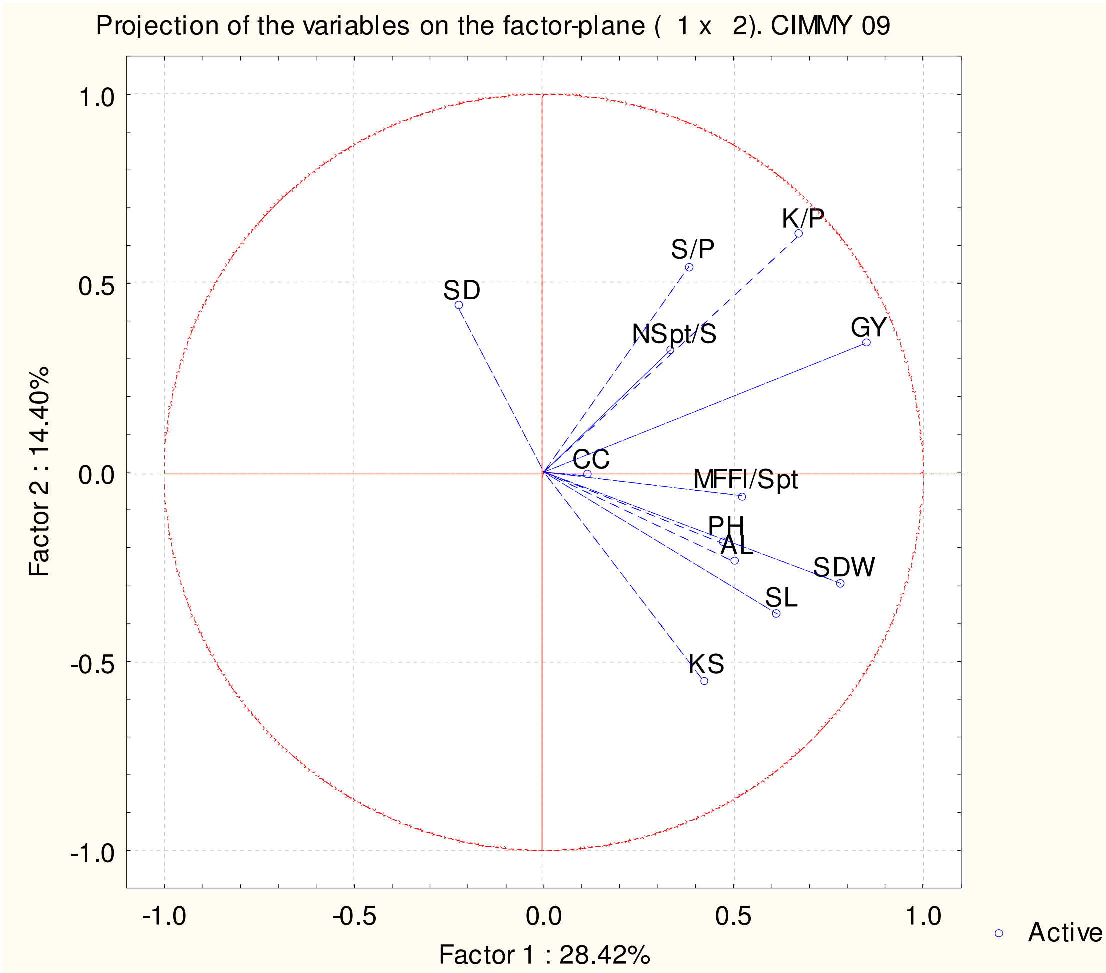

Figure 1a. PC1 and PC2 of variable in CIMMYT germplasm-2009. GY: Grain yield; K/P: number of kernels per plant; KS: kernel size as 100 grain weight; S/P: number of spikes per plant; NSpt/S: number of spikelets per spike; MFFL/Spt: maximum fertile florets per spikelet; SDW: spike dry weight; PH: plant height (cm); SL: spike length (cm); AL: awn length (cm); SD: spike density (number of spikelets/spike length); CC: chlorophyll contents.

length and awn length. In the dry season, plant height showed negative correlation with spike density. Spike length was negatively correlated with spike density and had positive correlation with all other traits except number of spikes per plant and chlorophyll contents. Awn length was in negative association with spike density but positive with other traits excluding number of spikes per plant, number of spikelets per spike and chlorophyll contents. Spike density had positive correlation with only number of spikelets per spike and negative with all other traits except grain yield, kernels per plant, number of spikes per plant and plant height. Chlorophyll content was the only trait that had no correlation with any other trait. (Table 1). The correlation pattern was confirmed by the projection of all yield traits on the first two principal components. In CIMMYT lines, all the traits except spike density had positive projection onto the first principal component (PC1). This revealed that there is negative correlation between spike density and all other traits. Chlorophyll contents hardly project on PC1 in both seasons and in the number of kernels per plant only in dry season. The projection on the second principal component (PC2) developed an interesting picture. Maximum fertile florets per spikelet, chlorophyll contents, awn length and plant height, hardly, projected on PC2. Basically, PC2 grouped the traits on the extent of their correlation with grain yield. In rainy season, trials yield traits of major importance were number of spikes per plant, number of kernels per plant and number of spikelets per spike. In dry season trials, the important traits were the number of spikes per plant, number of spikelets per spike, maximum fertile florets per spikelet, and spike dry weight. (Figure 1a and b).

In Pakistani germplasm, kernel size was also uncorrelated with grain yield, spike density and chlorophyll contents in both rainy and dry seasons (Table 2). Projection of traits on PC1 and PC2 also depicted the same pattern. Kernal size and spike density were

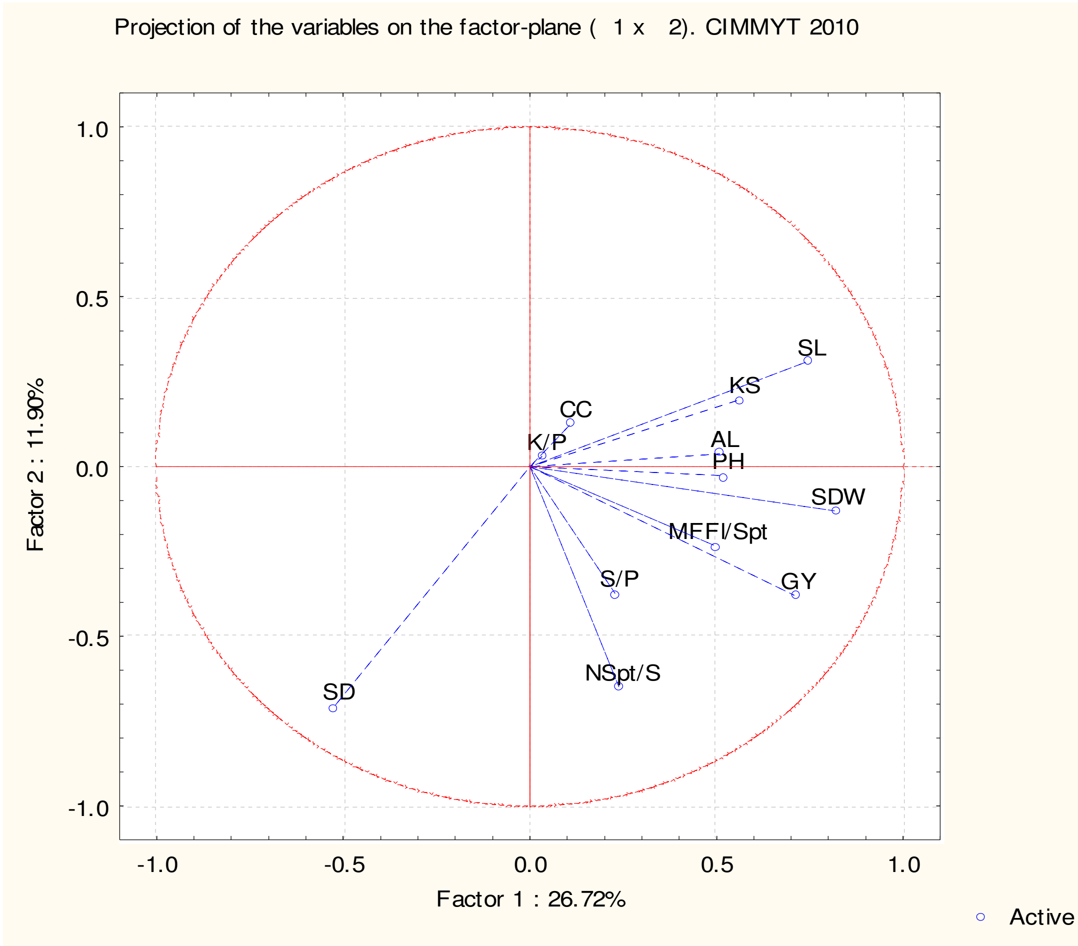

Figure 1b. PC1 and PC2 of variable in CIMMYT germplasm-2010. GY: Grain yield; K/P: number of kernels per plant; KS: kernel size as 100 grain weight; S/P: number of spikes per plant; NSpt/S: number of spikelets per spike; MFFL/Spt: maximum fertile florets per spikelet; SDW: spike dry weight; PH: plant height (cm); SL: spike length (cm); AL: awn length (cm); SD: spike density (number of spikelets/spike length); CC: chlorophyll contents.

projected on negative axis of PC1 and all other traits were in a positive direction (Figures 2a and b). The number of kernels per plant was negatively correlated with kernel size but had positive association with the number of spikes per plant, number of spikelets per spike, spike dry weight and plant height. This correlation pattern was also reflected in principal component analysis (Figures 2a and b). It showed positive correlation with spike length only in the dry season. Kernel size appeared to be in positive association only with spike dry weight and in negative association with the number of kernels per plant, number of spikes per plant, and number of spikelets per spike. Kernel size was in negative correlation with spike density in both seasons but was significant only in dry season. Spike dry weight was positively correlated with all those traits that were positively correlated with yield. It was negatively correlated with spike density only in the dry season. Plant height was also positively associated with spike dry weight and spike length. Spike length had positive correlation awn length but negative with spike density. Similar to CIMMYT, germplasm chlorophyll content was uncorrelated with all traits (Table 2).

The correlation pattern in the Indian population was different from that of the CIMMYT and Pakistani populations. The projection pattern of variables on PC1 and PC2 in Indian germplasm was also quite different from those in CIMMYT and Pakistani germplasm. In rainy seasons, the traits grouped with yield were the number of kernels per plant, and kernel size. In the dry season, the traits closely related to yield were the number of spikes per plant, awn length, and kernel size (Figure 3a and b). The number of kernels per plant, kernel size, and number of spikes per plant were the only attributes that had positive correction with yield. This positive correlation resulted into grouping of these traits when projected on PC1 and PC2 (Figures 3a and b). Kernel size depicted positive correlation only with yield. Number of spikes per plant showed negative relationship with maximum fertile florets per spikelet in both seasons and with spike density

Table 2. Correlation coefficient among various yield traits in Pakistan germplasm.

Yield trait	GY	K/P	KS	S/P	NSpt/S	MFFl/Spt	SDW	PH	SL	AL	SD	CC
GY	1.00	0.89**	0.06	0.68**	0.24**	0.21**	0.33**	0.32**	0.26**	0.15*	-0.06	0.06
K/P	0.87**	1.00	-0.36**	0.73**	0.33**	0.14	0.20*	0.26**	0.17*	0.10	0.11	0.00
KS	0.08	-0.39**	1.00	-0.22**	-0.23**	0.14	0.24**	0.04	0.13	0.12	-0.35**	0.09
S/P	0.71**	0.73**	-0.20**	1.00	0.14	-0.10	-0.07	0.14	0.05	0.11	0.07	0.00
NSpt/S	0.27**	0.33**	-0.23**	0.14	1.00	-0.05	0.38**	0.19*	0.47**	0.17*	0.37**	-0.09
MFFl/Spt	0.21**	0.14	0.14	-0.10	-0.05	1.00	0.37**	0.12	0.16*	0.06	-0.19*	0.07
SDW	0.37**	0.21**	0.26**	-0.08	0.40	0.38**	1.00	0.36**	0.51**	0.15	-0.21**	-0.06
PH	0.34**	0.26**	0.05	0.14	0.19	0.13	0.41**	1.00	0.27**	-0.01	-0.12	-0.14
SL	0.28**	0.17	0.13	0.05	0.47	0.16	0.53**	0.27**	1.00	0.24*	-0.64**	0.05
AL	0.16*	0.10	0.12	0.11	0.17	0.06	0.15	-0.01	0.24**	1.00	-0.09	-0.01
SD	-0.06	0.04	-0.15	0.03	0.26	-0.12	-0.19	-0.12	-0.51**	0.02	1.00	-0.12
CC	0.05	0.00	0.09	0.00	-0.08	0.07	-0.05	-0.14	0.05	-0.01	-0.07	1.00

Values below diagonal are for the year 2008-2009 (rainy season) and values above diagonal are for the year 2009-2010 (dry season). * Significant at 0.05; ** Significant at 0.01; GY: grain yield; K/P: number of kernels per plant; KS: kernel size as 100 grain weight; S/P: number of spikes per plant; NSpt/S: number of spikelets per spike; MFFL/Spt: maximum fertile florets per spikelet; SDW: spike dry weight; PH: plant height (cm); SL: spike length (cm); AL: awn length (cm); SD: spike density (number of spikelets/spike length); CC: chlorophyll contents.

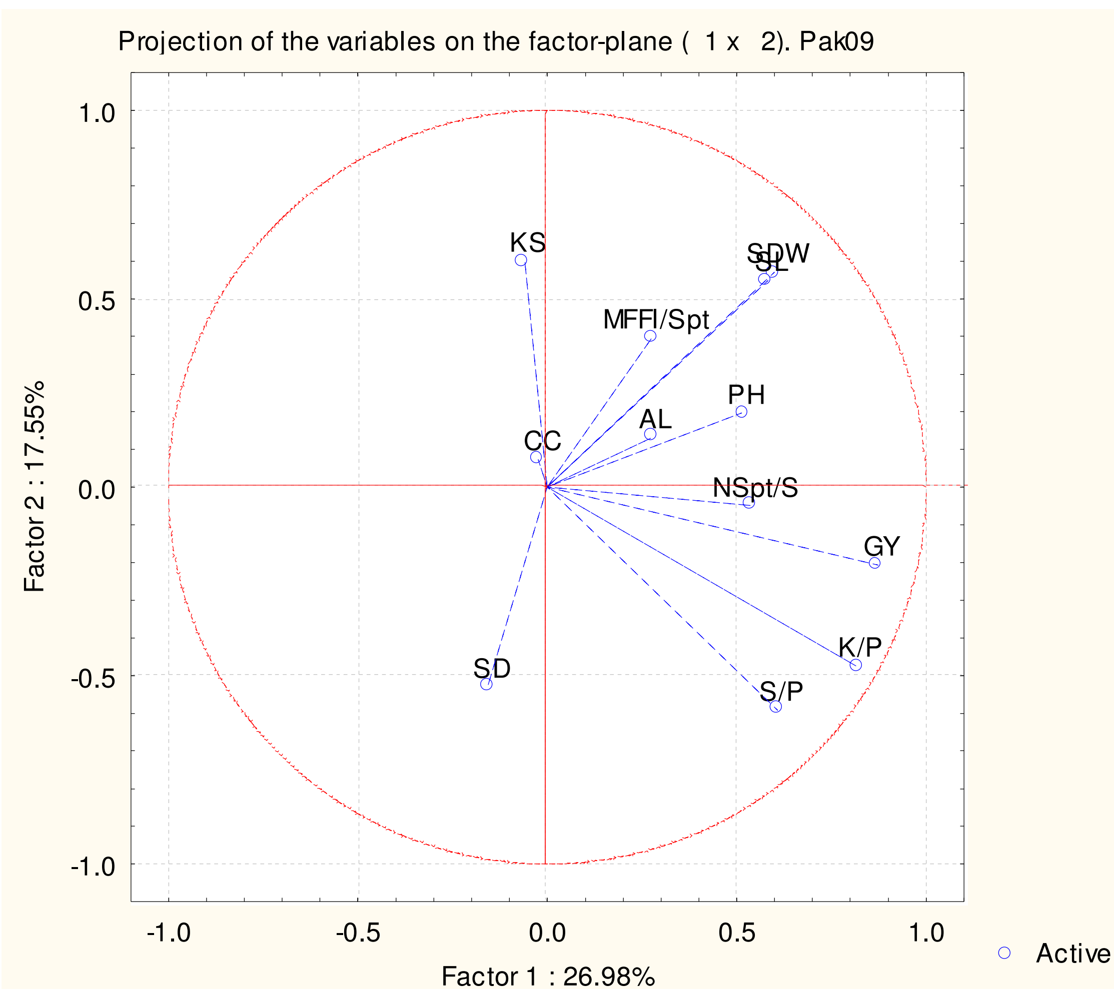

Figure 2a. PC1 and PC2 of variable in Pak germplasm-2009. GY: Grain yield; K/P: number of kernels per plant; KS: kernel size as 100 grain weight; S/P: number of spikes per plant; NSpt/S: number of spikelets per spike; MFFL/Spt: maximum fertile florets per spikelet; SDW: spike dry weight; PH: plant height (cm); SL: spike length (cm); AL: awn length (cm); SD: spike density (number of spikelets/spike length); CC: chlorophyll contents.

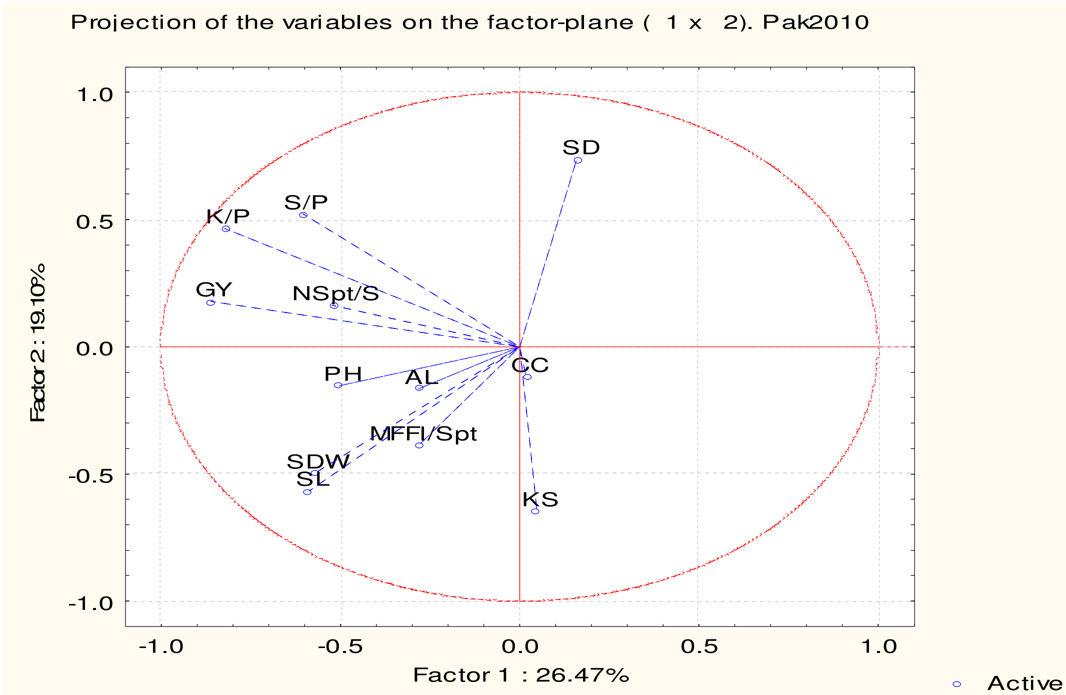

Figure 2b. PC1 and PC2 of variable in Pak germplasm-2010. GY: Grain yield; K/P: number of kernels per plant; KS: kernel size as 100 grain weight; S/P: number of spikes per plant; NSpt/S: number of spikelets per spike; MFFL/Spt: maximum fertile florets per spikelet; SDW: spike dry weight; PH: plant height (cm); SL: spike length (cm); AL: awn length (cm); SD: spike density (number of spikelets/spike length); CC: chlorophyll contents.

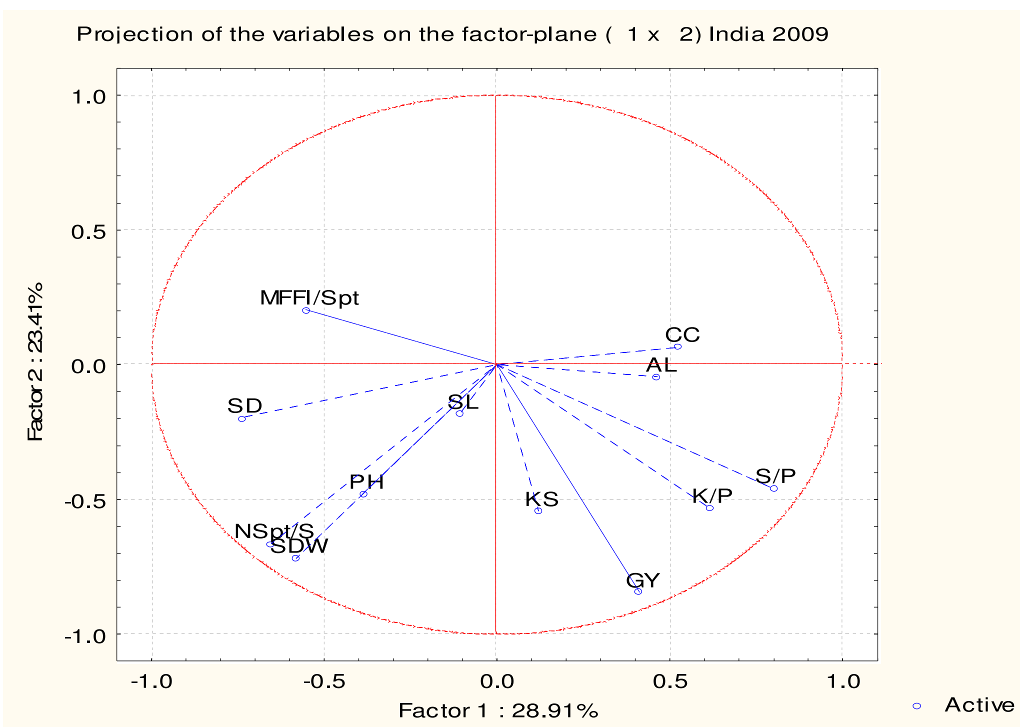

Figure 3a. PC1 and PC2 of variable in Indian germplasm-2009. GY: Grain yield; K/P: number of kernels per plant; KS: kernel size as 100 grain weight; S/P: number of spikes per plant; NSpt/S: number of spikelets per spike; MFFL/Spt: maximum fertile florets per spikelet; SDW: spike dry weight; PH: plant height (cm); SL: spike length (cm); AL: awn length (cm); SD: spike density (number of spikelets/spike length); CC: chlorophyll contents.

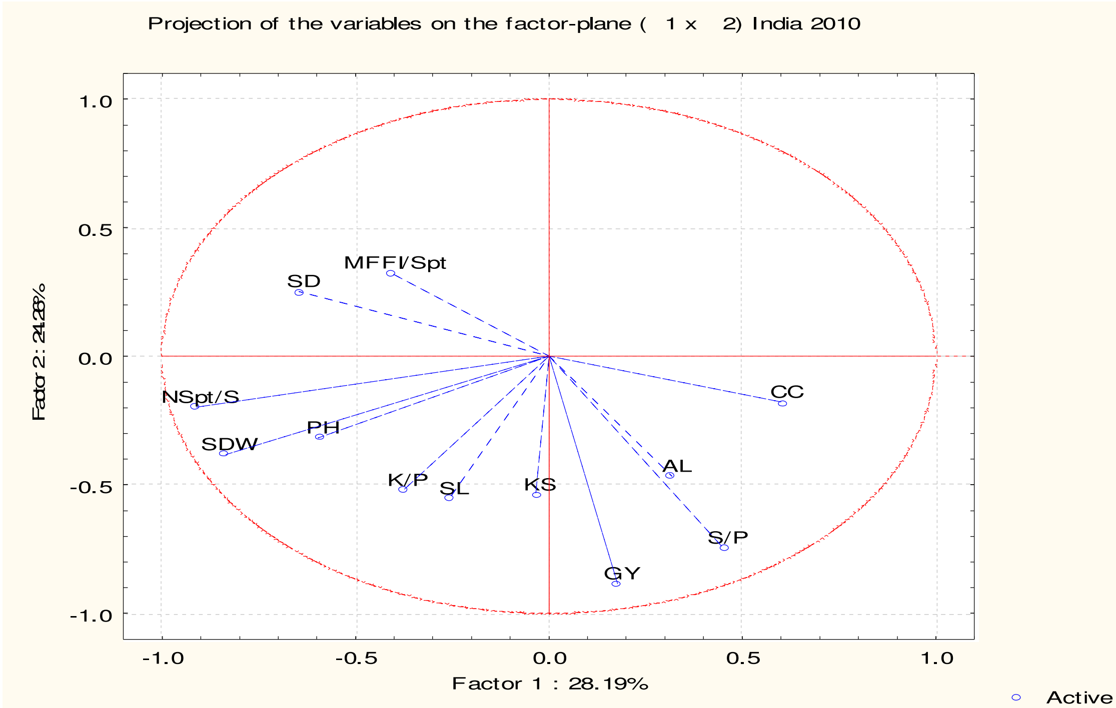

Figure 3b. PC1 and PC2 of variable in Indian germplasm-2010. GY: Grain yield; K/P: number of kernels per plant; KS: kernel size as 100 grain weight; S/P: number of spikes per plant; NSpt/S: number of spikelets per spike; MFFL/Spt: maximum fertile florets per spikelet; SDW: spike dry weight; PH: plant height (cm); SL: spike length (cm); AL: awn length (cm); SD: spike density (number of spikelets/spike length); CC: chlorophyll contents.

Table 3. Correlation coefficient among various yield traits in Indian germplasm.

Yield trait	GY	K/P	KS	S/P	NSpt/S	MFFl/Spt	SDW	PH	SL	AL	SD	CC
GY	1.00	0.32	0.55*	0.80**	0.11	-0.46*	0.17	0.03	0.29	0.30	-0.12	0.29
K/P	0.69**	1.00	0.17	0.20	0.36	-0.04	0.38	0.40	0.20	0.16	0.17	-0.09
KS	0.54*	-0.02	1.00	0.18	0.10	-0.26	0.41	0.07	-0.13	0.22	0.21	0.34
S/P	0.66**	0.81**	0.18	1.00	-0.15	-0.53*	-0.20	-0.06	0.35	0.21	-0.43	0.34
NSpt/S	0.28	0.08	0.10	-0.15	1.00	0.23	0.80**	0.47*	0.34	-0.33	0.66**	-0.53*
MFFl/Spt	-0.40	-0.31	-0.26	-0.53*	0.23	1.00	0.28	0.20	0.19	0.14	0.07	-0.10
SDW	0.38	-0.06	0.41	-0.20	0.80**	0.28	1.00	0.55**	0.43	-0.02	0.41	-0.37
PH	0.10	0.03	0.07	-0.07	0.48*	0.20	0.56**	1.00	0.36	0.00	0.17	-0.13
SL	-0.02	-0.01	-0.07	0.08	0.21	0.03	0.12	0.33	1.00	0.35	-0.48*	-0.37
AL	0.18	0.25	0.22	0.21	-0.33	0.14	-0.02	-0.01	-0.11	1.00	-0.57**	0.23
SD	-0.09	-0.36	0.22	-0.50*	0.59**	0.23	0.46*	0.14	0.05	-0.60**	1.00	-0.20
CC	0.14	0.12	0.34	0.33	-0.53*	-0.10	-0.37	-0.14	0.27	0.23	-0.16	1.00

Values below diagonal are for the year 2008-2009 (rainy season) and values above diagonal are for the year 2009-2010 (dry season). * Significant at 0.05; ** Significant at 0.01; GY: grain yield; K/P: number of kernels per plant; KS: kernel size as 100 grain weight; S/P: number of spikes per plant; NSpt/S: number of spikelets per spike; MFFL/Spt: maximum fertile florets per spikelet; SDW: spike dry weight; PH: plant height (cm); SL: spike length (cm); AL: awn length (cm); SD: spike density (number of spikelets/spike length); CC: chlorophyll contents.

only in rainy season. Number of spikelets per spike was in positive relationship with spike dry weight, plant height, and spike density, and negative with chlorophyll contents. Spike dry weight had positive correlation with plant height in both seasons and with spike density only in the rainy season. Spike length was negatively associated with spike density in dry season only, and awn length was negatively associated with spike density in both seasons. Unlike all other four groups, chlorophyll content was negatively correlated with number of spikelets per spike (Table 3).

In genotypes developed at ICARDA, the number of kernels per plant, number of spikes per plant, maximum

Table 4. Correlation coefficient among various yield traits in ICARDA germplasm.

Yield trait	GY	K/P	KS	S/P	NSpt/S	MFFl/Spt	SDW	PH	SL	AL	SD	CC
GY	1.00	0.85**	0.33*	0.71**	0.29	0.37*	0.55**	0.25	0.38*	-0.01	-0.20	0.02
K/P	0.84**	1.00	-0.20	0.85**	0.49**	0.36*	0.34*	-0.04	0.40**	-0.27	-0.07	0.03
KS	0.28	-0.20	1.00	-0.18	-0.34*	0.04	0.41**	0.55**	-0.01	0.45**	-0.26	-0.04
S/P	0.70**	0.85**	-0.18	1.00	0.29	0.10	0.10	-0.02	0.25	-0.29	-0.04	-0.10
NSpt/S	0.26	0.49**	-0.34*	0.29	1.00	0.15	0.32*	-0.15	0.48**	-0.20	0.18	-0.06
MFFl/Spt	0.38*	0.36*	0.04	0.10	0.15	1.00	0.47**	-0.06	0.40**	0.02	-0.37*	-0.05
SDW	0.54**	0.38*	0.41**	0.11	0.35*	0.57**	1.00	0.30*	0.54**	0.31*	-0.38*	-0.03
PH	0.23	-0.04	0.55**	-0.02	-0.15	-0.06	0.31*	1.00	0.05	0.55**	-0.17	0.00
SL	0.33*	0.40**	-0.01	0.25	0.48**	0.40**	0.58**	0.05	1.00	0.18	-0.76**	-0.16
AL	-0.04	-0.27	0.45**	-0.29	-0.20	0.02	0.31*	0.55**	0.18	1.00	-0.33*	-0.05
SD	-0.06	0.10	-0.31*	0.01	0.42**	-0.07	-0.12	-0.21	-0.13	-0.14	1.00	0.13
CC	0.02	0.03	-0.04	-0.10	-0.06	-0.05	-0.01	0.00	-0.16	-0.05	-0.14	1.00

Values below diagonal are for the year 2008-2009 (rainy season) and values above diagonal are for the year 2009-2010 (dry season). * Significant at 0.05; ** Significant at 0.01; GY: grain yield; K/P: number of kernels per plant; KS: kernel size as 100 grain weight; S/P: number of spikes per plant; NSpt/S: number of spikelets per spike; MFFL/Spt: maximum fertile florets per spikelet; SDW: spike dry weight; PH: plant height (cm); SL: spike length (cm); AL: awn length (cm); SD: spike density (number of spikelets/spike length); CC: chlorophyll contents.

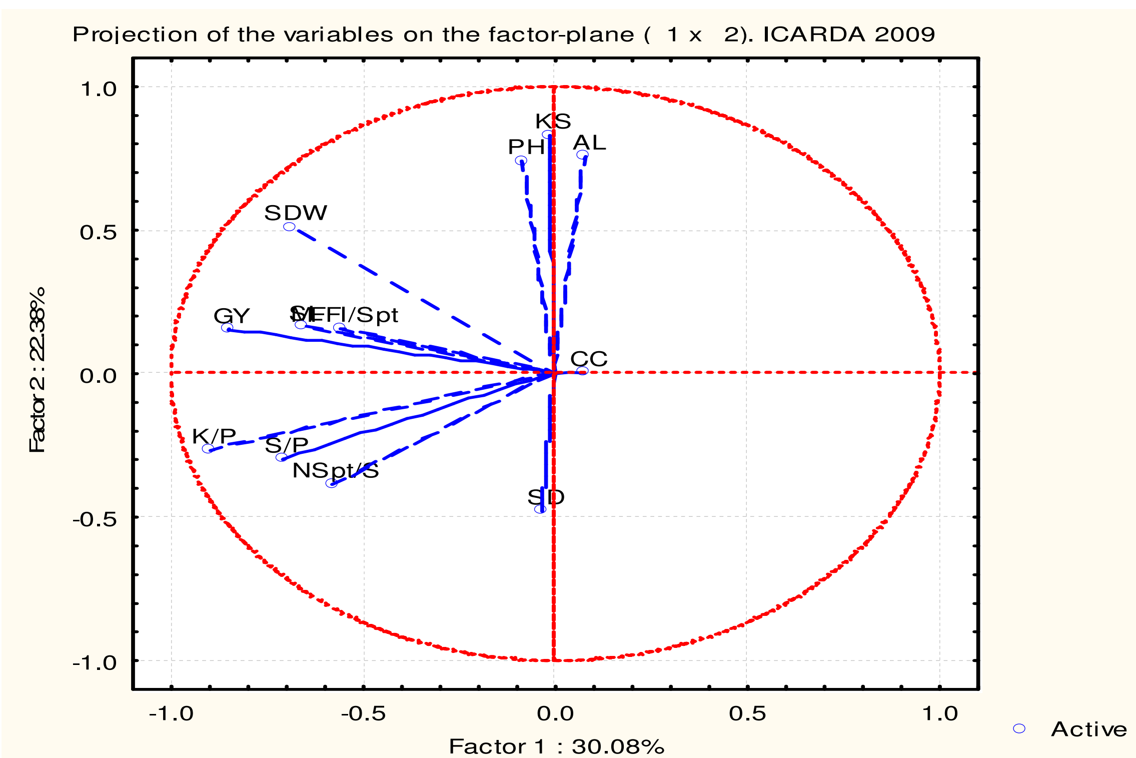

Figure 4a. PC1 and PC2 of variable in ICARDA germplasm-2009. GY: Grain yield; K/P: number of kernels per plant; KS: kernel size as 100 grain weight; S/P: number of spikes per plant; NSpt/S: number of spikelets per spike; MFFL/Spt: maximum fertile florets per spikelet; SDW: spike dry weight; PH: plant height (cm); SL: spike length (cm); AL: awn length (cm); SD: spike density (number of spikelets/spike length); CC: chlorophyll contents.

fertile florets per spikelet, spike dry weight, and spike length were positively correlated with grain yield (Table 4). The structure of variables on the first two PCs in ICARDA germplasm was quite consistent for both years. Kernals per plant, spike per plant and the number of spikelets per plant were projected together. Grain yield was projected with spike length, maximum fertile florets per spikelet and spike dry weight (Figures 4a and b). Kernel size was positively correlated with yield in dry season and had no correlation in rainy season. This

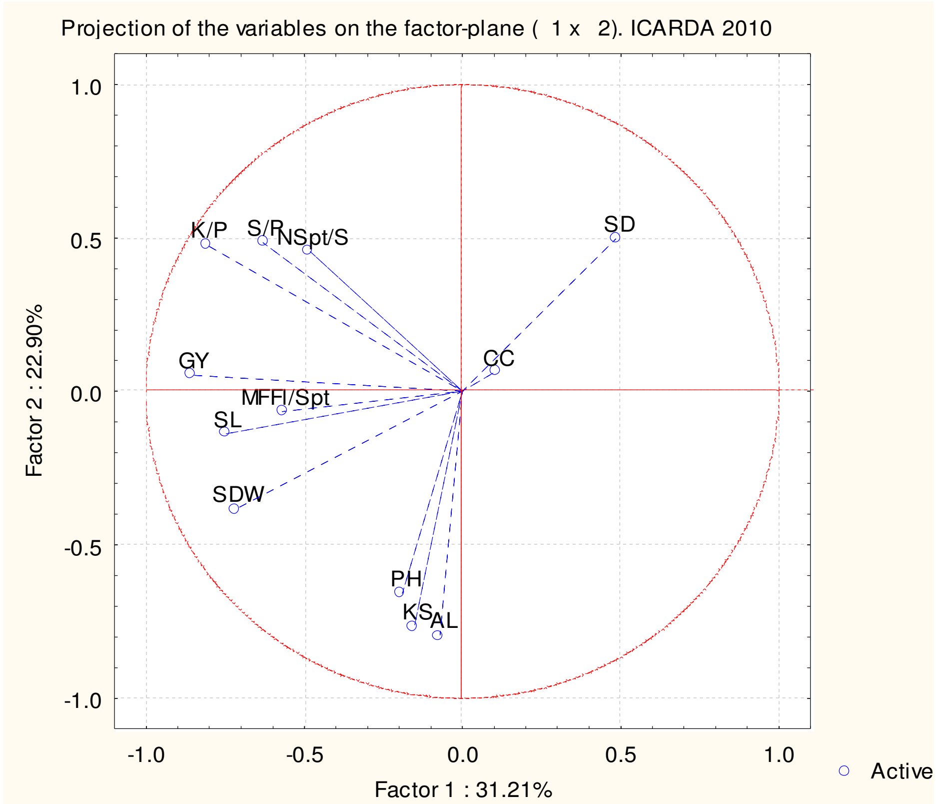

Figure 4b. PC1 and PC2 of variable in ICARDA germplasm-2010. GY: Grain yield; K/P: number of kernels per plant; KS: kernel size as 100 grain weight; S/P: number of spikes per plant; NSpt/S: number of spikelets per spike; MFFL/Spt: maximum fertile florets per spikelet; SDW: spike dry weight; PH: plant height (cm); SL: spike length (cm); AL: awn length (cm); SD: spike density (number of spikelets/spike length); CC: chlorophyll contents.

correlation of kernal size with grain yield was also prominant by principal component analysis (Figure 4a and b). Kernels per plant had negative correlation value with kernel size but was not significant in contrast to CIMMYT and Pakistani germplasm. It was positively correlated number of spikes per plant, number of spikelets per spike, and spike length. Kernel size was negatively related with number of spikelets per spike and positively with spike dry weight, plant height and awn length. The number of spikelets per spike had also positive correlation spike dry weight and spike length in both seasons, and with spike density only in rainy season. Maximum fertile florets per spikelet had positive correlation with spike dry weight and spike length. It had negative correlation with spike density in dry season only. Spike dry weight had also positive relationship with spike length and awn length. It showed negative correlation with spike density only in dry season as was in CIMMYT and Pakistani germplasm. Plant height was positively correlated with awn length as was in the CIMMYT germplasm. Spike length was negatively correlated with spike density in dry season and the pattern was similar as in CIMMYT, Pakistani and Indian germplasms (Table 4).

The group of miscellaneous genotypes had only three traits: The number of kernels per plant, number of spike per plant, and spike length; all three traits showed positive correlation with yield in both seasons. The number of kernels per plant showed positive correlation also with the number of spike per plant, maximum fertile florets per spike and spike length. Number of spikelets per spike was in positive correlation with spike dry weight and spike length in both seasons and negative with spike density in rainy season. Maximum fertile florets had positive correlation only with spike dry weight and the number of kernels per plant (Table 5). In the miscellaneous genotypes, the projection of variables on the first two PCs were similar in the rainy and dry seasons. The number of kernels per plant, spike length, and maximum fertile florets per spikelets appeared to be close to grain yield. (Figure 5a and b)

DISCUSSION

The pattern of traits correlation with grain yield was quite similar in CIMMYT and Pakistani germplasm. The structure of traits on PC1 was also similar to that of CIMMYT lines. The only difference was the irrelevance of kernel size

Table 5. Correlation coefficient among various yield traits in miscellaneous population.

Yield trait	GY	K/P	KS	S/P	NSpt/S	MFFl/Spt	SDW	PH	SL	AL	SD	CC
GY	1.00	0.91**	-0.02	0.65*	0.44	0.52	0.54	0.30	0.77**	0.14	-0.51	-0.01
K/P	0.93**	1.00	-0.42	0.66*	0.38	0.67*	0.51	0.17	0.79**	0.23	-0.60	0.15
KS	-0.05	-0.42	1.00	-0.16	0.05	-0.50	-0.04	0.29	-0.22	-0.26	0.37	-0.35
S/P	0.63	0.66*	-0.16	1.00	-0.16	-0.03	-0.05	0.26	0.54	0.18	-0.83**	0.50
NSpt/S	0.48	0.38	0.06	-0.16	1.00	0.55	0.81**	0.56	0.64*	-0.09	0.23	-0.47
MFFl/Spt	0.55	0.67*	-0.50	-0.03	0.55	1.00	0.78**	-0.05	0.51	0.13	-0.11	-0.09
SDW	0.57	0.51	-0.04	-0.05	0.81**	0.78**	1.00	0.44	0.66*	0.15	-0.02	-0.23
PH	0.32	0.17	0.29	0.26	0.56	-0.05	0.44	1.00	0.63	-0.29	-0.19	-0.15
SL	0.79**	0.79**	-0.22	0.54	0.64*	0.51	0.66*	0.63	1.00	0.01	-0.60	-0.10
AL	0.12	0.23	-0.26	0.18	-0.09	0.13	0.15	-0.29	0.01	1.00	-0.12	0.31
SD	-0.05	0.03	-0.11	0.19	-0.69*	-0.23	-0.64*	-0.65*	-0.35	-0.12	1.00	-0.37
CC	-0.03	0.15	-0.35	0.50	-0.47	-0.10	-0.23	-0.15	-0.10	0.31	0.22	1.00

Values below diagonal are for the year 2008-2009 (rainy season) and values above diagonal are for the year 2009-2010 (dry season). * Significant at 0.05; ** Significant at 0.01; GY: grain yield; K/P: number of kernels per plant; KS: kernel size as 100 grain weight; S/P: number of spikes per plant; NSpt/S: number of spikelets per spike; MFFL/Spt: maximum fertile florets per spikelet; SDW: spike dry weight; PH: plant height (cm); SL: spike length (cm); AL: awn length (cm); SD: spike density (number of spikelets/spike length); CC: chlorophyll contents.

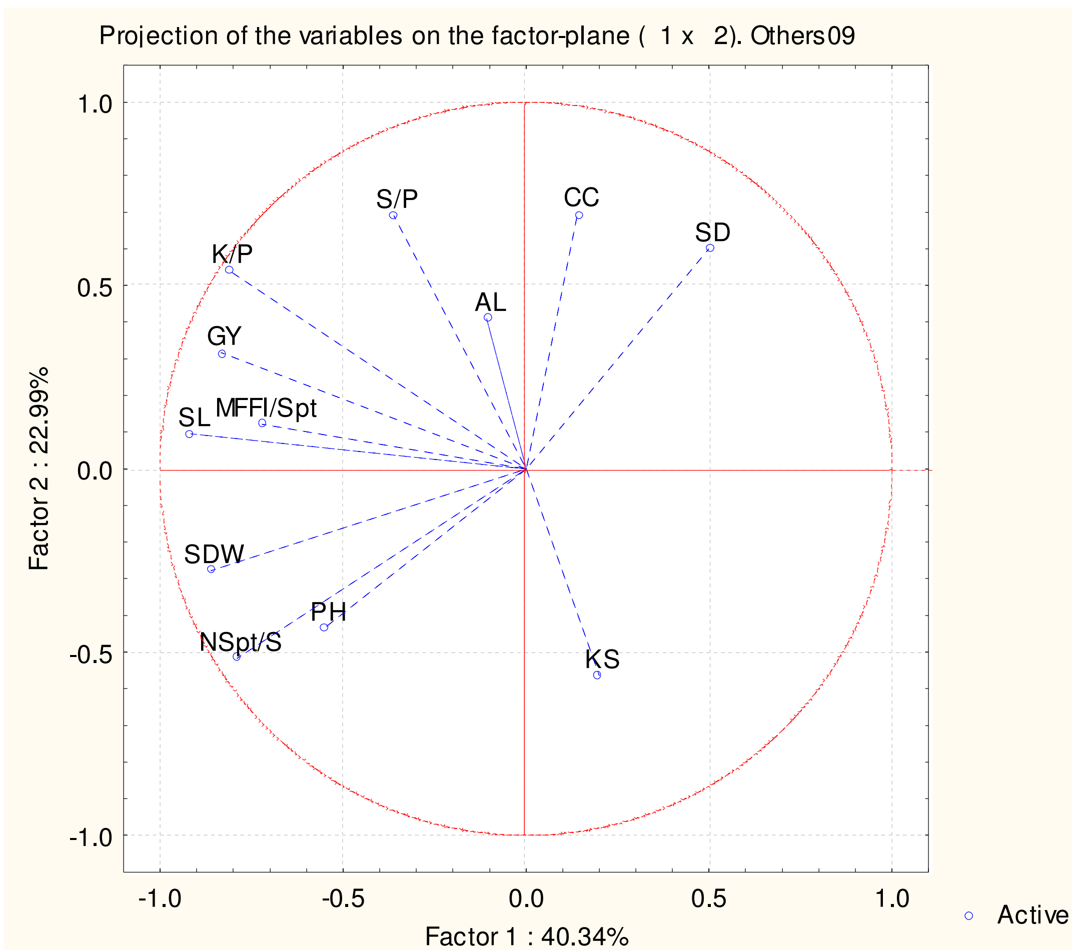

Figure 5a. PC1 and PC2 of variable in miscellaneous germplasm-2009. GY: Grain yield; K/P: number of kernels per plant; KS: kernel size as 100 grain weight; S/P: number of spikes per plant; NSpt/S: number of spikelets per spike; MFFL/Spt: maximum fertile florets per spikelet; SDW: spike dry weight; PH: plant height (cm); SL: spike length (cm); AL: awn length (cm); SD: spike density (number of spikelets/spike length); CC: chlorophyll contents.

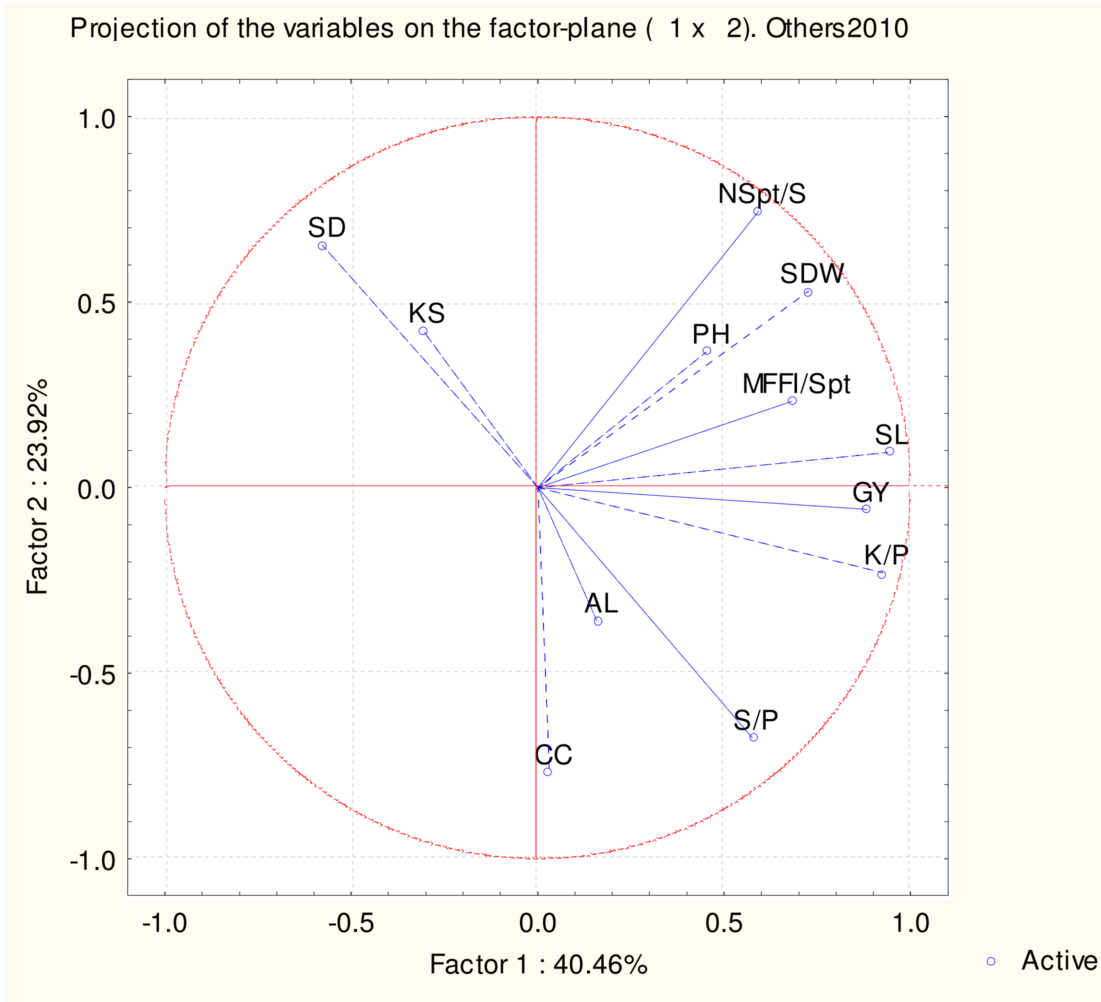

Figure 5b. PC1 and PC2 of variable in miscellaneous germplasm-2010. GY: Grain yield; K/P: number of kernels per plant; KS: kernel size as 100 grain weight; S/P: number of spikes per plant; NSpt/S: number of spikelets per spike; MFFL/Spt: maximum fertile florets per spikelet; SDW: spike dry weight; PH: plant height (cm); SL: spike length (cm); AL: awn length (cm); SD: spike density (number of spikelets/spike length); CC: chlorophyll contents.

and spike density with other important yield traits. The grouping of variables on PC2 was similar in both seasons. The number of kernels per plant, number of spikelets per spike, and number of spikes per plant were the traits grouped with yield. (Figures 1a and b; 2a and b). This was because of the excessive use of CIMMYT germplasm in Pakistani breeding programs. Majority of Pakistani varieties include CIMMYT lines in their parentage. For example, the parentage of Uqab-2000 is 'S'/NAC//BOW'S'. All the genotypes in Uqab-2000 are CIMMYT lines. The parentage of advance line V-00125 is BULBUL//F3.71/TRM/3/CROW'S'. Here again BULBUL and CROW'S' are CIMMYT lines. Parentage of Inqilab-91 is WL711/Crows, and that of MH-97 is CM85836-504-OY-OSY-OAP. Both these of varieties have CIMMYT lines in their parentage and they are repeatedly used as parents in other wheat varieties and advanced lines. Furthermore, the consistency of correlation patterns in both seasons show the stable gene expression and interaction for yield and yield traits. The major contributing traits to yield as shown by correlation analysis and principal component analysis were the number of kernels per plant, number of spikes per plant, spike length, and number of spikelets per plant. Furthermore, these traits were also positively correlated with each other. These results confirm the findings of Khan et al. (2010), Saleem et al. (2006), Kashif and Khaliq (2004), Khaliq et al. (2004), Aashfaq et al. (2003), Nayeem and Baig (2003), Shahid et al. (2002), Uddin et al. (1997), Mohy-ud-Din (1995) and Akhtar (1991). Spike dry weight was another trait that appeared as a key yield trait but was not used as selection parameter by breeders. This trait has highly significant correlation not only with grain yield but also with important yield traits including the number of kernels per plant, kernel size, number of spikelets per spike, maximum fertile florets, and spike length. Therefore, selection on spike dry weight may be useful for yield improvement. In the CIMMYT and Pakistani germplasms, kernel size and number of kernels per plant were negatively correlated. This negative correlation was also reported by Khan et al. (2010). Breaking this negative linkage between kernel size and number of kernels per plant was a challenge for breeder and geneticist to increase yield potential. Positive relationship between plant height and grain yield was also undesirable. This relationship was prominent in the high yielder wheat variety (SEHER-2006) in Pakistan. This positive but undesirable correlation have also been reported by Kashif and Khaliq (2004), Khaliq et al. (2004) and Akhtar et al. (1992) in Pakistani germplasm.

The correlation pattern in Indian germplasm depicts the different genetic constitutions and linkages between yield traits. It is clear from correlation and PCA that only the number of kernels per plant, kernel size, and number of spikes per plant were the traits contributing to yield. Selection on the basis of these traits will be fruitful working with Indian germplasm. Kotal et al. (2010) found similar pattern of correlation in Indian genotypes. No correlation between grain yield and plant height and between kernel size and number of kernels were desirable because selection on one trait did not have negative effect on the other trait. Spike dry weight appeared to be a very important trait in ICARDA lines. This pattern was similar to CIMMYT and Pakistani germplasm. Since spike dry weight was highly correlated with yield in positive direction, therefore, selection on this single trait might be very useful in yield gain. Yield potential of new wheat varieties can be improved by applying selection on number of kernels per plant, number of spikes per plant, spike length, and spike dry weight in CIMMYT, Pakistani and ICARDA genotypes. Working with Indian and miscellaneous genotypes, a selection on the number of kernels per plant and number of spikes per plant may be fruitful. Furthermore, three traits, the number of kernels per plant, number of spikes per plant and spike dry weight appeared to have positive effect on grain yield.

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