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Genetic Variability, Association and Path Studies in Wheat Germplasm for Yield and Quality Traits in Normal and Heat Stress Environments

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ABSTRACT

The present study was conducted to assess genetic variability, correlations and path coefficient for twelve metric traits in 75 diverse indigenous and exotic bread wheat genotypes in timely and late sown conditions. Significant genotypic differences were observed for all the traits studied indicating considerable amount of variation among genotypes. The high genotypic and phenotypic coefficients of variation were observed for sedimentation value, grain yield per plot and harvest index. High heritability and genetic advance was observed for 1000 grain weight (g), grain yield per plot (g), protein (%), sedimentation value (ml) and canopy temperature indicating the scope for these traits improvement through selection. Positive and significant correlation of grain yield per plot was with number of effective tillers per meter, biological yield per plot (g), harvest index (%) and direct effects over dependent trait revealed direct and positive effect of harvest index, biological yield per plot (g), effective tillers per meter in both normal and heat stress environment indicating direct selection based on these traits would result in higher breeding efficiency for improving grain yield.

Key words: *Correlation, Path analysis, Grain Yield, Canopy Temperature, Heat Stress.*

INTRODUCTION

Wheat is the most important food crop in India after rice and is a staple food of millions of people especially in northern and north-western part of the country. India is second largest wheat producing nation after China. Total production of wheat worldwide during 2017 was 754.31 million tonnes whereas India contributed 97.4 million tonnes. To meet the ever growing demand of food grain; increase in the production as well as productivity is required along with quality traits for providing nutritional security to ever growing population.

The major aim of any wheat breeding programme is to create new genetic variability and gather information about the genetic architecture of component traits that are polygenic in nature and also influenced by the environmental factors. Improvement in grain yield is feasible only by improving component traits.

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Information on direct and indirect influence of the trait helps in making the selection more effective for simultaneous improvements in yield, its components and quality traits. Correlation of grain yield with component traits help in the improvement of grain yield by means of indirect selection for the component traits and can be used for genetic improvement in grain yield. Indirect selection of genotypes through traits correlating significantly with grain yield as well as having high heritability is one of the most important aspect of breeding procedures along with selection directly for grain yield. Therefore, identification of the traits affecting grain yield and quality traits is of utmost importance.

MATERIAL AND METHODS

Seventy five genotypes of bread wheat (*Triticum aestivum* L.) differing in their performance were grown under normal (15th Nov. 2015) and heat stress environments (20th Dec. 2015) during the year 2015-2016 under field conditions at the experimental area of Wheat and Barley Section, Department of Genetics and Plant Breeding, CCS HAU, Hisar India. In order to create heat stress at anthesis and the reproductive stages, the sowing of the heat stress experiment was delayed by about 5 weeks. The experiments were conducted in a randomized complete block design with three replications for both environments and with a plot size of a 2 rows of 3 m length with a 30×10 cm spacing within rows and between plants. The recommended packages of practices were followed. Five competitive plants of each genotype in each replication and in each environment were randomly selected, tagged. The terminal plants of each plot were excluded to minimize the border effect. Data were recorded for Days to 50% heading, Days to maturity, Plant height (cm), Number of effective tillers per meter, Number of grains per ear, 1000 grain weight (g), Biological yield per plot(g), Grain yield per plot (g), Harvest index (%), Protein (%), Sedimentation value (ml) and Canopy temperature. The canopy temperature was recorded at 7 days and 21 days after anthesis during noon period (12 pm-2 pm). The viewing angle was around 45° to the horizontal line above the canopy so as to avoid the confounding effect of soil temperature[2].

Statistical Analysis

The data recorded from the present experiment was analyzed in a computer based statistical package INDOSTAT program. The analysis of variance for RBD was carried out for every character under each environment on the basis of model described by Panse and Sukhatme[16]. Genetic variability parameters like phenotypic and genotypic coefficient of variance, heritability and genetic advance were calculated following the formulae suggested by Burton and Devane[8], Burton[7] and Johnson *et al*.[11]. The correlation coefficient analysis was carried out using the formula of Al-Jibouri *et al*.[1]. The phenotypic correlations coefficients were used to work out path coefficient analysis. Path coefficients were obtained accordingly to Dewey and Lu[9].

RESULTS AND DISCUSSION

The analysis of variance indicated significant differences among the genotypes for all the 12 characters studied viz. days to 50% heading, days to maturity, plant height (cm), number of effective tillers per meter, number of grains per ear, 1000 grain weight (g), biological yield per plot (g), grain yield per plot (g), harvest index (%), protein (%), sedimentation value (ml) and canopy temperature indicating existence of sufficient genetic variation among various genotypes for the characters studied in both environments. The results asserted that there is plenty of scope for further improvement of wheat genotypes through selection and breeding. Similar results regarding variability have been reported earlier by Azimi *et al*.[4], Kumar *et al*.[13], and Yadav *et al*.[22].

Genetic variability, heritability and genetic advance

The presence of genetic variability for various traits among genotypes is a pre-requisite for breeding high yielding varieties, which leads to expression of various yield contributing characters. The estimates of PCV, GCV, heritability and genetic advance are helpful to determine the breeding method so as to improve a particular plant population for a specific trait. High heritability coupled with high genetic advance indicates additive gene effects governing these characters, therefore, simple selection may be effective for improvement. In the present study, the phenotypic coefficient of variation (PCV) found to be higher than the genotypic coefficient of variation (GCV) for all the traits studied indicating role of environment in normal and heat stress environment (Table 1 and 2). The high estimates of genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV) were observed for sedimentation value followed by grain yield per plot, and harvest index whereas, the moderate and low estimates of GCV and PCV was observed for traits like days to 50% heading, days to maturity, plant height (cm), number of effective tillers per meter, number of grains per ear, 1000 grain weight (g), biological yield per plot (g), protein (%) and canopy temperature in normal and heat stress environment. Similar results have been reported by Jain *et al*., Yadav *et al*.[22], and Bhushan *et al*.[5], for days to heading, days to maturity, plant height (cm), grain yield per plot (g) the occurrence of high variability for sedimentation value (ml) has also been observed by Preeti *et al*.[18], and Sharma and Panwar[20].

GCV along with heritability and genetic advance is considered as good estimate of genetic gain to be expected from selection on phenotypic performance. A trait having high heritability and high genetic advance reflects the usefulness of selection of plants based on phenotypic performance. The estimates of heritability (broad sense) were observed high in days to 50% heading, days to maturity, 1000 grain weight (g), grain yield per plot (g), protein (%), sedimentation value (ml) and canopy temperature but heritability (broad sense) was found to be moderate for plant height (cm), number of effective tillers per meter, number of grains per ear, biological yield per plot(g) and harvest index (%) and canopy temperature (post anthesis 7 days) in normal environment whereas in heat stress environment estimates of heritability (broad sense) were observed high in plant height (cm), 1000 grain weight (g), biological yield per plot (g), grain yield per plot (g), protein (%), sedimentation value (ml) but heritability (broad sense) was found to be moderate for days to 50% heading, days to maturity, number of effective tillers per meter, number of grains per ear, and harvest index (%) and canopy temperature (post anthesis 21 days). Further genetic advance as *per cent* of mean observed high for characters like sedimentation value (ml) followed by grain yield per plot (g) in normal and heat stress environment while the estimates of genetic advance as *per cent* of mean were moderate for plant height (cm), number of effective tillers per meter, number of grains per ear, 1000 grain weight (g), biological yield per plot (g), protein (%), sedimentation value (ml) and canopy temperature and low for days to 50% heading, days to maturity in normal and heat stress environment indicating that the improvement of these traits through selection as well as their exploitation through combination breeding. The estimates of high heritability coupled with high genetic advance, suggested that simple selection could be done for the improvement of these traits. Singh *et al.*, reported similar results for plant height, number of grains per spike, 1000 grain weight and grain yield. Moderate to high heritability coupled with high genetic advance as per cent of mean was observed for number of grains per spike, 1000 grain weight, grain yield, biological yield, number of tillers per meter row, harvest index and plant height by Kumar *et al.*[13].

High heritability values in yield contributing characters are useful for making selection, it indicates that the variation in these characters is mainly under genetic control and also less influenced by environment but selection based on this factor alone may limit the progress, as the same is very prone to environmental changes[15]. It is apparent that the improvement of various characters, individually or simultaneously, different selection intensities are to be exercised depending on estimates of genetic components of variability in view of level of their heritability. High genetic variations combined with high heritability could provide effective selection of phenotypic trait for further improvement in wheat through hybridization. Johnson *et al.*[11], stated that heritability estimates coupled with genetic advance were more helpful than heritability alone in predicting the progress from the selected better genotypes. However, there are limitations of using broad sense heritability as it includes both additive and non-additive gene effects. Therefore, it is necessary to estimate heritability in conjunction with the genetic advance. High heritability estimates coupled with high genetic advance for number of grains per ear, 1000 grain weight, biological yield per plot (g), grain yield per plot (g), protein (%), sedimentation value (ml) and canopy temperature (post-anthesis 7 days) indicated that high genetic gains could be achieved by strengthening the selection, Similar findings were also reported by Tazeen *et al.*[21], and Yadav *et al.*[22].

Correlation coefficient

Grain yield is a complex character and is influenced by several component characters. It is difficult to make improvement in yield through only direct selection for grain yield per plot on the basis of the selection of superior genotypes taking into consideration their phenotypic expression. Information regarding the nature and extent of association of morphological and quality characters would be helpful in developing suitable plant type for higher grain yield a complex character for which direct selection alone is not much effective in addition to the need for improvement of grain quality. The linkage or pleiotropy can be the underlying cause of correlation between traits. Correlation due to linkages can be broken by recombination, but correlation due to pleiotropy not easy to overcome as pleiotropy causes permanent correlations. In case of pleiotropy, the genetic improvement in one trait will necessarily bring the change in associated component traits. The knowledge with respect to the direction and magnitude of association of various traits with grain yield and quality proves to be of immense help in formulating an effective and efficient selection and screening programme for crop improvement. Mutual relationship between grain yield and its contributing characters (as given in Table 4 and Table 5) revealed that the genotypic correlation coefficient were higher than the corresponding phenotypic correlation coefficient for most of the traits in both normal and heat stress environment indicating strong inherent relationship between the traits, but suppressing the effect of the environment, which modified the phenotypic expression of these characters by reducing phenotypic coefficient values. Such environmental influences in reducing correlation coefficients in bread wheat were also reported by Phougat *et al.*[17]. In the present study in normal as well as heat stress environment, grain yield per plot was positively and significantly correlated with number of effective tillers per meter, number of grains per ear, 1000-grain weight, biological yield per plot (g) and harvest index (%) and significant negative correlation with canopy temperature (post-anthesis 7 and post-anthesis 21 days) in timely sown environment. The grain yield per plot was positively and significantly correlated with days to maturity in normal sown environment. Similar results were earlier reported by Anwar *et al.*, for positive genotypic correlation between days to maturity for grain yield per plant. Days to heading had positive and significant phenotypic correlation with days to maturity similar results also reported by Avinashe *et al*.[3]. Similar results for positive association of number of tillers per plant, number of grains per spike, biomass per plant, harvest index and canopy temperature depression with grain yield have been reported by Mandal and Dhanda[14]. Plant height showed significant negative correlation with number of grains per ear, grain yield per plot, harvest index and positive and significant correlation with biological yield per plot (g) in normal and heat stress environment. Number of effective tillers per meter showed highly significant positive correlation with number of grains per ear, 1000 grain weight (g), biological yield per plot, grain yield per plot, harvest index % and negative correlation with canopy temperature (post-anthesis 7 days and post-anthesis 21 days stage) in both the environments. Number of grains per ear showed significant negative correlation with plant height and canopy temperature at post-anthesis 7 days and post-anthesis 21 days stage. Biological yield per plot (g) showed significant and positive correlation with grain yield per plot and significant negative correlation with harvest index and canopy temperature (post-anthesis 7 days and post-anthesis 21 days) in normal environment. Harvest index showed significant negative correlation with canopy temperature (post-anthesis 7 and 21 days) in both the environments. Canopy temperature (post-anthesis 7 days and post-anthesis 21 days) showed significant negative correlation with number of effective tillers per meter, number of grains per ear, grain yield per plot and harvest index in both the environments. Canopy temperature (post-anthesis 21 days) showed significant negative correlation with 1000 grain weight and harvest index in both normal and heat stress environment, while canopy temperature (post-anthesis 7 days) had significant negative correlation with harvest index % in both normal and heat stress environment. Canopy temperature post-anthesis 21 days showed significant and positive association with canopy temperature at post-anthesis 7 days in both the environments. Similar results were reported by Kumar *et al.*[13], for significant positive association of grain yield with harvest index, 1000 grain weight, days to heading and maturity and Avinashe *et al*.[3], for positive and significant association of harvest index, biological yield per plant, and test weight were with grain yield per plant and Phougat *et. al.*[17], for positive correlation of grain yield per plant with the harvest index, biological yield per plant and tiller number per plant and Azimi *et al*.[4], for positive significant correlation of seed yield with biological yield, harvest index, thousand grain weight, plant height and number of grains per spike at both genotypic at phenotypic level.

Days to heading had positive and significant phenotypic correlation with days to maturity in both the environments. Plant height showed significant negative correlation with harvest index and positive significant correlation with biological yield per plot (g) in normal and heat stress environment and positive correlation with sedimentation value (ml) in heat stress environment. Number of effective tillers per meter showed highly significant positive correlation with number of grains per ear, 1000 grain weight (g), biological yield per plot, grain yield per plot, harvest index % and negative correlation with canopy temperature (post-anthesis 7 days and post-anthesis 21 days stage) in both the environments. Number of grains per ear had positive and significant phenotypic correlation with biological yield per plot, grain yield per plot and harvest index and number of grains per ear showed significant negative correlation with canopy temperature at post-anthesis 7 days and post-anthesis 21 days stage in both normal and heat stress environment. 1000-grain weight showed positive significant correlation with biological yield per plot, grain yield per plot and and negative correlation with canopy temperature (post-anthesis 21 days) in both normal and heat stress environment. 1000-grain weight showed significant positive correlation with protein in heat stress environment. Biological yield per plot (g) showed highly significant and positive correlation with grain yield per plot and significant negative correlation with canopy temperature (post-anthesis 7 days) in normal environment whereas canopy temperature (post-anthesis 21 days) showed significant negative correlation in both normal and heat stress environment. Harvest index showed significant negative correlation with canopy temperature post-anthesis 7 days and post-anthesis 21 days. Similar results were reported by Singh *et al.*, for significant correlation of harvest index and biological yield with grain yield. Also reported that CT under moisture stress conditions at grain filling stage had positive and significant association with CT at anthesis stage but negative and significant association with grain yield. The character association studies in bread wheat suggested that selection based on correlation studies could prove effective for improvement of grain yield .

Path coefficient

Correlation coefficients reveal the extent and nature of association between yield and its contributing characters but does not exhibit the direct and indirect effects of different contributing characters on yield *per se* performance. When more variables are considered in correlation, their indirect associations become more complicated and less obvious. In this situation, path coefficient analysis provides an effective means of splitting direct and indirect causes of association. Path coefficient provides a clear and more realistic picture by measuring the direct as well as indirect effect of one variable on the dependent variable via the other traits.The estimates of residual effect reflect the adequacy and appropriateness of the characters chosen for path analysis. In present study, the residual effect value was 0.0701 in normal environment and 0.0581 in heat stress environment, indicating that characters studied contributed 92.99% towards total variance in normal environment and 94.19 in heat stress environment and only 7.01% variation in normal environment and 5.81% variation in heat stress environment remained unaccounted.

A critical perusal of path coefficient analysis in which diagonal values are direct effect over dependent trait revealed direct and positive effect of harvest index, biological yield per plot (g), effective tillers per meter in normal and heat stress environment. However days to 50% heading, plant height (cm), number of grains per ear, 1000 grain weight, canopy temperature (post-anthesis 7 days and post-anthesis 21 days) indicated negative direct effect on grain yield per plot in both the environments. Similar results were reported by Rangare *et al.*[19], and Bhushan *et al.*[5], for days to heading and days to maturity. Similarly Kumar *et al.*[13], reported high positive direct effect of harvest index and biological yield and negative direct effect by number of tillers per meter row on grain yield posing as the main contributors. Khavarinejad *et al.*[12], Bhushan *et al.*[5], reported similar effects for biological yield and harvest index. The harvest index, which showed highest direct effect, also contributed to grain yield per plot indirectly through days to maturity, number of effective tillers per meter, number of grains per ear, 1000-grain weight. Plant height (cm) and biological yield per plot (g), protein (%) and canopy temperature (post-anthesis 7 and 21 days) had high negative indirect effects via harvest index on grain yield per plot (g). While, biological yield per plot showed indirect positive effects via number of effective tillers per meter, number of grains per ear, 1000 grain weight and protein% in both the environments. This suggested that direct selection based on these traits would result in increased breeding efficiency for improving grain yield per plot.

Among the evaluated genotypes, the most desirable genotype found to be HD2967 showed not only highest mean values for grain yield per plot, number of effective tillers per meter, number of grains per ear but also low canopy temperature. The genotypes *i.e.*WH542, WH711, WH1105 and DBW88 indicated high grain yield, therefore these could be utilized to improve grain yield in normal environment. For mitigating heat stress, the most desirable genotype found to be WH1142 which was not only highest in mean values for grain yield per plot but also had high number of effective tillers per meter, number of grains per ear,1000 grain weight (g) and harvest index. The genotypes *i.e.*WH542, WH1124 and DBW90 recorded high grain yield per plot therefore these could be utilized to improve grain yield in heat stress environment.

Table1: Mean, Range, Coefficient of variation , Heritability and Genetic advance in normal environment

Characters	Mean	Range	Coefficient of variation		Heritability (%)	GA as % of Mean
			Genotypic	Phenotypic		
Days to 50% heading	91.53	75.67-96.33	4.17	4.46	87.60	8.04
Days to maturity	138.01	126.67-146.33	3.00	3.27	84.00	5.66
Plant height (cm)	98.16	76.33-116.33	6.68	7.95	70.70	11.58
Number of Effective tillers per meter	127.26	106.33-146.67	6.93	8.35	68.90	11.85
Number of grains per ear	51.52	43.00-58.33	7.39	8.76	71.20	12.86
1000 grain weight (g)	41.14	36.25-45.72	5.71	6.30	82.20	10.67
Biological yield per plot(g)	1942.72	1546.00-2196.67	6.83	7.96	73.60	12.06
Grain yield per plot(g)	752.77	599.33-967.33	10.81	11.48	88.60	20.96
Harvest index (%)	38.86	31.10-46.50	9.48	11.00	74.30	16.84
Protein (%)	12.37	10.95-16.53	7.21	7.56	90.90	14.17
Sedimentation value (ml)	46.42	16.63-59.33	17.54	18.10	93.90	35.01
Canopy Temperature ^{o}C (post-anthesis 7 days)	22.41	17.47-25.80	8.07	8.78	84.60	15.29
Canopy Temperature ^{o}C (post-anthesis 21 days)	30.30	26.53-34.17	5.45	6.20	77.20	9.86

Table 2: Mean, Range, Coefficient of variation, Heritability and Genetic advance in heat stress environment

Characters	Mean	Range	Coefficient of variation		Heritability (%)	GA as % of Mean
			Genotypic	Phenotypic		
Days to 50% heading	82.22	74.67-89.67	3.62	4.12	77.20	6.55
Days to maturity	129.86	123.00-139.33	2.85	3.30	74.70	5.07
Plant height (cm)	91.69	73.00-113.67	8.89	9.79	82.40	16.61
Number of Effective tillers per meter	117.15	102.50-135.67	6.30	7.39	72.80	11.08
Number of grains per ear	50.62	42.67-58.33	6.80	8.32	66.80	11.44
1000 grain weight (g)	40.93	33.68-45.22	6.39	6.98	83.70	12.04
Biological yield per plot(g)	1659.07	1201.33-2016.00	10.75	11.35	89.70	20.97
Grain yield per plot (g)	645.00	451.33-838.67	13.97	14.64	91.00	27.44
Harvest index (%)	39.00	30.00-45.80	10.42	11.71	79.20	19.10
Protein (%)	12.23	10.67-16.10	6.49	7.14	82.70	12.15
Sedimentation value (ml)	45.71	16.43-57.67	16.40	17.07	92.30	32.46
Canopy Temperature ^{o}C (post-anthesis 7 days)	25.40	21.63-27.50	4.57	5.30	74.20	8.10
Canopy Temperature ^{o}C (post-anthesis 21 days)	32.33	25.70-35.20	6.36	6.94	84.00	12.01

Table 3: Correlation coefficients for normal environment (genotypic correlation coefficients above diagonal, phenotypic correlation coefficients below diagonal)

	Days to 50% heading	Days to maturity	Plant height (cm)	Number of Effective tillers per meter	Number of grains per ear	1000 grain weight (g)	Biological yield per plot(g)	Grain yield per plot(g)	Harvest index (%)	Protein (%)	Sedimentation value (ml)	Canopy Temperature °C (post-anthesis 7 days)	Canopy Temperature °C (post-anthesis 21 days)
Days to 50% heading	1.00	0.72**	-0.06	0.00	0.02	-0.12	0.00	0.01	0.00	-0.02	-0.01	-0.01	-0.08
Days to maturity	0.63**	1.00	-0.09	0.07	0.29*	0.01	0.17	0.23*	0.13	0.02	-0.05	-0.16	-0.23*
Plant height (cm)	-0.08	-0.08	1.00	-0.23*	-0.29*	0.15	0.34**	-0.31**	-0.56**	0.05	0.17	0.10	0.08
Number of effective tillers per meter	-0.01	0.06	-0.16	1.00	0.64**	0.49**	0.38**	0.77**	0.60**	-0.18	-0.06	-0.40**	-0.52**
Number of grains per ear	0.04	0.23*	-0.23*	0.41**	1.00	0.14	0.36**	0.80**	0.63**	-0.04	0.11	-0.57**	-0.49**
1000 grain weight (g)	-0.12	0.01	0.15	0.36**	0.08	1.00	0.38**	0.48**	0.29*	-0.02	-0.11	-0.28*	-0.37**
Biological yield per plot(g)	0.01	0.12	0.28*	0.28*	0.25*	0.29*	1.00	0.47**	-0.18	0.25	0.11	-0.33**	-0.48**
Grain yield per plot (g)	0.01	0.21	-0.27*	0.61**	0.64**	0.41**	0.37**	1.00	0.79**	0.00	-0.02	-0.48	-0.54**
Harvest index (%)	0.01	0.13	-0.46**	0.42**	0.48**	0.23*	-0.32**	0.76**	1.00	-0.17	-0.10	-0.30**	-0.27*
Protein (%)	-0.04	0.02	0.06	-0.11	-0.02	-0.01	0.21	-0.01	-0.14	1.00	0.13	0.10	0.06
Sedimentation value (ml)	-0.02	-0.04	0.14	-0.03	0.10	-0.09	0.07	-0.02	-0.06	0.12	1.00	0.20	0.14
Canopy Temperature °C (post- anthesis 7 days)	-0.01	-0.15	0.07	-0.27*	-0.41**	-0.21	-0.25*	-0.41**	-0.24*	0.09	0.17	1.00	0.67**
Canopy Temperature °C (post-anthesis 21 days)	-0.08	-0.18	0.04	-0.39**	-0.40**	-0.30**	-0.40**	-0.49**	0.21	0.07	0.12	0.55**	1.00

Table 4: Correlation coefficients for heat stress environment (genotypic correlation coefficients above diagonal, phenotypic correlation coefficients below diagonal)

	Days to 50% heading	Days to maturity	Plant height (cm)	Number of Effective tillers per meter	Number of grains per ear	1000 grain weight (g)	Biological yield per plot(g)	Grain yield per plot(g)	Harvest index (%)	Protein (%)	Sedimentation value (ml)	Canopy Temperature °C (post-anthesis 7 days)	Canopy Temperature °C (post-anthesis 21 days)
Days to 50% heading	1.00	0.76**	0.05	-0.26*	-0.12	0.12	0.03	-0.19	-0.25*	-0.13	0.03	0.22	0.20
Days to maturity	0.69**	1.00	0.14	-0.12	0.01	0.23*	0.13	-0.10	-0.24*	0.06	0.13	0.23*	0.20
Plant height (cm)	0.05	0.13	1.00	0.22	-0.01	0.25*	0.51**	0.18	-0.28*	-0.02	0.29*	0.08	-0.13
Number of effective tillers per meter	-0.24*	-0.11	0.20	1.00	0.55**	0.33**	0.56**	0.76**	0.40**	0.19	0.19	-0.32**	-0.40**
Number of grains per ear	-0.10	0.01	-0.02	0.49**	1.00	0.06	0.29*	0.68**	0.58**	0.12	0.11	-0.41**	-0.39**
1000 grain weight (g)	0.11	0.21	0.22	0.29*	0.03	1.00	0.28*	0.35**	0.17	0.36**	-0.04	-0.11	-0.34**
Biological yield per plot(g)	0.03	0.11	0.48**	0.52**	0.26*	0.27*	1.00	0.65**	-0.18	0.16	0.10	-0.22	-0.40**
Grain yield per plot (g)	-0.17	-0.10	0.17	0.71**	0.63**	0.33**	0.63**	1.00	0.63**	0.19	-0.02	-0.56**	-0.67**
Harvest index (%)	-0.22	-0.21	-0.26*	0.36**	0.53**	0.16	-0.20	0.63**	1.00	0.08	-0.12	-0.49**	-0.44**
Protein (%)	-0.11	0.05	-0.02	0.17	0.11	0.35**	0.15	0.18	0.07	1.00	0.01	-0.04	-0.17
Sedimentation value (ml)	0.03	0.12	0.27*	0.17	0.10	-0.04	0.10	-0.02	-0.12	0.01	1.00	0.19	0.04
Canopy Temperature °C (post- anthesis 7 days)	0.20	0.21	0.07	-0.29*	-0.35**	-0.11	-0.21	-0.53**	-0.45**	-0.04	0.19	1.00	0.63**
Canopy Temperature °C (post-anthesis 21 days)	0.19	0.19	-0.12	-0.37**	-0.36**	-0.32**	-0.38**	-0.63**	-0.41**	-0.15	0.04	0.57**	1.00

Table 5: Path coefficient analysis results showing direct (diagonal) and indirect effects on grain yield in normal environment

	Days to 50% heading	Days to maturity	Plant height (cm)	Number of Effective tillers per meter	Number of grains per ear	1000 grain weight (g)	Biological yield per plot(g)	Harvest index (%)	Protein (%)	Sedimentation value (ml)	Canopy Temperature °C (post-anthesis 7 days)	Canopy Temperature °C (post-anthesis 21 days)	Grain yield per plot (g)
Days to 50% heading	-0.0085	-0.0053	0.0007	0.0001	-0.0004	0.001	-0.0001	0.0001	0.0003	0.0002	0.0001	0.0007	0.0077
Days to maturity	0.0039	0.0062	-0.0005	0.0004	0.0014	0.0001	0.0007	0.0008	0.0001	-0.0003	-0.0009	-0.0011	0.2063
Plant height (cm)	0.0012	0.0012	-0.0160	0.0026	0.0035	-0.0024	-0.0045	0.0074	-0.0009	-0.0022	-0.0012	-0.0006	-0.2693
Number of Effective tillers per meter	-0.0001	0.0003	-0.0009	0.0055	0.0023	0.002	0.0016	0.0023	-0.0006	-0.0002	-0.0015	-0.0022	0.606
Number of grains per ear	-0.0002	-0.0013	0.0012	-0.0023	-0.0056	-0.0005	-0.0014	-0.0027	0.0001	-0.0006	0.0023	0.0022	0.6388
1000 grain weight (g)	0.0024	-0.0001	-0.0029	-0.0070	-0.0016	-0.0197	-0.0057	-0.0046	0.0001	0.0018	0.0041	0.0059	0.4092
Biological yield per plot(g)	0.0096	0.0797	0.1951	0.1937	0.1711	0.1979	0.6893	-0.2190	0.1441	0.0516	-0.1690	-0.2747	0.3747
Harvest index (%)	-0.0019	0.1235	-0.4447	0.4072	0.4629	0.2270	-0.3079	0.9688	-0.1399	-0.0618	-0.2343	-0.2052	0.7571
Protein (%)	0.0003	-0.0002	-0.0006	0.0011	0.0002	0.0001	-0.0020	0.0014	-0.0097	-0.0012	-0.0009	-0.0007	-0.0074
Sedimentation value (ml)	0.0001	0.0001	-0.0002	0.0001	-0.0001	0.0001	-0.0001	0.0001	-0.0001	-0.0012	-0.0002	-0.0001	-00.0154
Canopy Temperature °C (post- anthesis 7 days)	0.0001	0.0002	-0.0001	0.0003	0.0005	0.0003	0.0003	0.0003	-0.0001	-0.0002	-0.0012	-0.0007	-0.4090
Canopy Temperature °C (post- anthesis 21 days)	0.0009	0.0021	-0.0004	0.0044	0.0045	0.0034	0.0045	0.0024	-0.0008	-0.0013	-0.0063	-0.0114	-4878.00

R SQUARE = 0.9951 RESIDUAL EFFECT = 0.0701

Table 6: Path coefficient analysis results showing direct (diagonal) and indirect effects on grain yield in heat stress environment

	Days to 50% heading	Days to maturity	Plant height (cm)	Number of Effective tillers per meter	Number of grains per ear	1000 grain weight (g)	Biological yield per plot(g)	Harvest index (%)	Protein (%)	Sedimentation value (ml)	Canopy Temperature °C (post-anthesis 7 days)	Canopy Temperature °C (post-anthesis 21 days)	Grain yield per plot (g)
Days to 50% heading	-0.0009	-0.0006	0.0001	0.0002	0.0001	-0.0001	0.0001	0.0002	0.0001	0.0001	-0.0002	-0.0002	-0.1724
Days to maturity	-0.0093	-0.0135	-0.0018	0.0014	0.0001	-0.0028	-0.0015	0.0029	-0.0007	-0.0016	-0.0028	-0.0026	-0.0985
Plant height (cm)	-0.0006	-0.0017	-0.0129	-0.0026	0.0003	-0.0029	-0.006	0.0033	0.0003	-0.0035	-0.001	0.0016	0.1662
Number of Effective tillers per meter	-0.0078	-0.0035	0.0066	0.0329	0.016	0.0094	0.0171	0.0117	0.0057	0.0057	-0.0096	-0.0121	0.7088
Number of grains per ear	-0.0013	0.0001	-0.0003	0.0064	0.0132	0.0004	0.0035	0.007	0.0015	0.0013	-0.0047	-0.0048	0.6316
1000 grain weight (g)	-0.0004	-0.0008	-0.0009	-0.0011	-0.0001	-0.0038	-0.0029	-0.0006	-0.0013	0.0002	0.0004	0.0012	0.3307
Biological yield per plot(g)	0.0193	0.0845	0.3703	0.3992	0.2015	0.2036	0.7651	-0.1544	0.115	0.0795	-0.1599	-0.2873	0.6318
Harvest index (%)	-0.1672	-0.1586	-0.1939	0.2668	0.3949	0.1195	-0.1513	0.7499	0.049	-0.0863	-0.3359	-0.3111	0.6287
Protein (%)	-0.0005	0.0003	-0.0001	0.0008	0.0005	0.0017	0.0007	0.0003	0.0047	0.0001	-0.0002	-0.0007	0.1769
Sedimentation value (ml)	-0.0003	-0.0012	-0.0028	-0.0018	-0.001	0.0004	-0.0011	0.0012	0.0001	-0.0102	-0.0019	-0.0004	-0.0158
Canopy Temperature °C (post- anthesis 7 days)	-0.0002	-0.0002	-0.0001	0.0003	0.0003	0.0001	0.0002	0.0004	0.0001	-0.0002	-0.0009	-0.0005	-0.5261
Canopy Temperature °C (post- anthesis 21 days)	-0.0032	-0.0032	0.002	0.0061	0.006	0.0053	0.0063	0.0069	0.0026	-0.0006	-0.0095	-0.0167	-0.6335

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