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Study of variability, heritability, character association and selection index in spring wheat

Mohammed Shafiuzzaman[1], Md. Najrul Islam[2], Nizamul Haque Patwary[1], Saida Akter Porag[1], Labony Yeasmin[3]

[1]Department of Agricultural Extension, Ministry of Agriculture, Government of the People's Republic of Bangladesh
[2]Department of Agronomy, Bangladesh Agricultural University (BAU), Mymensingh-2202, Bangladesh
[3]Dhaka Cantonment Public Girls School & College, Dhaka, Bangladesh

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***Corresponding Author:**

Mohammed Shafiuzzaman
Email: shafiagril@gmail.com

ABSTRACT

A study was carried out with 20 spring wheat genotypes of diverse origin to obtain information on genetic variability, heritability, genetic advance, relationship between yield and yield contributing characters, selection indices and their relative efficiencies in improvement of grain yield. In addition index score based on important yield attributes were estimated for all genotypes along with their phenotypic rank scores. There were significant variations for all the characters suggesting the presence of genetic variability among the genotypes. Considering yield plant^{-1} the genotype Mayoor was the best and that was followed by HT-11, Sourav, and Kav-2. It has also higher number of grains spike-1 and harvest index. KAV-2 ranked high for spikes plant-1, spikelets spike-1 grains spike-1 and harvest index. Sourav ranked high for spike length, spikelets spike-1, 100 - grain weight and harvest index. The genotype HT-11 had high mean performance for grains spike-1 and harvest index. The differences between genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV) were small for plant height, spike length, spikelets spike-1 and 100 grain weight indicating these characters are less affected by environment and mostly governed by genetic factors. Among the eight studied characters plant height, spike length, and 100- grain weight, displayed high heritability coupled with high genetic advance and spikes plant^{-1} and harvest index showed moderate heritability with high genetic advance. These characters had also high phenotypic coefficients of variation. So, selection of spring wheat genotypes based on these characters would be effective. Positive correlation found for grain yield plant^{-1} with spike length, grains spike, 100-grain weight and harvest index. Among them harvest index was significantly correlated with grain yield plant^{-1} at phenotypic level suggesting that genotypes with high partitioning efficiency gave increase in grain yield plant^{-1}. Spikes plant^{-1} and harvest index had high positive direct effects on grain yield. The phenotypic correlation of harvest index with grain yield plant^{-1} also high. The correlation coefficient of spikes plant^{-1} with grain yield plant^{-1} was low though their direct effects were high. Study of selection indices through discriminant function suggests that plant height + grains spike^{-1}+ grain yield plant^{-1} had the maximum genetic advance and relative efficiency than grain yield alone. Considering both phenotypic rank value and index score the genotypes, HT-11, Ning, Protiva and Mayoor were the superior among the genotypes under studied and suggest that these four genotypes could be used as parents for hybridization programme for wheat improvement.

INTRODUCTION

Spring wheat is an important cereal crop in the world. It has been cultivated extensively in temperate, sub-temperate and tropical zones. It has now become the second most important staple crop in Bangladesh in terms of acreage and production. In 2013-2014, wheat was grown on 429.61 thousand hectares of land and production was 1303.00 thousand tons (BBS, 2014). In addition about 1.5 to 2.0 million tons of wheat grains is imported each year to meet the food shortage in Bangladesh. Now a day's Bangladesh has made substantial progress in increasing production of wheat which favored by suitable climate of Bangladesh for wheat cultivation (Swaminathan, 1986). The average yield of wheat grain in this country is only 3..03 t ha^{-1} (BBS, 14). The reasons behind the low yield are due to the abiotic and biotic stresses and release of very limited number of wheat varieties. It justifies the need of wheat breeding for improving its yield in Bangladesh.

Grain yield in wheat is a complex character and it is the product of three primary yield components, number of spikes plant^{-1}, number of grains spike^{-1} and grain yield. These three primary yield components determine grain yield plant^{-1} through their multiplicative function. Harvest index is considered as one of the most important physiological component in bread wheat. In addition, the characters plant height, spike length, spikelets spike^{-1} and 100 grain weight are also correlated with grain yield and known as yield contributing characters. These characters are polygenic in nature and susceptible to environmental influence. It is therefore, necessary to separate the total phenotypic variation into heritable and non-heritable components for the purpose of planning improvement of these characters. In this concern, studies on genotypic and phenotypic coefficient of variation, heritability and genetic advance become important.

Grain yield in wheat is correlated with primary yield components and also with other morphological and physiological characters. These yield contributing characters are also correlated between themselves. Therefore, the relationship between grain yield and different contributing characters establishes a complex chain which could be further analyzed in more simple way through path coefficients. The path coefficient breaks the correlation coefficient of the yield with its contributing characters into direct and indirect effects. Such analyses reflect light on the real causes of relationship. As the yield is a complex character and also influenced by its component characters, direct selection for yield is often misleading. Criteria of selection may be different in different breeding populations depending on their genotypic background. Efficiency of selection under such circumstances can sometimes be improved by taking into consideration simultaneously the phenotypic values of a number of plant characters which are correlated with genotypic values of the characters under consideration.

The technique of discriminant function developed by Fisher (1936) and adopted for plant selection by Smith (1936) it is useful in improvement of yield by combination of characters. For improving yield, index selection is superior on the basis of yield alone. Therefore, discriminant function based on important characters for selection has proved to be very useful in plant and highly helpful to discriminate undesirable genotypes on the basis of their performance. The present studies were undertaken to evaluate the performance of some wheat varieties regarding variability for yield and different yield contributing character characters, and also to study of heritability and genetic advance of grain yield and other yield contributing characters.

MATERIALS AND METHODS

Experimental site

The experiment was conducted at the field laboratory of the Department of Genetics and Plant Breeding, Bangladesh Agricultural University (BAU), Mymensingh under irrigated condition. The experiment was carried out in the land which was medium high belonging to the old Brahmaputra floodplain, Agro-Ecological Zone (AEZ-9) having non calcareous dark gray soil (UNDP and FAO, 1998). The soil was sandy loam with pH value of 6.5. The climate of the experimental location during the wheat crop season is characterized by a relatively low rainfall and temperature from December to March.

Plant materials

The materials of this study were consisted of 20 genotypes of spring wheat (Table 1). They were collected from Wheat germplasm collection in the Department of Genetics and Plant Breeding, BAU, Mymensingh.

Table 1. List of wheat genotypes with their breeder institute, source and origin

Genotypes	Breeder Institute	Country of Origin
Wuhan	-	Pakistan
HT-11	CIMMYT	Mexico
Barkat	BAR1	Bangladesh
SA-92	CIMMYT	Mexico
Kheri	BARI	Bangladesh
Sourav	BARI	Bangladesh
Sebia	-	USA
Bulbul	-	Pakistan
Ananda	BARI	Bangladesh
NK-5	BAU	Bangladesh
KRL-14	IARI	India
Chyria-3	CIMMYT	Mexico
Akbar	BARI	Bangladesh
Gourav	BARI	Bangladesh
KAV-2	CIMMYT	Mexico
Anza	CIMMYT	Mexico
Ning	-	China
Protiva	BARI	Bangladesh
Pavon	CIMMYT	Mexico
Mayoor	CIMMYT	Mexico

Cultivation procedure

The experimental plot was thoroughly prepared by ploughing with power tiller followed by harrowing and laddering. After laddering the weeds and the stubbles of previous crops were removed from the land. Recommended doses of urea, tripple super phosphate, muriate of potash, gypsum and cowdung were applied at 200, 150, 80, 50 and 10000 kg ha^{-1}, respectively. Half the amounts of urea, full amount of triple super phosphate, muriate of potash, gypsum and cowdung were applied to the soil at the time of final land preparation. The rest of the urea was top dressed in two equal splits one at tillering and other at booting stages. The experiment was set up in a randomized complete block design with three replications. The plot size was 2 m $\times$ 2.5 m. The distance between two plots was 50 cm and the distance between two blocks was 100 cm. The spacing between row to row and plant to plant in the same row were 20 cm and 5 cm, respectively. The seeds of 20 wheat genotypes were sown in the field following line sowing. Intercultural practices were done uniformly for all genotypes. Thinning was done 25 days after sowing. Weeding was done when become necessary. The crop was irrigated two times one at the crown root initiation stage and the other at the peak tillering stage. Ten plants from each plot were randomly selected to collect the data and they harvested by uprooting. Border plants were discarded to avoid border effects. Data were collected from 10 randomly selected plants for measuring the growth, yield and yield contributing characters of wheat genotypes.

Statistical Analysis

All the collected data were statistically analyzed. Mean values for each character were used for statistical analysis. Analysis of variance was done for all the characters under study using the mean values (Singh and Chaudhury, 1985). The total variability was partitioned into treatments (genotypes), blocks (replications) and error components. When the F-ratio was significant, the differences between mean values were tested by Duncan's Multiple Range Test (DMRT) Steel and Torrie (1960). Genotypic and phenotypic variances, coefficients of variation, heritability, and genetic advance were estimated according to the formula given by Johnson et al, (1955). Moreover, genetic advance in percent of mean was calculated by the following formula proposed by Comstock and Robinson (1952), genotypic and phenotypic covariances were calculated using the formula suggested by Singh and Chaudhary (1985), genotypic and phenotypic correlation coefficients were estimated using the following formula suggested by Johnson et al. (1955) and Singh and Chaudhury (1985).

The components of correlation coefficients of different yield contributing characters with yield were partitioned into components of direct and indirect effects by path co-efficient analysis. Path coefficient analysis was done according to the procedure stated by Singh and Chaudhury (1985) and Dabholkar (1992) which was originally suggested by Wright (1921). In the present study, grain yield plant^{-1} considered as the resultant character (effect) and the seven yield contributing characters were considered as the causal factors. After calculating the direct and indirect effects of the characters, residual effect (R) was calculated using the following formula suggested by Singh and Choudhury (1985). Selection indices were constructed using the methods developed by Smith (1936) based on the discriminant function as proposed by Fisher (1936). The expected genetic advance (GA) through selection was calculated by following formula (Singh and Chaudhary, 1985).

RESULT AND DISCUSSION

Growth and yield performance of wheat genotypes

It is observed that different genotypes have significant difference in performance for growth and yield characters (Table 2). Considering yield plant^{-1} the genotype Mayoor was the best and that was followed by HT-11, Sourav, and Kav-2. The genotype Mayoor also had higher number of grains spike"^{1} and harvest index while, KAV-2 had higher number of spikes plant^{-1}, spikelets spike^{-1} grains spike^{-1} and harvest index. Sourav had greater spike length, spikelets spike^{-1}, 100-grain weight and harvest index. The genotype HT-11 had higher mean performance for grains spike^{-1} and harvest index. Among these 4 genotypes HT-11 was tall type and others were semi dwarf with the plant height ranging from 80.43 to 91.48 cm. That means these varieties were tolerant to lodging. All these four genotypes ranked high for harvest index suggesting that they were physiologically efficient in partitioning photosynthates to economic yield (grain yield).

Table 2. Performance of 20 spring wheat genotypes for yield and yield contributing characters.

Genotypes	Plant height (cm)	Spikes plant^{-1}	Spike length (cm)	Spikelets spike^{-1}	Grain spike^{-1}	100 Grain weight (g)	Harvest index	Grain yield plant^{-1} (g)
Wuhan	92.74 d-g^{z}	7.97 be	10. 53 b-d	19.37 a-e	39.83 a-d	3.79 c-h	30.52 a-d	9.58 a-c
HT-11	129.60 b	6.27 c	9.83 ef	18. 63 c-e	45.73 ab	3.96 c-f	29.78 a-d	10.91 ab
Barkat	92.42 e-g	6.37 c	10.84 bc	19. 67 a-d	37.80 b-d	3.88 c-g	30.10 a-d	8.21 a-c
SA-92	100.41 c	7.39 bc	10.81 bc	19. 90 a-c	40.34 a-d	3.11 g-i	26.85 b-d	7.83 a-c
Kheri	139. 78 a	10.33 ab	8.89 g	19. 60 a-e	38.97 b-d	2.82 i	21.52 d	7.39 bc
Sourav	87.64 gh	8.20 bc	10.90 ab	19.60 a-e	37.03 b-d	4.5 8 a-c	29.89 a-d	10.37 a-c
Sebia	93.69 d-e	6.60 c	10. 66 b-d	19.43 a-e	39.63 a-d	3.74 d-h	27.82 b-d	7.48 a-c
Bulbul	92.43 e-g	6.20 c	10.92 ab	19.77 a-d	51.63 a	3.28 m	30.48 a-d	7.51 a-c
Ananda	94.24 d-f	7.90 bc	9.67 f	18.77 b-e	36.00 b-d	3.85 c-h	26 38 b-d	8.42 a-c
NK.-5	97.82 c-d	11. 23 a	10.27 c-e	19.13 b-e	37.40 b-d	3.38 e-i	24.43 cd	8.47 a-c
KRL14	99.22 c	10.13 ab	11. 42 a	19.67 a-d	32.37 cd	4.45 a-d	24.44 cd	9.48 a-c
Chyria3	93.33 d-f	6.47 c	9.58 f	18.33 e	45.53 ab	4.39 a-d	35.02 ab	10.50 a-c
Akbar	87.26 h	5.90 c	10. 14 d-f	18.57 de	31.80 cd	4.88 ab	32.42 a-c	7.22 bc
Gourab	86.75 h	7.67 bc	10. 35 b-e	18.93 b-e	33.57 b-d	5. 09 a	31.74 a-c	9.87 a-c
KAV-2	80.43 i	8.83 a-c	10.11 d-f	20.63 a	40.50 a-d	4.17 b-c	31.37 a-c	10.54 a-c
Anza	89.84 f-h	8.60 a-c	8.79 g	19.43 a-e	28.73 d	3.05 hi	24.23 cd	5.83 c
Ning	93.37d-f	6.17 c	9.88 ef	18.63 c-e	35.80 b-d	4.78 ab	39.18 a	8.72 a-c
Protiva	97.37 c-e	7. 37 bc	10. 29 c-e	19.67 a-d	34.80 b-d	4.31 a-d	34.86 ab	9.74 a-c
Pavan	92.70 d-g	7. 83 bc	10. 75 bc	19.97 ab	39.70 a-d	2.70 i	24.69 cd	6.14 bc
Moyor	91 .48 f-h	7. 53 bc	10.15 de	19.97 b-e	4 1.63 a-c	4.24 b-d	39.06 a	12.33 a
Range	80.43-139.78	5.90-11.23	8.79-11.42	18.57-20.63	28.73-51.63	2.70-5.09	21.52-39.06	5.83-12.33
General mean	96.61	7.75	10.24	19.33	38.44	3.92	29.74	8.83
CV (%)^{y}	2.17	15.39	2.31	2.56	16.77	8.30	12.28	20.98

^{z}Means within column followed by different letters are significant according to the DMRT at $P < 0.05$.
^{y}CV = Coefficient of variance

Table 3. Genotypic coefficient of variation, phenotypic coefficient of variation, heritability, genetic advance and genetic advance in % of mean for yield and yield contributing characters.

Characters	GCV	PCV	Heritability (%h^2_b)	Genetic advance (GA)	GA in % of mean
Plant height	14.34	14.51	97.77	28.22	29.21
Spikes plant^{-1}	17.11	23.02	55.28	2.03	26.20
Spike length	6.39	6.80	88.45	1.27	12.38
Spikelets spike^{-1}	2.59	3.64	50.40	0.73	3.78
Grains spike^{-1}	9.74	19.39	25.23	3.87	10.07
100- grain weight	17.04	18.95	80.83	1.24	31.55
Harvest index	14.71	19.16	58.96	6.92	23.27
Grain yield plant^{-1}	14.67	25.61	32.89	1.53	17.34

For grain size the genotype Gourav was the best and it produced bold sized grain this was followed by Akbar, Ning and Sourav. The genotype Bulbul produces the highest number of grains spike^{-1} and that was followed by HT-11, Chyria-3 and Mayoor. The genotype KAV-2 produced highest number of spikelets spike^{-1} and that was followed by Pavon and SA-92. For spike length, the genotype Sourav appeared at best and that was followed by Bulbul, Wuhan and SA-92. The genotype NK-5 produced the highest number of spikes and that was followed by Kheri, KAV-2 and Anza. The genotype Sourav is a released genotype from Wheat Research Centre of Bangladesh Agricultural Research Institute and it was now being cultivated commercially. The genotype Mayoor and HT-11 are collected from CIMMYT and being cultivated in BAU farm over several years that means these genotypes are well adapted to the climate of local growing conditions.

Variability for yield and yield contributing characters

It appears that there were highest amount of variation for grain yield plant^{-1} at phenotypic level and this was followed by spikes plant^{-1}, grains spike^{-1}, 100-grain weight and plant height (Table 3). All these characters estimated PCV more than 14% which could be considered as quite high. The GCV for these characters were also high except number grains spike^{-1}. Grains spike^{-1} estimated 9.94% GCV. Coefficients of variation for other two characters, spikelets spike^{-1} and spike length at both phenotypic and genotypic levels were less than 10% and that could be considered as quite low. Mandal and Sarker (1996) observed wide range of variation for plant height and grains spike^{-1} in spring wheat. Balachand and Lodhi (1994) recorded maximum genotypic coefficient of variation in plant height followed by number of grains spike^{-1} and grain yield plant^{-1}.

Das and Rahman (1984) observed moderate to high GCV and PCV for spikes plant^{-1} and 100-grain weight and low GCV and PCV for spike length in spring wheat. Endaie and Waines (1989) observed the highest coefficients of variation for spikes plant^{-1} and moderate GCV and PCV for grains spike^{-1}. Sharma (1998) studied 98 wheat genotypes and observed moderate genotypic and phenotypic coefficients of variation for spike length. In another study with 98 genotypes of wheat, moderate genotypic and phenotypic coefficients of variation for harvest index (Krishnawat and Sharma, 1998). Singh and Yunus (1988) found moderately high genotypic and phenotypic coefficients of variation for harvest index. Berma et al. (1990) studied variation for grain yield in spring wheat and reported higher genotypic and phenotypic coefficients of variation for grain yield plant^{-1}. Tripathi et al. (1973) estimated high coefficients of variation for grain yield in wheat at both genotypic and phenotypic levels.

It is observed that the difference between GCV and PCV were lower for the characters plant height, spike length and spikelets spike^{-1} (Table 3). This indicates that these three characters were stable over the environments, thus selection would be effective for improvement of these characters on the basis of phenotypic performance. Wide range of variability found for the characters plant height, spikes plant^{-1}, 100 grain weight, harvest index, grains spike^{-1} and grain yield plant^{-1}, suggested that these characters should be used further breeding programme because more the variability better is the response to selection.

Heritability for yield and yield contributing characters

Estimates of heritability in broad sense indicate that plant height, spike length and 100-grain weight were highly heritable characters. Spikes plant^{-1}, spikelets spike^{-1} and harvest index were medium heritable characters. The character grains spike^{-1} and grain yield plant^{-1} estimates low heritability.

Genetic advance for yield and yield contributing characters

Estimates of genetic advance in percentage of mean indicate that 100-grain weight achieved the highest response under selection and this was followed by plant height, spikes plant^{-1} and harvest index. All these characters had estimated more than 20% genetic advance over their mean. Among these characters 100-grain weight and plant height had comparatively high PCV and high heritability that suggest that selection for these characters would give better response than others. Although the spike length had high heritability but their genetic advance were comparatively low and that was due to their low estimates of PCV. From the present study, it is noticed that plant height, spike length, 100-grain weight and harvest index had moderate to high heritability coupled with high genetic advance indicating the predominance of additive gene effects. Therefore, plant height, spike length and 100-grain weight could be considered as most important characters to be used for making effective selection.

Relationship between yield and yield contributing characters

In general, it is observed that the magnitudes of genotypic correlations were higher than that of phenotypic correlations, indicating fairly strong inherent relationships between the characters. In many cases, the difference between genotypic and phenotypic correlation coefficient were high, signifying the importance of environmental effects on relationship between them at phenotypic level. Joshi et al. (1982) reported that the inherent relationships among the characters which to a certain extent was suppressed by the environment.

It appears that grain yield plant^{-1} was positively correlated with spike length, grains spike^{-1}, 100-grain weight and harvest index both at genotypic and phenotypic levels (Table 4). Among them, harvest index was significantly correlated with grain yield plant^{-1} at phenotypic level suggesting that genotypes with high partitioning efficiency gave increase in grain yield plant^{-1}. Previous study also found positive correlation of grain yield plant^{-1} with number of grains spike^{-1}, 100-grain weight and harvest index (Sairi et al. 1990).

The genotypic correlation coefficient of plant height, spikes plant^{-1}, spikelets spike^{-1} with grain yield was negative but their corresponding phenotypic correlation coefficients were positive. This was due to the influence of environment, which turned the negative correlation at genotypic level to getting positive ones at phenotypic level. Study of the correlation at yield components level exhibits that plant height was positively correlated with spikes plant^{-1} and grains spike^{-1}, indicating that spikes plant^{-1} and grains spike^{-1} would be increased with the increase of plant height. On the other hand, plant height was negatively and significantly correlated with harvest index. This result suggests that taller plants in wheat are less efficient to partitioning their photosynthates to the grains.

Number of spikes plant^{-1} was positively correlated spikelets spike^{-1}. This result suggests that spikelets spike^{-1} would be increased with the increase of spikes plant^{-1}. Negative and significant correlation was found between spikes plant^{-1} and grains spike^{-1} and harvest index, indicating that grains spike^{-1} and harvest index would be increased with the decrease of spikes plant^{-1}. Spike length was positively correlated with the others yield contributing characters indicating that increase of spike length increases other yield contributing characters.

Number of grains spike^{-1} was negatively correlated with 100-grain weight. These two components of yield are known to be mutually compensating i.e. increases in one component would decrease the other. Singh et. al. (1998) reported that grains spike^{-1} was negatively correlated with 100-grain weight. On the other hand a positive association of number of grains spike^{-1} was found with harvest index. This result indicated that high partitioning efficiency to economic sink was due to increase in number of grains spike^{-1}. Positive and significant relationship was found between 100-grain weight and harvest index. Earlier study reported positive correlation of 100-grain weight with spike length while negative correlation with spikes plant^{-1} (Razzaque et al. 1981). In another study, negative correlation between number of grains spike^{-1} and 100-grain weight also reported (Mishra et al. 2001).

The results of present study indicate that spike length, number of grains spike^{-1}, 100-grain weight and harvest index exhibited positive association with grain yield. Among the three primary yield components, grains spike^{-1} is more important than other two. Harvest index is the most important physiological yield component. Among the yield contributing components harvest index showed positive and significant correlation with grain yield at phenotypic level. This signifies importance of them in selection and screening programme in spring wheat improvement in the present material. These characters should be taken into consideration for selection for yield improvement.

Table 4. Genotypic (G) and phenotypic (P) correlation coefficients between yield and yield contributing characters in spring wheat.

Characters		Spikes plant^{-1}	Spike length	Spikelets spike^{-1}	Grains Spike^{-1}	100-Grain weight	Harvest index	Grain yield plant^{-1}
Plant height	G	0.243	-0.376	-0.146	0.330	-0.397	-0.434*	-0.062
	P	0.194	-0.354	-0.094	0.148	-0.358	-0.306	0.002
Spikes plant"^{1}	G		-0.180	0.360	-0.587*	-0.357	-0.764**	-0.355
	P		-0.002	0.340	-0.124	-0.278	-0.451*	0.224
Spike length	G			0.375	0.167	0.180	0.054	0.104
	P			0.363	0.167	0.160	0.034	0.147
Spikelets spike"^{1}	G				-0.096	-0.521	-0.530*	-0.526*
	P				0155	-0.357	-0.226	0.042
Grains spike"^{1}	G					-0.272	0.212	0.128
	P					-0.271	0.174	0.348
100-grain weight	G						0.772*	0.860**
	P						0.550*	0.354
Harvest index	G						0.660*	
	P						0.546*	

* and ** indicate significant at 5% and 1% level of significance respectively.

Path coefficient analysis

It is observed that spikes plant^{-1} and harvest index had high positive direct effects on grain yield (Table 5). The phenotypic correlation of harvest index with grain yield plant^{-1} also high. Such high correlation with grain yield plant^{-1} was mainly due to the high positive direct effect of harvest index and considerable positive indirect effects via, plant height, grains spike^{-1} and 100-grain weight. The correlation coefficient of spikes plant^{-1} with grain yield plant^{-1} was low though their direct effects were high. The negative indirect effects of spikes plant^{-1} via harvest index and 100-grain weight reduced the correlation between grain yield plant^{-1} and spikes plant^{-1}. Uddin (1997) found the highest direct effect of number of spikes plant^{-1} on grain yield plant^{-1}. Chaturvedi and Gupta (1995) observed high positive direct effects of number of spikes plant^{-1} and harvest index on grain yield. Shamsuddin (1987) also reported high direct effect of these two characters on grain yield plant^{-1}.

Table 5. Path coefficients of different yield contributing characters on grain yield in spring wheat.

Characters	Plant height	Spikes plant^{-1}	Spike length	Spikelet spike^{-1}	Grain spike^{-1}	100-grain weight	Harvest index	Phenotypic correlation with grain yield plant^{-1}
Plant height	**0.168**	0.116	-0.019	-0.038	0.054	-0.123	0.190	0.002
Spikes plant^{-1}	0.033	**0.599**	-0.0001	0.014	-0.045	-0.095	-0.281	0.224
Spike length	-0.059	-0.0012	**0.056**	0.015	0.061	0.055	0.021	0.147
Spikelets spike^{-1}	-0.016	0.203	0.020	**0.040**	0.057	-0.123	-0.141	0.042
Grains spike^{-1}	0.025	-0.074	0.0093	0.0062	**0.367**	-0.093	0.108	0.348
100-grain weight	-0.060	-0.166	0.0089	-0.014	-0.099	**0.343**	-3.63	0.354
Harvest index	0.773	0.077	-0.123	-0.470	0.773	4.331	**0.622**	0.546*

Residual effect = 0.516; * Indicate significant at 5% level of significance and • Bold value indicate direct effect of different yield contributing characters on grain yield plant^{-1}.

Plant height had low positive direct effects on grain yield plant^{-1}. The correlation coefficient between plant height and grain yield plant^{-1} was also very low. Such low correlation might be due to negative indirect effects of plant height via, spike length, spikelets spike^{-1} and 100-grain weight. Similarly spike length had low positive direct effects on grain yield plant^{-1}. It might be due to the negative indirect effects of spike length via plant height and spikes plant^{-1}. The effects of spike length via other character also very low.

Number of grains spike^{-1} possessed high positive direct effects on grain yield plant^{-1}. The correlation between number of grains spike^{-1} and grain yield plant^{-1} was also positive and high. Such high correlation of grains spike^{-1} with grain yield plant^{-1} was mainly due to its high direct effect on grain yield plant^{-1}. Similarly, 100-grain weight had also high and positive direct effect on grain yield plant^{-1}. The correlation of it with grain yield plant^{-1} was positive and high. Ibrahim (1994) reported higher direct effect of these two characters on grain yield plant^{-1}.

Spikelets spike^{-1} had negligible direct effects on grain yield plant^{-1}. It also expressed very low correlation with grain yield plant^{-1}, which was mainly the negative indirect effect of spikelets spike^{-1} via 100-grain weight, height and harvest index. The present study suggests that spikes plant^{-1}, grains spike^{-1},100-grain weight and harvest index were the most important characters that contribute directly to grain yield plant^{-1}. Spikes plant^{-1}, grains spike^{-1} and 100-grain weight are the primary yield components and harvest index is one of the important physiological yield components in spring wheat. Grain yield is defined in term of these characters. Thus information and the results of the present study suggest that selection index comprising of these characters would be worthwhile for grain yield improvement in spring wheat.

Discriminant function analysis

Twenty eight discriminant functions were constructed considering eight different characters both as single and or joint in indices (Table 6). The genetic advance of grain yield plant^{-1} was 1.139 and relative efficiency was considered as 100 percent. Almost all indices have higher relative efficiency than grain yield plant^{-1} alone. Only the index made by spikelets spike^{-1} alone has lower relative efficiency than grain yield plant^{-1} alone.

Out of eight different characters included in indices the genetic advance estimated high for plant height alone that turned out the highest relative efficiency over straight selection for grain yield. The lowest genetic advance as character spikelets spike^{-1} followed by spike length. From the result it was that plant height appeared as predominating single character for increasing yield from the genotypes.

Among the combinations involving two characters, plant height + grain yield plant^{-1} showed maximum genetic advance and relative efficiency. The other combinations like harvest index + grain yield plant^{-1} also shown higher relative efficiency than other combinations. Weber (1994) obtained higher relative efficiency when selection index comprised of 100-grain yield plant^{-1}.

Considering three characters, all the indices had higher relative efficiency than grain yield plant^{-1} alone. Among the combinations plant height + grains spike^{-1} + grain yield plant^{-1} had the maximum genetic advance and relative efficiency followed by plant height + spikes plant^{-1} grain yield plant^{-1}, plant height + spike length + grain yield plant^{-1} and plant height + 100-grain weight + grain yield plant^{-1}. Siahpoosh et al. (2001) showed that grain yield, number of grains spike^{-1} and number of spikelets spike^{-1} were the best indices for increasing grain yield in wheat.

Table 6. Discriminant function analysis.

Function	Genetic advance	%RE
Variable 1	28.21	2476.73
Variable2	2.03	178.23
Variable 3	1.27	111.50
Variable 4	0.73	64.09
Variable 5	3.87	339.77
Variable 6	1.24	108.69
Variable 7	6.92	607.55
Variable 8	1.14	100.00
Variable 1+2	28.07	2464.27
Variable 2+8	1.50	131.52
Variable 5+8	4.11	360.76
Variable 6+8	3.49	307.11
Variable 7+8	8.31	729.15
Variable 1+2+8	28.74	2522.82
Variable 1+3+8	27.59	2422.56
Variable 1+5+8	29.82	2618.44
Variable 1+6+8	27.32	2398.59
Variable 1+7+8	25.05	2198.95
Variable 4+5+8	2.30	229.80
Variable 4+6+8	3.52	309.04
Variable 4+7+8	8.15	714.66
Variable 3+4+5+8	4.19	367.52
Variable 3+4+6+8	3.60	315.89
Variable 2+4+5+8	1.88	165.14
Variable 2+4+6+8	2.68	234.94
Variable 2+4+7+8	4.66	409.13
Variable 2+3+4+5+6+8	4.73	415.10
Variable 1+2+3+4+5+6+7+8	26.88	2359.96

Variable 1 = Plant height; Variable 5 = Grains spike^{-1}
Variable 2 = Spikes plant^{-1}; Variable 6 = 100-grain weight
Variable 3 = Spike length; Variable 7 = Harvest index
Variable 4 = Spikelets spike^{-1}; Variable 8 = Grain yield plant^{-1}

Considering four characters, maximum relative efficiency was obtained in combination of spikes plant^{-1} + spikelets spike^{-1} + harvest index + grain yield plant^{-1}. The other combinations had also higher relative efficiency over selection for grain yield plant^{-1} alone. Raut and Khorgade (1989) found higher relative efficiency when selection index based on spikes plant^{-1} + spikelets spike^{-1} + grains spikes^{-1} + grain yield plant^{-1}. The relative efficiency of 415.10% was obtained in the combination of number of spikes plant^{-1} + spike length + spikelets spike^{-1} + grains spike^{-1} + 100-grain weight + grain yield plant^{-1}.

Finally the selection index based on eight yield and yield contributing characters, plant height + spikes plant^{-1} + spike length + spikelets spike^{-1} + grains spike^{-1} + 100-grain weight + harvest index + grain yield plant^{-1} showed remarkably higher relative efficiency than grain yield alone.

Overall analysis of the results of the present study revealed that response in grain yield in spring wheat was achieved by selecting on plant height, spikes plant^{-1}, spike length, spikelets spike^{-1}, grains spike^{-1}, 100-grain weight and harvest index. These yield contributing characters realized remarkably higher genetic advance in comparison to straight selection for grain yield. Therefore, selection on yield contributing characters rather than only yield itself is suggested for improvement of yield in spring wheat.

Discriminant score and phenotypic rank of the genotypes

Discriminant score for each genotype of each genotype of wheat has been estimated by taking into account all eight characters viz. plant height, spikes plant^{-1}, spike length, spikelets spike^{-1}, grains spike^{-1}, 100-grain weight and harvest index and grain yield plant^{-1}. This is because as these characters possessed remarkably higher genetic advance and relative efficiency than grain yield alone.

The index score based on the eight characters for each of the genotypes were estimated and the range of the index scores was from 37.72 to 97.62 (Table 7). The higher index score was estimated for the genotype HT-11 which was followed by Kheri, Ning, Chyria-3, Protiva and Mayoor. The lowest index score was estimated for the genotype KAV-2. Lower index score was also computed for the wheat genotypes Anza and Pavon. The higher index score against the particular genotype forwarded a guide line to select the parent for using further breeding programme. Therefore, the genotypes HT-11, Kheri, Ning, Protiva and Mayoor were found better as compared to other genotypes.

Table 7. Index score and phenotypic rank value of 20 spring wheat genotypes.

Genotypes	Index score	Phenotypic rank value
Wuhan	53.51	41
HT-11	97.62	43
Barkat	53.64	36
SA-92	55.02	38
Kheri	85.90	36
Sourav	48.69	46
Sebia	53.20	34
Bulbul	53.91	42
Ananda	53.29	29
NK-5	47.46	37
KRL14	55.18	46
ChyriaS	66.53	42
Akbar	55.86	33
Gourab	52.91	47
KAV-2	37.71	38
Anza	39.52	20
Ning	67.49	38
Provita	62.01	43
Pavan	42.62	34
Mayoor	60.24	48

Correlation coefficient between index score and phenotypic rank value r = 0.297

The genotypes under study, ranked on the basis of individual score secured by each of the eight characters. The phenotypic rank ranged from 20 to 48 (Table 7) and the highest rank was estimated for the genotypes Mayoor followed by Gourav, Sourav and KRL-14. Therefore, the genotypes Sourav, Gourav, KRL-14 and Mayoor appeared as promising for utilization in further breeding programme.

A simple correlation coefficient was estimated between phenotypic rank values and index score. There was a positive relation between phenotypic rank value and index score. The correlation coefficient was 0.297. Index score is more important consideration than phenotypic rank values for selecting superior genotypes for further wheat improvement programme. It was found that the wheat genotypes HT-11, Kheri, Chyria-3, Ning, Protiva and Mayoor processed higher index score than other genotypes. Among the genotypes Mayoor, Protiva and HT-11 had higher phenotypic rank values. For above discussion it was concluded that HT-11, Ning, Protiva and Mayoor was the superior wheat genotypes among the genotypes studied and suggested that these four genotypes would be used as parents for hybridization programme for wheat improvement.

CONCLUSION

Considering yield plant^{-1} the genotype Mayoor was the best and that was followed by HT-11, Sourav, and Kav-2. Among these genotypes Mayoor also ranked high for number of grains spike^{-1} and harvest index. KAV-2 ranked high for spikes plant^{-1}, spikelets spike^{-1} grains spike^{-1} and harvest index. Sourav ranked high for spike length, spikelets spike^{-1}, 100-grain weight and harvest index. The genotype HT-11 had high mean performance for grains spike^{-1} and harvest index. The variations among the genotypes were studied through GCV and PCV. The differences between genotypic and phenotypic coefficients of variation were small for plant height, spike length, spikelets spike^{-1} and 100-grain weight indicating these characters are less affected by environment and mostly governed by genetic factors. Among the eight characters plant height, spike length, and 100-grain weight, displayed high heritability coupled with high genetic advance and spikes plant^{-1} and harvest index showed moderate heritability with high genetic advance. These characters had also high phenotypic coefficients of variation. So, selection of spring wheat genotypes based on these characters would be effective. Positive correlation found for grain yield plant^{-1} with spike length, grains spike, 100-grain weight and harvest index. Among them harvest index was significantly correlated with grain yield plant^{-1} at phenotypic level suggesting that genotypes with high partitioning efficiency gave increase in grain yield plant^{-1}. Spikes plant^{-1} and harvest index had high positive direct effects on grain yield. The phenotypic correlation of harvest index with grain yield plant^{-1} also high. Such high correlation with grain yield plant^{-1} was mainly due to the high positive direct effect of harvest index and considerable positive indirect effects via, plant height, grains spike^{-1} and 100-grain weight. The correlation coefficient of spikes plant^{-1} with grain yield plant^{-1} was low though their direct effects were high. Study of selection indices through discriminant function suggests that plant height + grains spike^{-1} + grain yield plant^{-1} had the maximum genetic advance and relative efficiency than grain yield alone. Considering both phenotypic rank value and index score the genotypes, HT-11, Ning, Protiva and Mayoor were the superior among the genotypes under studied and suggest that these four genotypes could be used as parents for hybridization programme for wheat improvement.

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