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Full Length Research Paper

Genotypic and phenotypic interrelationships among yield and yield components in Egyptian bread wheat genotypes

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Two field experiments were conducted in 2008/2009 and 2009/2010 growing seasons at the experimental farm of the Faculty of Agriculture, Cairo University, Giza, Egypt. Ten Egyptian bread wheat genotypes were planted in a randomized complete block design with three replications and evaluated for eight characters. The aim was to study the phenotypic and genotypic correlations and genotypic path analysis for grain yield and yield components. Highly significant differences were observed among genotypes for all the eight studied traits. Statistical analysis showed that genotypic correlation coefficients were higher than the corresponding phenotypic correlation coefficients in most of the traits. The results revealed positive association in between number of tillers plant^{-1}, number of spikelets spike^{-1}, spike length, number of grains spike^{-1} and 1000 grain weight with grain yield plant^{-1} at both genotypic and phenotypic levels. However, days to 50% heading and plant height contributed negatively towards grain yield at both levels. Path analysis showed that maximum positive direct effect on grain yield plant^{-1} was contributed mostly by number of grains spike^{-1}, followed by number of tillers plant^{-1} and 1000-grain weights were the major contributors towards grain yield. Since these three characters had high correlation and also high direct effect thus direct selection for these three characters should be of a major concern for a plant breeder. It was, therefore, suggested that number of grains spike^{-1}, number of tillers plant^{-1} and 1000-grain weight should be given emphasis for future wheat yield improvement programs.

Key words: Wheat, variability, phenotypic and genotypic correlation, path coefficients, yield, yield components.

INTRODUCTION

Bread wheat (*Triticum aestivum* L.) is one of the most important crops in Egypt and cultivated area is about 1.2 million hectares (2.85 milion feddan). The local production is about 8 million tons however; it covers less than 60% of local consumption (FAO, 2009). An important objective of the Egyptian Government is consequently to reduce the dependence on imported wheat by enhancing average grain yield and production. Increasing wheat productivity is a national target in Egypt to fill the gap between wheat consumption and production. Yield of wheat can be increased by two ways, that is, either by bringing more land area under cultivation or by increasing its yield per unit area. Currently, it is not possible to increase area under wheat due to other competitive winter crops and water shortage. The only alternative is to obtain higher yield per unit area by growing new high yielding varieties and better crop management. To develop elite genotypes, knowledge on inter relationship among yield and its component characters, direct and indirect contribution towards yield are important. Before initiating any breeding program, it is essential to obtain information regarding the inter-relationship between various yield attributing characters with grain yield. Grain yield is a complex trait and is highly influenced by many genetic factors and environmental fluctuations. Selection for grain yield can only be effective if desired genetic variability is present in

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the genetic stock. In a plant breeding programme, direct selection for yield as such could be misleading. A successful selection depends upon the information on the genetic variability and association of morpho-agronomic traits with grain yield. Knowledge of association between yield and yield components will serve to make simultaneous selection for more characters.

Genotypic and phenotypic correlations are important in determining the degree to which various yield contributing characters are associated. The increase in yield can be possible if the existing genetic resources and information are properly utilized. Knowledge of correlation between different traits is necessary in plant breeding. If two traits are positively correlated, then one trait can be improved indirectly by improving the other trait. Correlation coefficients are useful if indirect selection of a secondary trait is to be used for improving the primary trait of interest. Correlation studies along with path analysis provide a better understanding of the association of different characters with grain yield. Path coefficient analysis separates the direct effects from the indirect effects through other related characters by partitioning the correlation coefficient (Dixit and Dubey, 1984). Keeping previous facts in view, the present study was conducted to derive information on phenotypic, genotypic correlation, direct and indirect effects of yield components in breed wheat yield of different genotypes. This may help wheat breeders in reshaping and improving future wheat breeding strategies.

MATERIALS AND METHODS

Plant materials

This investigation was carried out at the experimental farm of the Faculty of Agriculture, Giza, Cairo University, Egypt, (30° 02'N Latitude and 31° 13' E Longitudes, Altitude 22.50 m), during the two successive growing seasons, 2008 to 2009 and 2009 to 2010. The experimental material comprised of 10 Egyptian breed wheat genotypes viz., Sids 1, Sids 4, Sids 12, Gemmiza 7, Gemmiza 9, Gimmiza 10, Sakha 8, Sakha 69, Sakha 93 and Giza 168. They were used as treatments and evaluated in the study. These varieties selected from germplasm bank of Wheat Research Program, Agricultural Research Center, Egypt represented a wide genetic background.

Experimental design and cultivation practices

The experiments were designed in a randomized complete block design (RCBD) with three replications. Each replicate consisted of ten plots with one commercial cultivar. Seeds were hand drilled and each cultivar was sown in six rows. Each row was of 3.0 m long, with a row to row distance of 0.20 m while distance between plants was 0.02 m. The experimental plot area was 3.6 m^2. All experimental plots were subjected to uniform agronomic practices. Cultivars were sown at the seed rate of 500 seed m^{-2} and sowing dates were 22nd and 23rd of November in the two successive seasons, respectively. The crop was subjected to recommended package of agronomic and plant protection practices to obtain a healthy crop. Calcium super phosphate (15.5% P_2O_5) was applied during soil preparation at the rate of 37 kg ha^{-1} P_2O_5. Six irrigations were added during growth by flooding system. Total nitrogen fertilization was applied at a rate of 140 kg ha^{-1} N as urea (46.5%) in two equal doses, before the first and second irrigations. All the recommended cultural practices were followed up to harvest.

Data collection

Data were recorded on the days to 50% heading by visual observations. Data on yield and yield components were recorded on plants randomly selected from the two middle rows. Observations were recorded on ten randomly selected plants in each variety per replication for the following traits viz., plant height (cm), number of tillers $plant^{-1}$, spike length (cm), number of spikelets $spike^{-1}$, number of grains $spike^{-1}$, 1000-grain weight (g) and grain yield $plant^{-1}$ (g).

Statistical analysis

The analysis of variance (ANOVA) and covariance (ANCOVA) for randomized complete block with combined data from the two seasons were performed for each variant, following the procedure of Steel et al. (1997). Genotypic and phenotypic variances and co-variances were computed from ANOVA and ANCOVA and used to estimate genotypic and phenotypic correlations among traits. Phenotypic and genotypic correlation coefficients were calculated as outlined by Kwon and Torrie (1964) from the corresponding variance and covariance components as follows:

$$r_G = \frac{COV_G\,(x_1, x_2)}{\sqrt{V_{G.}\,(x_1).V_G\,(x_2)}}$$

Where, COV_G (x_1, x_2) =Genetic covariance among x_1 and x_2; V_G (x_1) and V_G (x_2) = Genetic variance for trait x_1 and x_2, respectively. Genotypic correlation was tested for its statistical significance using the method of Reeve (1955) and Robertson (1959). The genotypic correlation was considered significant if its absolute value exceeded the twice of its respective standard value.

$$r_p = \frac{COV_p\,(x_1, x_2)}{\sqrt{V_{p.}(x_1).V_p(x_2)}}$$

Where, COV_p (x_1, x_2) =Phenotypic covariance among trait x_1 and x_2; V_p (x_1) and V_p (x_2) = Phenotypic variance for trait x_1 and x_2, respectively. Statistical significance of phenotypic correlation coefficients was determined by using “t” test as described by Steel et al. (1997). Path coefficient analysis was performed according to the method of Dewey and Lu (1959) by solving simultaneous equations using genotypic correlations. Grain yield $plant^{-1}$ was kept as resultant variable and other characters as causal variables. For this purpose computer software MSTAT-C (version 2.10) was used.

RESULTS AND DISCUSSION

Mean performance and variability

The development of an effective plant breeding program and the efficiency of selection largely depends upon the

Table 1. Mean squares, standard error of means, mean and range for eight quantitative characters of ten wheat varieties.

Character	Mean squares	Standard error per mean	Mean	Range
Days to (50%) heading	26.57**	1.82	85.6	80.1-95.44
Plant height (cm)	453.54**	2.94	92.54	70.6-122.3
No of tillers plant^{-1}	25.47**	1.66	9.55	5.89-20.36
Spike length (cm)	9.74**	0.64	10.14	8.65-14.22
No of spikelets spike^{-1}	25.78**	0.91	17.54	15.35-25.67
No of grains spike^{-1}	398.67**	4.26	45.32	33.56-71.27
1000-grain weight (g)	88.99**	0.36	45.57	35.27-58.42
Grain yield plant^{-1} (g)	130.54**	2.66	16.42	10.22-39.25

** = Highly significant at P=0.01.

magnitude of genetic variability existed in plant material under study, because it is pre-requisite for finding nature and extent of association among various yield and yield components. Therefore analysis of variance was applied in order to test the significance of differences. Results of mean squares from the combined analysis of variance (Table 1) showed highly significant differences ($P < 0.01$) among all the cultivars in terms of all characters measured; thus indicating that there is variability between the cultivars studied. This result implied that this population of wheat cultivars would respond positively to selection. Based on a two-year data, all the characteristics examined showed a wide range of variation in days to 50% heading (80.10 to 95.44 days), plant height (70.60 to 122.3 cm), number of tillers plant^{-1} (5.89 to 20.36), spike length (8.65 to 14.22 cm), number of spikelets spike^{-1}(15.35 to 25.67), number of grains spike^{-1} (33.56 to 71.27), 1000-grain weight (35.27 to 58.42 g) and grain yield plant^{-1} (10.22 to 39.25 g) (Table 1). Such considerable range of variations provided a good opportunity for yield improvement.

Genotypic and phenotypic correlations

Genotypic and phenotypic correlations for all possible combinations for traits under study are presented in Table 2. A positive value of r shows that the changes of two variables are in the same direction, that is, high values of one variable are associated with high values of other and vice versa. In general the magnitude of genotypic correlations (r_g) was higher than those of phenotypic correlations (r_p). This revealed that association among these characters was under genetic control and indicating the preponderance of genetic variance in expression of characters. It might be due to depressing effect of environment on character association as reported earlier for wheat crop (Ahmad et al., 1978; Parodha and Joshi, 1970). When value of "r_p" was greater than "r_g", it showed that apparent association of two traits was not only due to genes but also due to favorable influence of environment. By contrast, if value of *r* was zero or insignificant (Table 2), this showed that these two traits were independent.

Days to heading

Days to heading showed negative association with grain yield plant^{-1} at both phenotypic and genotypic levels (r_p = - 0.095, r_g = - 0.177). However, the associations were insignificant. Negative correlation indicated their inverse relationship with each other. Mondal et al. (1997), Narwal et al. (1999), Ismail (2001) and Khokhar et al. (2010) found similar results in their studies.

Plant height

The correlation between plant height and grain yield plant^{-1} was negative and highly significant at both phenotypic and genotypic levels (r_p = -0.585**, r_g = -0.645**) which indicates that selection of short stature genotypes may be effective for better grain yield. It seems logical to select for short stature genotypes for lodging resistance coupled with high yield. Similar results have been found by Saeed (1995), Khan et al. (2003), Iqbal et al. (2007) and Khokhar et al. (2010). The negative association of plant height with number of grains spike^{-1} (Table 2) is due to the fact that an increase in plant height leads to an increase in biological yield, thereby decreasing the number of grains spike^{-1}.

Number of tillers per plant

The correlation between number of tillers plant^{-1} and grain yield per plant was positive and highly significant at both phenotypic and genotypic levels (r_p = 0.665**, r_g = 0.703**). Number of tillers plant^{-1} was positively and highly significantly associated with spike length, number of grains spike^{-1} and 1000-grain weight at genotypic level. Also, results revealed that significant positive correlations among the traits were found on phenotypic level.

Table 2. Upper diagonal estimates of phenotypic correlation (r_p) and lower diagonal genotypic correlation (r_g) coefficients between grain yield plant^{-1} and its seven contributing characters in breed wheat.

Phenotypic correlation (rp) / Genotypic correlation (rg)	Days to (50%) heading	Plant height (cm)	No. of tillers plant^{-1}	Spike length (cm)	No of spikelets spike^{-1}	No of grains spike^{-1}	1000-grain weight (g)	Grain yield plant^{-1} (g)
Days to (50%) heading	1	0.187^{ns}	0.054^{ns}	0.314*	-0.084^{ns}	0.221*	-0.135^{ns}	-0.095^{ns}
Plant height (cm)	0.353*	1	-0.241*	-0.542**	0.105^{ns}	-0.432**	-0.106^{ns}	-0.585**
No of tillers plant^{-1}	0.088^{ns}	-0.336*	1	0.279*	0.183^{ns}	0.293*	0.288*	0.665**
Spike length (cm)	0.385*	-0.181^{ns}	0.546**	1	0.235*	0.355*	0.412**	0.254*
No of spikelets spike^{-1}	-0.134^{ns}	0.134^{ns}	0.275*	0.292*	1	0.733**	-0.177^{ns}	0.548**
No of grains spike^{-1}	0.274*	-0.558**	0.478**	0.411*	0.844**	1	0.223*	0.612**
1000-grain weight (g)	-0.149^{ns}	-0.130^{ns}	0.614**	0.695**	-0.141^{ns}	0.321*	1	0.114^{ns}
Grain yield plant^{-1} (g)	-0.177^{ns}	-0.645**	0.703**	0.319*	0.626**	0.704**	0.138^{ns}	1

** = Highly Significant at *P*=0.01, * = Significant at *P*=0.05, ns = Not significant at *P*=0.05.

Chowdhry et al. (2000) reported similar results. This finding indicated that number of tillers plant^{-1} may be an effective trait to select higher yielding genotypes.

Spike length

Spike length was in positive relationship at both phenotypic and genotypic levels with grain yield plant^{-1} (r_p = 0.319*, r_g = 0.254*). Also, it was positively correlated with number of grains spike^{-1} at both phenotypic and genotypic levels (r_p = 0.355*, r_g = 0.411*). Singh et al. (2001) reported that the spike length had positive and highly significant correlation with grain yield of main spike. These results are supported by the findings of earlier researchers like Shah et al. (1988) and Akram et al. (2008). A positive and significant correlation was observed between spike length and number of spikelets spike^{-1}. It means that with the increase in spike length there was a significant increase in number of spikelets spike^{-1} as discussed by Adnan et al. (1994) and Ul-haq et al. (2010). There was a positive and significant correlation between spike length and number of grains spike^{-1}. Similar with the findings of Ansari et al. (1997) and Ul-haq et al. (2010).

Number of spikelets spike^{-1}

Number of spikelets spike^{-1} was in positive relationship and highly significant at both phenotypic and genotypic levels with grain yield plant^{-1} (r_p = 0.548**, r_g = 0.626**). A highly significant and positive correlation was observed between numbers of spikelets spike^{-1} and numbers of grains spike^{-1} i n accordance with the findings of Ahmad and Chaudhry (1987), Mohammad et al. (2002) and Kashif and Khaliq (2004). On the contrary, Khokhar et al. (2010) observed number of spikelets spike^{-1} as significantly and negatively correlated with grain yield. The number of spikelets spike^{-1} showed positive and significant correlation with number of tillers plant^{-1} and spike length at both the phenotypic and the genotypic levels. Chowdhry et al. (2000) and Khan and Dar (2010) reported similar results.

Number of grains spike^{-1}

It had positive and highly significant association with grain yield plant^{-1} at both phenotypic and genotypic levels (r_p = 0.612**, r_g = 0.704). Similarly it had significant positive relationship with 1000-grain weight but with negligible effects. The perusal of both the correlation coefficient results suggested that number of grains spike^{-1} should be given prime importance regarding its contribution to yield. These results suggest that selections should be based on number of grains spike^{-1} for developing new wheat varieties. These results are substantiated with those of Alam et al. (1992), Singh et al. (1999), Singh and Singh (2001), Lad et al. (2003), Aycecik and Yildirim (2006) and Inamullah et al. (2006).

Table 3. Genotypic path coefficient analysis of seven characters on grain yield plant^{-1} in wheat over the two years.

Trait	Days to (50%) heading	Plant height (cm)	No of tillers plant^{-1}	Spike length (cm)	No of spikelets spike^{-1}	No of grains spike^{-1}	1000-grain weight (g)	Grain yield plant^{-1} (rg)
Days to (50%) heading	(- 0.545)	-0.125	-0.107	0.408	0.054	0.208	-0.073	-0.180
Plant height (cm)	0.135	(-0.486)	0.278	-0.172	0.023	-0.488	0.065	-0.645**
No of tillers plant^{-1}	-0.092	-0.067	(0.688)	-0.045	-0.122	0.368	-0.027	0.703**
Spike length (cm)	-0.067	-0.047	0.271	(-0.074**)**	-0.054	0.384	-0.094	0.319*
No of spikelets spike^{-1}	-0.096	-0.131	0.413	-0.084	(-0.139)	0.715	-0.052	0.626**
No of grains spike^{-1}	-0.030	-0.156	0.340	-0.034	-0.174	(0.814)	-0.056	0.704**
1000-grain weight (g)	-0.177	-0.019	-0.028	0.276	-0.015	-0.214	(0.316)	0.139

Italic figures denotes direct effects while regular figures denotes indirect effects; Residual effect =0.14.

Thousand grain weight

1000-grain weight showed positive and insignificant association with grain yield plant^{-1} at both phenotypic and genotypic levels (r_p = 0.114, r_g = 0.138). This result is in agreement with the results of Mondal et al. (1997), Dokuyucu and Akaya (1999), Mondal and Khajuria (2001), Sarkar et al. (2002) and Khaliq et al. (2004). 1000-grain weight was also negatively but insignificantly correlated at both genotypic and phenotypic levels with plant height and days to heading. Similar results have been found by Shahid et al. (2002) and Saleem et al. (2006), found that 1000-grain weight was negatively and insignificantly correlated at genotypic and phenotypic levels with plant height. The study of correlation among yield and yield contributing traits suggests that number of tillers plant^{-1}, spike length, number of spikelets spike^{-1}, number of grains spike^{-1} and 1000-grain weight were the most important characters which possessed positive association with grain yield plant^{-1}. Overall, an intensive selection for these traits will automatically improve grain yield in wheat. Since the five traits are correlated, selection in one of the traits will implicitly result in the improvement of the other traits. Therefore, these characters could be utilized in breeding program to improve varieties for higher yield.

Path coefficient analysis

Knowledge of correlation alone is often misleading as the correlation observed may not be always true. Two characters may show correlation just because they are correlated with a common third one. In such cases, it becomes necessary to use a method which takes into account the causal relationship between the variables, in addition to the degree of such relationship. Path coefficient analysis measures the direct influence of one variable upon the other, and permits separation of correlation coefficients into components of direct and indirect effects. Portioning of total correlation into direct and indirect effects provide actual information on contribution of characters and thus form the basis for selection to improve the yield. The result of genotypic correlation coefficients was partitioned into direct and indirect effects through various yield contributing characters.

Path coefficient analysis was carried out using coefficient of all the traits with grain yield plant^{-1} (Table 3). Maximum positive direct effect on grain yield plant^{-1} was contributed mostly by number of grains spike^{-1} (0.814), followed by number of tillers plant^{-1} (0.688) and 1000-grain weight (0.316). This means that a slight increase in one of these traits may directly contribute to grain yield. Similar results were reported by Dhonde et al. (2000), Satya et al. (2002) and Khan and Dar (2010). On the other hand, the maximum negative direct effect was exhibited by days to 50% heading (-0.545), followed by plant height (-0.486), number of spikelets spike^{-1} (-0.139) and spike length is negative but negligible (-0.074). Residual effects (0.14) indicated that seven characters included in this study explained high percentage of variation in grain yield. Also, indicated that in addition to the previous variables, there are also other factors to justify grain yield changes.

Days to 50% heading versus grain yield

Direct effect of days to 50% heading was negative with non significant correlation. The negative direct effect of days to 50% heading on grain yield per plant was (-0.545). The selection of this trait will be ineffective. Although, indirect effect via number of grains spike^{-1} and spike length was positive and high and these traits could be selected for yield improvement. Some authors also indicated the negative effect of days to 50% heading on grain yield (Yildirim et al., 1996; Narwal et al., 1999).

Plant height versus grain yield

Plant height directly affected the grain yield in negative direction (Table 3). The negative direct effect of plant height was highly great (-0.486), and its correlation with grain yield plant^{-1} was negative and highly significant. Similar results were reported by Chowdhry et al. (1986) and Ali et al. (2008). It is due to high percentage of dry matter accumulation towards the height of the plant in tillers plant^{-1} affecting the grain yield. Indirect effects of plant height via, days to 50% heading, tillers plant^{-1}, spikelets spike^{-1} and 1000-grain weight was positive whereas it was negative through spike length and grains spike^{-1} (Table 3).

Tillers per plant versus grain yield

A close view of results (Table 3) indicated that number of productive tillers plant^{-1} exhibited a high positive direct effect and highly significant genotypic correlation coefficient indicating the true relationship. Therefore direct selection through this trait will be effective for yield improvement. The genotypic correlation between tillers per plant (0.703) and the grain yield is almost equal to its direct effect (0.688), thus it shows true relationship and direct selection for higher number of tillers plant^{-1} would be enough to increase grain yield. Singh and Chaudhary (1979) suggested that if the correlation coefficient between a causal factor and the effect (that is, grain yield) is almost equal to its direct effect, then correlation explains the true relationship and direct selection through this trait will be effective. The indirect effect of this trait *via* number of grains per spike was also positive and high while it was negative through days at 50% heading, plant height, spike length, spikelets spike^{-1} and 1000-grain weight. These results are similar to those obtained by Shamsuddin (1987), Simane (1998) and Ali et al. (2008).

Spike length versus grain yield

Spike length is a character of considerable importance, as the larger spike is likely to produce more grains and eventually higher yield plant^{-1}. Direct effect was negative and low and correlation coefficient with positive significant between spike length and grain yield plant^{-1}. This was mainly due to the indirect positive effect of number of grains spike^{-1} and the indirect selection for thistrait will be effective to improve yield. Similar results have been reported earlier (Aycicek and Yildirim, 2006).

Number of spikelets per spike versus grain yield

Number of spikelets spike^{-1} had negative direct effect on grain yield plant^{-1} and had maximum positive indirect effect through number of grains spike^{-1} and number of tillers plant^{-1}. These results are congruent with the finding of Subhani and Chowdhry (2000), Tamman et al. (2000), Shahid et al. (2002) and Lad et al. (2003).

Number of grains per spike versus grain yield

The highest positive direct effect and highly significant positive correlation coefficient was recorded between number of grains spike^{-1} and grain yield plant^{-1}. It is evident that grain yield can be increased reliably by increasing of number of grains spike^{-1}. The direct selection for this trait will be effective. Basirat (1994) suggested that the highest direct effect on grain yield is related to number of grain spike^{-1}. Dokuyucu and Akkaya (1999), Moghaddam et al. (1998), Narwal et al. (1999), Khan et al. (1999), Mohammed et al. (2002), Aycicek and Yildirim (2006), Ali et al. (2008) and Mollasadeghi and Shahryari (2011) also reported positive direct effect of number of grains spike^{-1} and its positive association with grain yield in wheat genotypes and these findings support the present results. The indirect effect *via* number of productive tillers plant^{-1} was also positive.

Thousand grain weight versus grain yield

Thousand grain weight exhibited positive direct effect with negligible correlation. Selection for this trait will not be rewarding for yield improvement. Aycicek and Yildirim (2006) also reported positive but small direct effects of 1000-grain weight on grain yield in wheat. Soghi et al. (2006) by examining relationship between yields with yield components of 19 advanced wheat lines showed that direct effect of one-thousand grain weight was little. Results of the study showed that these genotypes may provide good source of material for further breeding program. An over all, it is logical to conclude that number of grains spike^{-1}, number of tillers plant^{-1} and 1000-grain weight were the major contributors towards grain yield since these three characters had high correlation and also high direct effect thus direct selection for these three character should be major concern for plant wheat breeder.

Conclusion

Highly significant differences were observed among the bread wheat varieties evaluated for all the eight studied traits. Genotypic correlation coefficients were higher than the corresponding phenotypic correlation coefficients in most of the traits. Highly significant correlations were found between grain yield per plant and number of tillers plant^{-1}, number of spikelets spike^{-1}, spike length, number of grains spike^{-1} and 1000 grain weight at both phenotypic and genotypic levels. However, days to 50% heading and plant height contributed negatively towards grain yield at both levels. Path analysis showed that maximum positive direct effect on grain yield plant^{-1} was contributed mostly by number of grains spike^{-1}, followed by number of tillers plant^{-1} and 1000-grain weights were the major contributors towards grain yield. There are three characters which showed significant contribution towards the final grain yield are number of tillers plant^{-1}, number of grains plant^{-1} and thousand grain weights. It was, therefore, suggested that number of grains spike^{-1}, number of tillers plant^{-1} and 1000 grain weight should be given emphasis for future wheat yield improvement programs.

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