Genetic Variability and Relative Importance of Nine Phenological and Physiological Characters Studied in Spring Wheat (*Triticum aestivum* L.)

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Summary

Experiment was designed to establish a more definitive relationship of phenological and physiological traits with yield in wheat using twenty five spring wheat genotypes. Because many of these traits are interrelated, correlation coefficient, path analysis and principal component analysis were used to expose these relationships more clearly. Experiment was conducted at the Wheat Research Center, Bangladesh Agricultural Research Institute, Gazipur during the Rabi season of 2009-10. The analysis of variances showed highly significant variations among the genotypes for all the traits studied. The results revealed that moderate to high heritability along with moderate genetic advances for ground coverage, biomass, grain filling duration and grain filling rate offer chances of expected response to selection. The association of phenological traits with grain yield suggests selecting the genotypes with early maturity and relatively long grain filling duration for the development of high yielding wheat cultivars. Significant negative correlation of physiological maturity and canopy temperature with biomass, grain filling rate and grain yield revealed that early maturing genotypes having high biomass can change their physiology to suit with variable environments to attain a high grain yield. Path analysis confirmed physiological maturity, grain filling duration and grain filling rate as major contributing characters for improvement of wheat grain yield through their direct effects. The rest of the traits contributed indirectly either via grain filling duration or grain filling rate. The latent vectors obtained from principal component analysis also identified grain filling attributes, biomass and physiological maturity as major contributors to the differentiation of studied genotypes. Screening of wheat genotypes on the basis of these traits may be more fruitful and may have long lasting effect to supplement empirical breeding approach.

Key words

phenological and physiological traits, variability, path coefficient, principal component analysis, spring wheat

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Introduction

Wheat (*Triticum aestivum* L.) is one of the major food crops of majority populace of Bangladesh. But its per acre yield is very low in comparison with other countries of the world. Therefore, a big portion of national economy has to be spent on the import of wheat to cope with the ever increasing food and feed needs of the country due to population multiplication in arithmetic fashion.

To improve yield of wheat in different environments, it is necessary to identify selection criteria that can identify high-yielding genotypes in variable environments. A better understanding of relatively simple crop-physiological attributes that determine yield in a wide range of conditions may be instrumental for assisting future breeding (Slafer and Araus, 2007). Conventional breeding strategies are based on empirical selection for yield that is far from being optimal without understanding of a physiological and molecular basis that may help target the key traits that limit yield (Cattivelli et al., 2008). Thus, screening and selection of genotypes on the basis of physiological traits is indispensable in addition to agronomic attributes (Kirigwi et al., 2007; Venuprasad et al., 2007).

Genetic variability is required to achieve genetic gains in a breeding program. In plant breeding program, direct selection for yield as such could be misleading. A successful selection depends upon the information on the genetic variability and association of morpho-physiological traits with grain yield. Correlation studies along with path analysis provide a better understanding of the association of different characters with grain yield. On the other hand, principal component analysis (PCA) has been found to give more specific information on each of the component characters (Salehi et al., 2013). Hence, the relationships between yield and some phenological and physiological characters of spring wheat cultivars were investigated in this study. Furthermore, the relationships were further analyzed using path coefficient and principal component analysis (PCA).

The objective of this study was to evaluate the phenological and physiological variation of twenty five spring wheat genotypes used in genetic improvement program. Here, the author also wished to evaluate the degree of genetic relationship among yield and different phenological and physiological traits, so as to predict the responses of yield on these traits.

Materials and methods

The present study was conducted at the experimental field of the Wheat Research Center, Bangladesh Agricultural Research Institute, Gazipur during the cropping season 2009-10. The experimental site was situated between 23°46'N latitude and 90°23'E longitude with elevation of 8 m above sea level. The climate of this place is characterized by wet summer and dry winter. Twenty four spring wheat genotypes along with a popular variety "Shatabdi" were planted in randomized complete block design with three replications. Seeds of each genotype were sown in unit plot size of 2.5 m long with six rows in lines 20 cm apart on the 24th November, 2009 as irrigated timely sown condition. Standard agronomic practices were adopted for the experiments. At maturity, the central 0.8 m^2 (1m x 4 rows) areas of each of the plot were harvested for recording grain yield (g m^{-2}) and biomass (g m^{-2}). Data were collected on the following phenological characters *viz.*, days to anthesis, flag leaf senescence (day), grain filling duration (day), physiological maturity (day) and physiological characters *viz.*, canopy temperature (^{0}C), chlorophyll content (SPAD unit), ground coverage (scale) and grain filling rate (g m^{-2} d^{-1}). A hand held infra-red thermometer was used to measure canopy temperature for individual genotype. The canopy temperature was measured two times at three days interval at vegetative stage during noon period under bright sun and less wind and the average of two measurements was used for statistical analysis. Chlorophyll content of leaves was measured in five fully expended sunlit flag leaves *in vivo* by a Minolta spad meter at anthesis and expressed in SPAD unit. Ground coverage was recorded visually at 35 days after sowing and expressed on 0-10 scale.

The data collected on different phenological and physiological traits were subjected to different biometrical analyses to determine variances, genotypic and phenotypic coefficient of variations, heritability (broad sense) and genetic advances. Analysis of variance was done for different characters and the genotypic and phenotypic coefficients of variations (Burton, 1952), heritability in broad sense (h^2b) and the expected genetic advance (GA) for different characters under selection (Johnson et al., 1955) were estimated. Genotypic and phenotypic correlations were determined according to the method developed by Kwon and Torrie (1964). Partitioning the correlation coefficient into direct and indirect effects on the traits was done through the path analysis (Dewey and Lu, 1959). The latent vector obtained from principal component analysis (PCA) was done by using GENSTAT 5 Release 4.1 (PC/Windos NT) soft ware program (Digby et al., 1989). Statistical analysis of the data was performed with MSTAT-C (Michigan State University, 1991) and Excel software (Microsoft, 2007) was used to draw the figure.

Results and discussion

The analyses of variance (Table 1) showed highly significant differences ($P<0.01$) among the genotypes for yield and all phenological and physiological characters studied in spring wheat. Variation among the genotypes and their response to selection for phenological and physiological characters revealed that the genotypes showed usual minimum variation for phenological characters. It means that although the genotypes were significantly different, there was narrow range of genetic variation among them. Physiological characters and grain yield showed moderate variations among the genotypes except canopy temperature and chlorophyll content of flag leaf. The characters ground coverage, biomass production, grain filling rate and grain yield showed variations of more than 10% relative to the mean among the genotypes.

Estimates of heritability for different characters ranged between 43 to 83% and the characters days to anthesis, flag leaf senescence, physiological maturity, grain filling duration and biomass exhibited high heritability (>60%), whereas ground coverage, canopy temperature, chlorophyll content of flag leaf, grain filling rate and grain yield showed moderate heritability (40-60%). Grain filling duration showed the highest heritability (83.13%) among the traits. Mohammadi et al. (2004) observed that grain filling duration had the highest heritability among all the traits studied in wheat. The characters grain

Table 1. Mean squares for genotypes, coefficient of variation, components of genotypic and phenotypic variation, heritability and genetic advance of 25 spring wheat genotypes for grain yield and phenological and physiological characters

Character	MS	CV (%)	Range	GCV	PCV	h^2b	GA (% of mean)
Anthesis	21.68**	2.38	62-76	4.40	5.00	77.46	6.82
FLS	7.01**	1.18	98-104	1.65	2.05	66.38	2.37
PM	8.91**	1.24	102.5-111.0	1.75	2.14	66.74	2.52
GFD	14.41**	3.05	32-42	6.76	7.41	83.13	10.85
GC_{35}	1.01**	9.34	4.0-5.7	8.73	11.82	54.55	11.35
CT_{vg}	2.90**	4.38	19.35-23.62	4.72	6.44	53.79	6.10
CHL_a	10.94*	4.95	40.45-50.50	3.88	5.92	43.08	4.49
Biomass	29064.67**	7.0	937.5-1452.5	9.12	11.50	62.90	12.73
GFR	4.44**	10.92	11.03-17.18	9.14	12.45	53.90	11.82
GY	6479.46**	11.97	415.00-632.50	9.00	12.79	49.59	11.17

*and ** indicates significant at 5% and 1% levels of probability, respectively; MS, Mean squares for genotypes; CV, Coefficient of variation; GCV, Genptypic coefficient of variation; PCV, Phenotypic coefficient of variation; h^2b, Heritability in broad sense; GA, Genetic advance; FLS, Flag leaf senescence (day); PM, Physiological maturity (day); GFD, Grain filling duration (day); GC_{35}, Ground coverage at 35 days (scale); CTvg, Canopy temperature at vegetative stage (°C); CHLa, Chlorophyll content at anthesis (SPAD); Biomass, Biomass m^{-2} (g); GFR, Grain filling rate (g m^{-2} d^{-1}); GY, Grain yield (g)

Table 2. Genotypic (r_g) and phenotypic (r_p) correlation coefficients among the yield and its phenological and physiological components in wheat

Character	r	FLS	PM	GFD	GC_{35}	CT_{vg}	CHL_a	Biomass	GFR	GY
Anthesis	r_g	0.699**	0.559**	-0.791**	0.072	0.481*	-0.111	-0.592**	0.026	-0.591**
	r_p	0.624**	0.600**	-0.752**	-0.127	0.361	-0.128	-0.484*	-0.015	-0.468*
FLS	r_g		0.919**	-0.162	0.204	0.482*	0.016	-0.513**	-0.453*	-0.612**
	r_p		0.806**	-0.114	-0.021	0.337	0.064	-0.275	-0.198	-0.271
PM	r_g			0.066	0.108	0.694**	0.030	-0.425*	-0.529**	-0.506**
	r_p			0.077	-0.152	0.346	0.019	-0.235	-0.354	-0.311
GFD	r_g				-0.007	-0.066	0.155	0.398	-0.422*	0.337
	r_p				0.033	-0.165	0.175	0.410*	-0.272	0.327
GC_{35}	r_g					0.105	0.195	0.140	0.168	0.186
	r_p					0.094	0.108	0.063	0.106	0.133
CT_{vg}	r_g						-0.274	-0.554**	-0.557**	-0.626**
	r_p						-0.186	-0.472*	-0.341	-0.429*
CHL_a	r_g							0.349	0.146	0.278
	r_p							0.261	0.218	0.305
Biomass	r_g								0.688**	0.998**
	r_p								0.622**	0.866**
GFR	r_g									0.708**
	r_p									0.817**

* and ** indicate significant at 5% and 1% levels of probability, respectively; FLS, Flag leaf senescence (day); PM, Physiological maturity (day); GFD, Grain filling duration (day); GC_{35}, Ground coverage at 35 days (scale); CTvg, Canopy temperature at vegetative stage (°C); CHLa, Chlorophyll content at anthesis (SPAD); Biomass, Bio mass m^{-2} (g); GFR, Grain filling rate (g m^{-2} d^{-1}); GY, Grain yield (g)

filling duration, ground coverage, biomass, grain filling rate and grain yield exhibited more than 10% of genetic advance (% of mean) and it was the highest in biomass. The results revealed that moderate to high heritability along with moderate genetic advances for grain filling duration, ground coverage, biomass, grain filling rate and grain yield offer chances of expected response to selection. Several investigators reported moderate to high heritability estimates and genetic advance (in % of mean) for biomass (Chaturvedi and Gupta, 1995; Sharma et al., 1995; Shoran, 1995; Chandra et al., 2004; Rahman, 2009a) and grain filling rate (Barma, 2005; Rahman, 2009a) in wheat.

Correlation analysis helps to determine effective traits for indirect selection of superior genotypes. Therefore, determination of correlation coefficients between the characters has a considerable importance in selection of breeding materials. The genotypic and phenotypic correlation coefficients among grain yield and phenological and physiological characters are presented in the Table 2. The results revealed that anthesis period had significant positive correlation both at genotypic and phenotypic levels with flag leaf senescence (0.699** and 0.624**, respectively) and physiological maturity (0.559** and 0.600**, respectively) indicated that longer vegetative period would delay leaf senescence and maturity. But it showed significant negative correlation both at genotypic and phenotypic levels with grain filling duration (-0.791** and -0.752**, respectively), biomass (-0.592** and -0.484*, respectively) and grain yield (-0.591** and -0.468*, respectively). Barma et al. (1990) and Amin et al. (1992) reported significant negative correlation between days to anthesis and grain filling duration, suggesting that the longer the vegetative period the shorter the grain filling period would

Table 3. Path analysis of phenological and physiological characters on yield of wheat

Character		Effect via									Total genotypic correlation (r_g) with grain yield
		Anthesis	FLS	PM	GFD	GC_{35}	CT_{vg}	CHL_a	Biomass	GFR	
Anthesis	P	**-0.121**	-0.495	0.474	-0.57	0.007	-0.146	0.001	0.228	0.031	-0.591**
	%	**5.83**	23.87	22.86	27.49	0.33	7.04	0.04	10.99	1.49	
FLS	P	-0.085	**-0.708**	0.779	-0.116	0.021	-0.146	-0.0001	0.198	-0.554	-0.612**
	%	3.26	**27.16**	29.88	4.45	0.81	5.60	0.00	7.59	21.25	
PM	P	-0.068	-0.651	**0.848**	0.047	0.011	-0.21	0.0002	0.164	-0.647	-0.506**
	%	2.57	24.60	**32.05**	1.78	0.42	7.94	0.01	6.20	24.45	
GFD	P	0.096	0.114	0.055	**0.721**	-0.0007	0.02	-0.001	-0.153	-0.516	0.337
	%	5.73	6.80	3.28	**43.00**	0.04	1.19	0.06	9.13	30.77	
GC_{35}	P	-0.008	-0.144	0.091	-0.005	**0.107**	-0.004	-0.001	-0.054	0.205	0.186
	%	1.29	23.26	14.70	0.81	**17.29**	0.65	0.16	8.72	33.12	
CT_{vg}	P	-0.058	-0.341	0.588	-0.047	0.001	**-0.303**	0.002	0.213	-0.681	-0.626**
	%	2.60	15.26	26.32	2.10	0.04	**13.56**	0.09	9.53	30.48	
CHL_a	P	0.013	-0.011	0.025	0.111	0.021	0.083	**-0.009**	-0.134	0.178	0.278
	%	2.22	1.88	4.27	18.97	3.59	14.19	**1.54**	22.91	30.43	
Biomass	P	0.072	0.363	-0.36	0.287	0.015	0.168	-0.003	**-0.386**	0.841	0.998**
	%	2.89	14.55	14.43	11.50	0.60	6.73	0.12	**15.47**	33.71	
GFR	P	-0.003	0.321	-0.448	-0.304	0.018	0.169	-0.001	-0.265	**1.223**	0.708**
	%	0.11	11.66	16.28	11.05	0.65	6.14	0.04	9.63	**44.44**	

Residual effect = √-0.008; Bold figures in diagonal line indicates direct effects; P, Path coefficient; %. Percentage direct and indirect effects; ** indicate significant at 1% level of probability

be. Furthermore, grain filling duration is mainly associated with yield by anthesis period and grain filling rate (Rahman, 2009b). Hence, early anthesis significantly increases grain filling duration as well as grain yield. Burio et al. (2004) also found negative correlation of days to flowering with grain yield that supports the present findings.

The character days to flag leaf senescence exhibited strong significant positive correlation (0.919** and 0.806** at genotypic and phenotypic levels, respectively) with physiological maturity. In contrast, both flag leaf senescence and physiological maturity showed negative correlation significant only at genotypic level with biomass (-0.513** and -0.425*, respectively), grain filling rate (-0.453* and -0.529**, respectively) and grain yield (-0.612** and -0.506**, respectively). It suggests that relatively late maturing genotypes filled grain at a slow rate. Therefore, early maturing genotypes having high grain filling rate should have increased yield. Although ground coverage and chlorophyll content at anthesis showed relatively low correlation with the rest of the traits, their relationship with biomass, grain filling rate and grain yield indicated their effects on overall net canopy photosynthesis. Reynolds et al. (2000) found positive correlation of chlorophyll content with biomass under heat stress condition in wheat. Canopy temperature at vegetative stage was found significant and positively correlated with anthesis, flag leaf senescence and physiological maturity only at genotypic level indicating that delayed maturity would increase canopy temperature. On the other hand, both canopy temperature and physiological maturity were significantly and negatively correlated with grain yield, biomass and grain filling rate. This revealed that early maturing genotypes having high biomass can keep their canopy cooler at the post anthesis stage. Thus, they changed their physiology to suit with variable environments to attain a high grain yield. The correlations of biomass with grain filling rate and grain yield suggested that grain yield can be increased by increasing biomass as high biomass will help accumulating more photosynthates in the developing grain. Many investigators also observed strong and positive association between biomass and grain yield (Sharma, 1993; Chaturvedi and Gupta, 1995; Reynolds et al., 1994 and 1997; Rahman et al., 1997; Singh et al., 1997; Subhani et al., 2000; Barma, 2005; Tripathi et al., 2011). Likewise, the association of grain filling rate with grain yield revealed that faster grain filling rate increased the grain yield significantly, which is in concurrence with several cited studies (Rahman et al., 1997; Barma, 2005; Rahman, 2009a).

The correlation coefficient measures the mutual association between a pair of variables. When more than two variables are involved, the correlations per se do not give the complete information of their relationships. Therefore, partitioning the correlation coefficient into direct and indirect effects on the traits was done through the path analysis technique. The path coefficient analysis is particularly useful for the study of the cause and the effect relationship, because it simultaneously considers several variables in data set to obtain the coefficients (Fakorede and Opeke, 1985). Path analysis at genotypic level for phenological and physiological characters (Table 3) confirmed the importance of interaction between these traits and grain yield of wheat. Among the traits, grain filling duration and grain filling rate had high contribution through direct effects (43.00% and 44.44%, respectively) to grain yield whereas others contributed indirectly either via grain filling duration or grain filling rate. The indirect effect of grain filling duration on yield is solely expressed via grain filling rate. However, the indirect effect of grain filling rate on yield is expressed mainly through physiological maturity and grain filling duration in negative direction and via flag leaf senescence in positive direction. This suggests that grain yield of a genotype would be increased if it had filled grain at higher rate in a shorter time. Although physiological maturity had positive direct effects (32.05%) on grain yield, it

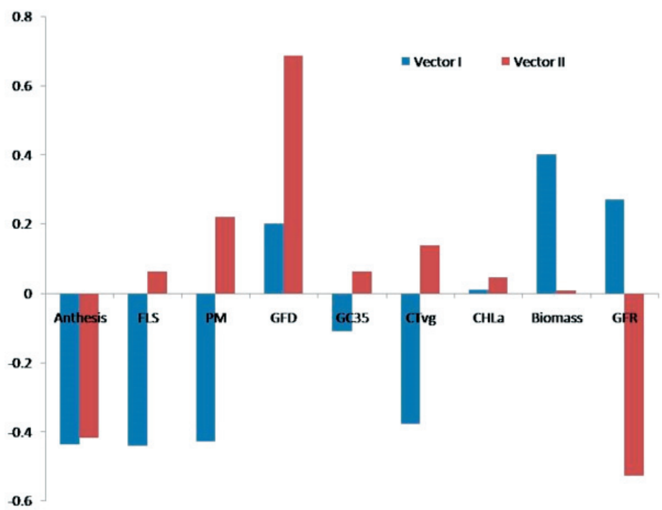

Figure 1. Latent vectors for nine phenological and physiological characters of 25 spring wheat genotypes

contributed considerable amount of negative indirect effects via flag leaf senescence and grain filling rate that minimized the correlation co-efficient between physiological maturity and grain yield that becomes significantly negative. Tripathi et al. (2011) described positive direct effect of days to maturity as one of the major contributor to seed yield of bread wheat. Moreover, anthesis days showed the highest negative indirect effects (27.49%) on yield via grain filling duration followed by flag leaf senescence (23.87%). It means that early anthesis would increase grain filling duration and ultimately affect the yield.

Ground coverage and canopy temperature possess the highest indirect effect via grain filling rate (33.12% and 30.48%, respectively). Chlorophyll content was correlated with yield by its positive indirect effect via grain filling rate and grain filling duration. Talebi et al. (2010) reported negligible direct effects of canopy temperature and chlorophyll content, but they find the highest positive indirect effect via spike yield for both those traits studied in irrigated durum wheat. This result is partially consistent with the present study. A higher biomass production, particularly during grain filling period, would have an advantage because the translocation of assimilates from the vegetative parts of a plant to seeds contributes significantly to the yield (Pheloung and Siddique, 1991). In this study, though direct effect of biomass was observed to be low in magnitude, it was correlated with grain yield mainly by its positive indirect effect (33.71%) via grain filling rate. There were also indirect effects of biomass on yield via flag leaf senescence, physiological maturity and grain filling duration. Therefore, other phenological and physiological traits have also established the importance of biomass for the increase of yield that made a highly significant correlation (0.998**) with grain yield.

Principal component analysis was performed to determine the relationship between studied phenological and physiological traits. It reflects the importance of the largest contributor to the total variation at each axis of differentiation (Sharma, 1998). The first two axes of the PCA explained 57.29% (38.16 and 19.13%, respectively) of the total variability found. Figure 1 showed the latent vectors obtained from principal component analysis. From the positive absolute value of the two vectors, it revealed that grain filling duration and biomass production had the greatest contribution to the differentiation of studied genotypes. The positive absolute values of vector I and negative absolute values of vector II for grain filling rate also indicated the responsibility of primary differentiation, while on the contrary, physiological maturity is responsible for secondary differentiation. In the present study, the genotypes differentiated because of relatively high contribution of few characters rather than small contribution from each character. Hailegiorgis et al. (2011) and Salehi et al. (2013) identified grain filling duration, grain filling rate and biological yield as major contributing characters for genetic improvement of wheat grain yield. The results obtained from principal component analysis also confirmed those from the correlation study.

Conclusion

Grain yield in wheat could be improved through indirect selection of grain filling duration, biomass and grain filling rate. Ground coverage also offers chances of expected response to selection. The association of grain yield with physiological maturity, biomass, grain filling duration and grain filling rate suggests the use of these traits as criteria during selection of high yielding wheat cultivars. Several authors had also given emphasis on the grain filling and biomass for increases in genetic yield potential in wheat (Reynolds et al., 2007), durum wheat (Alvaro et al., 2008; Boveiri et al., 2014) and maize (Golezani and Tajbakhsh, 2012). Screening of wheat genotypes on the basis of these traits may be fruitful and may have long lasting effect as a consequence of breeding and evolution of new genotypes.

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