



Genetic parameters, trait associations and path coefficient analysis of yield-related traits in maize (*Zea mays* L.) under heat stress conditions

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Abstract

Maize (*Zea mays* L., $2n = 20$) is one of the most versatile and extensively cultivated crops worldwide, flourishing in diverse agro-climatic environments. Despite its wide adaptability, maize productivity is frequently compromised by heat stress, resulting in significant declines in grain yield. Keeping these facts in consideration, the present study was undertaken to evaluate genetic parameters, interrelationships among yield and yield-related traits and the direct and indirect effects of these traits on yield under heat stress, utilising 29 maize inbred lines during the 2016 growing season, employing a randomised complete block design (RCBD) with 3 replications. The estimates of genetic parameters revealed that the trait grains per plant exhibited the highest genetic advance (GA) in conjunction with high heritability, followed by plant height and 500-grain weight. The association study revealed that both grains per plant and 500-grain weight were significantly and positively linked with grain yield per plant at both genotypic and phenotypic levels. Moreover, characteristics including pollen viability, cell membrane thermo-stability, plant height and ear height exhibited a strong positive genotypic association with grain yield. The anthesis-silking period showed a substantial negative correlation with grain yield at the genotypic level. Path coefficient analysis indicated that grains per plant, 500-grain weight, shelling percentage, ear height, cell membrane thermo-stability, days to 50 % physiological maturity, days to 50 % anthesis and grain filling period exerted the most significant direct and positive phenotypic influences on grain yield. At the phenotypic level, number of grains per plant exerted the highest positive direct effect on grain yield, followed by 500-grain weight.

Keywords: climate resilience; genetic parameters; heritability; trait association; yield components; *Zea mays*

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1. Introduction

Maize (*Zea mays* L., $2n = 20$), often referred to as the "queen of cereals," plays a pivotal role in global agriculture owing to its diverse applications (1). It is not only a principal food for millions but also serves as a major component in livestock feed, industrial raw materials and biofuel production. In India, maize is grown on approximately 8.69 million hectares (ha) with an average productivity of around 3416 kg/ha (2). One of the most important states for maize production, Bihar grows the grain in the kharif, rabi and spring seasons. The demand for maize is expected to surge dramatically due to the anticipated rapid increase in the population of India, which is predicted to go from 1.34 billion in 2017 to approximately 1.5 billion by 2030 and may reach 1.66 billion by 2050 (3). This increase is primarily due to the growing consumption of animal-derived foods such as milk, eggs and meat-sectors heavily reliant

on maize-based feed (4). However, a major challenge lies ahead: bridging the widening gap between current production levels and the future demand for food, all while grappling with the adverse effects of climate change. Under the present growth trajectory and climate stressors, food production may fall short of future requirements (5). One strategic solution involves narrowing the "yield gap", the difference between actual farm yields and the crop's potential productivity. Research suggests that closing this yield gap alone in developing nations could lead to a global increase in maize production by up to 45 % (6).

Despite this potential, climate change presents a significant threat, particularly in tropical zones where rainfed maize is widely cultivated. Rising temperatures and erratic rainfall patterns are already impacting yields, with regions in Africa among the most severely affected (7). One of the most critical abiotic stresses affecting maize is heat stress,

especially during vulnerable stages like flowering. Temperatures between 35 °C and 45 °C (8) can disrupt key physiological processes, resulting in poor pollination, fertilisation failure and yield reductions ranging from 15 % to over 80 %, depending on the severity and duration (9–11).

Increased temperatures also curtail the growing period (12), reduce light absorption (13), heighten respiration rates, limit photosynthesis (14) and cause pollen sterility (15). Studies have shown that female reproductive organs in maize tend to be more resilient to heat compared to male organs (16), yet the interval between silking and fertilisation is extremely temperature-sensitive (17). For instance, in the U.S. Corn Belt, an increase from 22–28 °C during the grain-filling stage led to a 10 % yield drop, while a 6 °C rise resulted in losses of up to 42 % (6, 18).

Nearly 0.70 million ha of maize crop land in Bihar produces 2.40 million metric tons of grain every year. Sowing the crop too early in January often results in poor germination due to low temperatures, while late planting can expose the crop to heat stress during its reproductive stages, adversely affecting yield. Given that grain yield is a complex polygenic trait shaped by both genetic and environmental factors, breeding for heat tolerance has become a research priority. The development of heat-tolerant maize varieties poses a significant challenge because heat tolerance is a polygenic trait controlled by multiple genes (19). To date, progress in creating resilient inbred lines remains limited. Consequently, it is critical to know which secondary characteristics such as anthesis-silking interval, chlorophyll content, pollen viability, relative water content, canopy temperature, cell membrane stability, stay-green, etc. significantly affect grain yield when heat stress is present. In order to make better selection decisions in breeding programs, tools like path coefficient analysis and correlation can be used to discover these important features. Previous researchers underscore the need for understanding the direct and indirect effects of yield-related features on selection strategies, especially in habitats prone to stress (20, 21). Such insights are invaluable in accelerating the development of high-performing, heat-resilient maize genotypes, ensuring food security in the face of climate change.

2. Materials and Methods

The experiment was carried out at the Research Farm, Department of Plant Breeding and Genetics, of Bihar Agricultural University at Sabour, Bhagalpur, Bihar, India, falling under Zone-III A. Geographically, the experimental area is situated at the latitude between 25° 07'–25° 30' N, longitude between 86° 37'–87° 30' E and altitude of 42.98 m above the mean sea level. The experimental area falls under the sub-tropical zone and is characterized by a hot summer, moderate to heavy

rainfall and cold winter. The average rainfall is about 1100 mm distributed between the second fortnight of June and the first fortnight of October. The hottest and coldest months of the year are May–June and January respectively. The maximum average temperature goes beyond 40 °C from May–June, whereas the minimum and maximum average temperatures are 8 °C and 21.8 °C respectively, in January. Twenty-nine maize inbred lines were cultivated to screen for heat stress-tolerance and susceptible inbred lines under high-temperature conditions (>32 °C) during the flowering period in the spring of 2016, utilising a randomised complete block design (RCBD) with 3 replications. A maximum temperature of >32 °C is commonly used to define heat stress in maize because temperatures above this level adversely affect photosynthesis, membrane stability, enzyme activity, pollen viability and grain set, with the reproductive stage being particularly susceptible (22). Each plot comprised two rows, each 5 m in length, with a spacing of 60 cm between rows and 20 cm between plants within each row. To ensure an optimal plant population, two seeds were gently sown in each hill and after a week of germination, one seedling was removed from each hill. In order to cultivate the robust harvest, the field was prepared using conventional tillage and fertilisers were applied according to the recommended dose of 120 : 60 : 40 kg nitrogen, phosphorus and potassium (NPK) ha⁻¹, with the full dose of P and K and one-third of N applied as basal, while the remaining N was top-dressed in two equal splits at the knee-height and tasseling stages. Regular irrigation was provided at critical growth stages to prevent moisture stress and ensure that the imposed treatment represented heat stress alone rather than combined heat and drought stress. Weeds were controlled through timely manual weeding. Crop protection measures were taken using recommended insecticides and fungicides applications. Fig. 1 shows that under normal conditions, the average minimum and maximum air temperatures at pollination time were 19.85 °C and 31.04 °C respectively. Under heat stress conditions, the values were 23.21 °C and 35.98 °C. For each replication, 10 plants were selected at random from each plot to collect data on the following traits, such as pollen viability (%), cell membrane thermal stability (%), plant height (cm), ear height (cm), grain yield per plant (g/p) and shelling percentage (%). The traits such as days to 50 % anthesis (days) and days to 50 % silk (days) were documented on a plot basis. The time it took to reach 50 % silking and 50 % anthesis was used as the two variables to determine the anthesis-silking interval. The difference between the days to 50 % silk and days to 50 % physiological maturity (days) was used to compute the grain filling duration (days). From the bulk seed sample taken from every plot and replication, the 500-grain weight (g) was recorded. For pollen viability, we used the method described in the following equation by counting the number of darkly and completely stained and unstained pollen grains after staining in an iodine-potassium iodide solution (23).



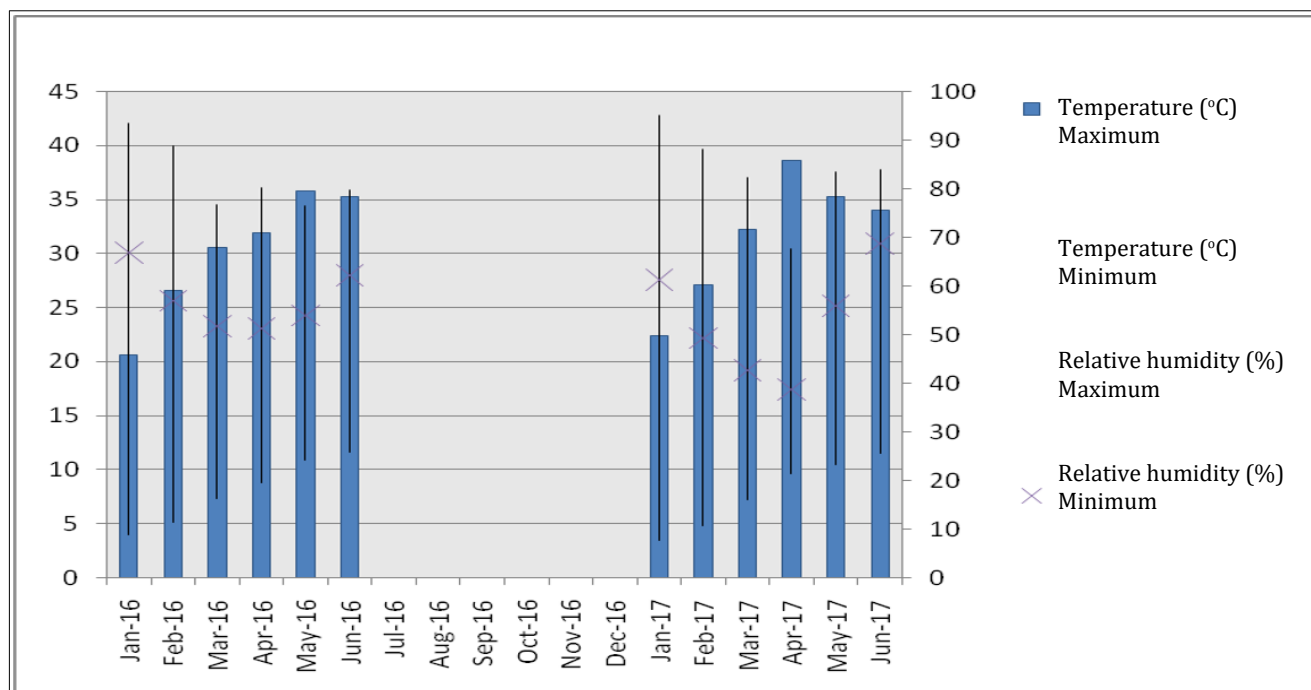


Fig. 1. A meteorological profile for the growth season of crops.

$$\text{Pollen viability (\%)} = \left[\frac{(\text{Number of darkly stained pollen grains})}{(\text{Total number of pollen grains counted})} \right] \times 100$$

For cell membrane thermostability, we used the formula described in the late 1960s by C.Y. Sullivan of the University of Nebraska.

$$\text{Cell membrane thermostability (\%)} = 1 - \left[\frac{\left(\frac{T_1}{T_2} \right)}{\left(\frac{C_1}{C_2} \right)} \right] \times 100$$

Where, T_1 = initial electrical conductivity (EC) of the heat-treated leaf sample before autoclaving; T_2 = final EC of the heat-treated sample after autoclaving, representing total electrolytes; C_1 = initial EC of the control (non-heated) leaf sample before autoclaving; C_2 = final EC of the control sample after autoclaving.

The data on all the traits under study were recorded replication wise and their mean value was subjected to statistical analysis using the INDOSTAT software. Partitioning the variance components into genotypic coefficient of variation (GCV), phenotypic coefficient of variation (PCV) and genetic advance (GA) (24) and heritability was calculated in the present experiment. The correlation coefficient and path coefficient analysis were performed for the traits under study (25–27). Using the procedure described by, we were able to calculate the correlation coefficient between the various attributes (28). In accordance with early research, the path coefficient

analysis was used to separate the correlation coefficients into direct and indirect effects (26).

3. Results and Discussion

Genetic parameters

The estimates of genetic parameters offer critical insights into the genetic basis of the traits, advising breeding decisions pointed at improving varieties. Results from this study's estimations of genetic parameters showed that environmental factors had an impact on the expression of all of the traits studied, with PCV marginally higher than GCV (Fig. 2). The traits like grain yield per plant had the highest GCV (57.73), followed by the trait grains per plant (39.99), shelling percentage (34.30) and pollen viability (34.10), with slightly higher PCV. High GCV indicates the presence of substantial genetic variability among the genotypes, providing ample scope for effective selection and genetic improvement. The effectiveness of selection in a breeding programme is enhanced by the magnitude of heritability in conjunction with GA. The study highlighted that the trait grains per plant showed the highest GA coupled with high heritability ($h^2(\text{bs})$) (GA=104.49 and $h^2(\text{bs}) = 95$), followed by plant height (GA= 41.81 and $h^2(\text{bs}) = 97$) and 500-grain weight (GA= 40.83 and $h^2(\text{bs}) = 95$), which indicated the importance of these traits in breeding programmes. These findings are in close conformity with the findings of previous studies (29) in sorghum, (30) in maize and (31) in rose.

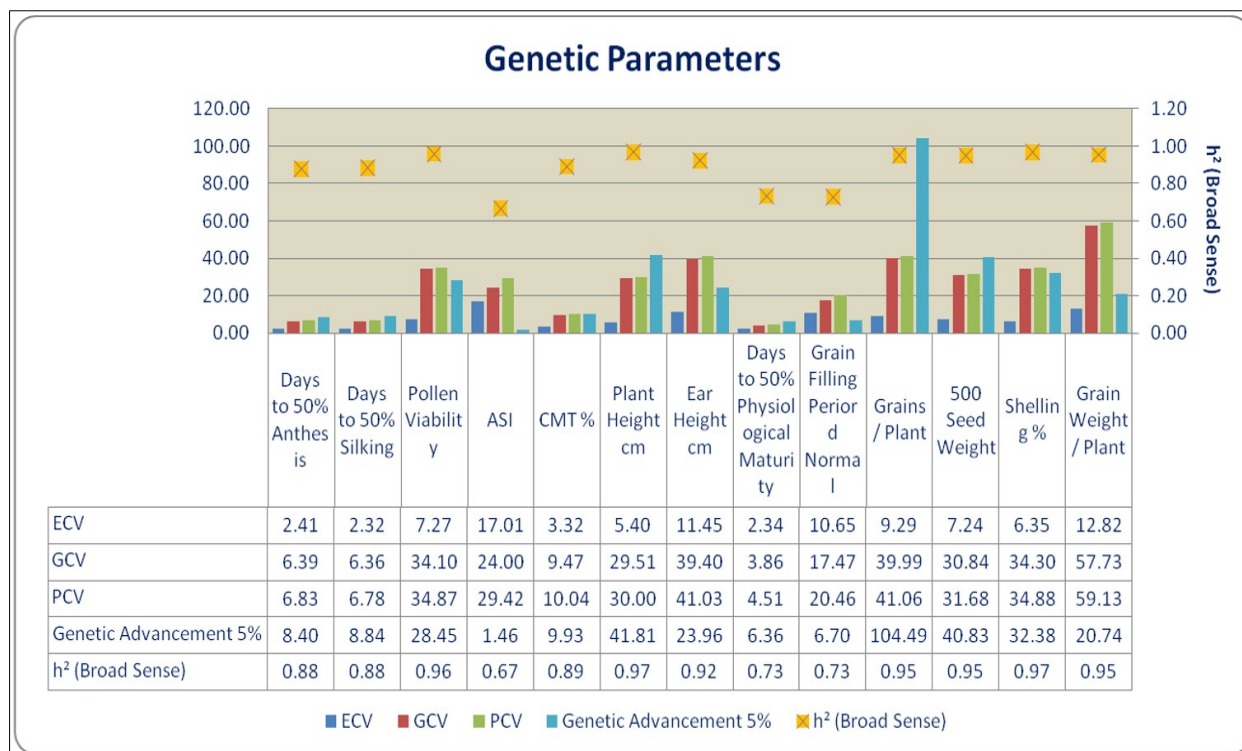


Fig. 2. Genetic parameters for traits under study. PCV: phenotypic coefficient of variation; GCV: genotypic coefficient of variation; ECV: environmental coefficient of variation.

Trait associations

The analysis of correlation coefficients revealed that genotypic correlation coefficients were generally higher in magnitude and consistent in direction compared to their corresponding phenotypic correlations (Tables 1 and 2). This pattern suggests a strong inherent genetic relationship among the traits evaluated under heat stress environments. The traits plant height, ear height, weight of 500 grains and number of grains per plant were all positively and significantly correlated with grain yield. These findings are consistent with those of earlier studies, reported similar associations under stress environments (32). Furthermore, significant and positive associations of grain yield with plant height, ear height, number of grains per plant and shelling percentage under heat stress were also in agreement with the findings of previous studies (33, 34). Grain yield was found to be significantly inversely correlated with anthesis-silking interval (ASI), further supporting the idea that a shorter ASI is a beneficial characteristic when heat stress is present because it ensures better synchronisation between pollen shed (anthesis) and silk emergence (silking), thereby improving pollination, fertilisation and kernel set. The higher genotypic correlation coefficients suggest that these associations are primarily governed by genetic factors, making these traits reliable targets for selection in breeding programmes aimed at improving yield under elevated temperature conditions. Further examination of the direct and indirect contributions of attributes like grains per plant, 500-grain weight and

shelling percentage to grain production under heat stress should be conducted by path coefficient analysis, given the significant and positive relationships with grain yield.

Path coefficient analysis

Using path coefficient analysis, we were able to separate the correlation coefficients into direct and indirect effects, which helped us better understand how different features affected grain yield under heat stress and how they interacted with one another. Table 3 shows that of the 13 characteristics studied, the number of grains per plant had the greatest positive direct effect on grain yield per plant (0.5743) at the phenotypic level, followed by 500-grain weight (0.2905), while Table 4 shows that at the genotypic level, days to 50 % silking (0.8155) and pollen viability (0.7081) had the highest positive direct effects on grain yield per plant. The results highlight the importance of these traits as key yield components in heat-stressed environments. Shelling percentage and ear height also showed low but positively impacting grain yield directly. The traits such as days to 50 % anthesis, cell membrane thermostability, days to 50 % physiological maturity and grain filling period exhibited negligible but positive direct effects. On the flip side, there was little evidence that characteristics including pollen viability, plant height, anthesis-silking interval and days to 50 % silking had any detrimental impact on grain output. Regarding indirect impacts, the number of grains per plant contributed most positively to grain yield indirectly via cell membrane thermostability, followed

by 500-grain weight, shelling percentage, ASI, ear height, days to 50 % silking, physiological maturity, anthesis, plant height and grain filling period. Pollen viability exhibited a tiny negative indirect impact on grain yield via cell membrane thermostability. These results are supported by previous studies. The strong positive direct impact of number of grains per plant on grain output under heat stress concurs with the findings of (33, 35). Similarly, the low positive direct effect of shelling percentage was reported (35), although observed a higher positive effect (33). The positive contribution of ear height is in agreement with previous studies (9, 32), while another study noted a slight negative influence (35). Negligible positive effects of days to 50 % anthesis and cell membrane

thermostability on grain yield are also consistent with early results (35). The observed negative direct effects of plant height are also aligned with previous findings (33). In contrast, the negative direct effects of days to 50 % silking and ASI observed in this study, who found these traits to exert higher positive and moderate negative effects, respectively (35). The phenotypic residual impact was found to be 0.270, indicating that a substantial proportion of variation in grain yield was influenced by other factors not included in the present analysis.

Table 1. Coefficient of phenotypic correlation for 13 quantitative traits in heat-stressed maize

Character	Days to 50 % anthesis	Days to 50 % silking	Pollen viability	Anthesis silking interval	Cell membrane thermostability (%)	Plant height (cm)	Ear height (cm)	Days to 50 % physiological maturity	Grain filling period normal	Grains/plant	500-grain weight	Shelling %	Grain yield/plant
Days to 50 % anthesis	1.000	0.976**	-0.029	0.087	-0.103	-0.209	-0.218*	0.593**	-0.503**	-0.140	-0.094	-0.104	-0.166
Days to 50 % silking	0.976**	1.000	-0.100	0.303**	-0.243*	-0.231*	-0.259*	0.525**	-0.593**	-0.245*	-0.205	-0.232*	-0.305*
Pollen viability	-0.029	-0.100	1.000	-0.329**	0.607**	0.626**	0.514**	0.112	0.215*	0.558**	0.445**	0.739**	0.642**
Anthesis silking interval	0.087	0.303**	-0.329**	1.000	-0.662**	-0.139	-0.227**	-0.192	-0.512**	-0.509**	-0.523**	-0.605**	-0.664*
Cell membrane thermostability (%)	-0.103	-0.243*	0.607**	-0.662**	1.000	0.128	0.179	0.130	0.388**	0.743**	0.534**	0.815**	0.816**
Plant height (cm)	-0.209	-0.231*	0.626**	-0.139	0.128	1.000	0.756**	-0.004	0.248*	0.295**	0.205	0.352**	0.372**
Ear height (cm)	-0.218*	-0.259*	0.514**	-0.227**	0.179	0.756**	1.000	-0.166	0.125	0.202	0.301**	0.355**	0.389**
Days to 50 % physiological maturity	0.593**	0.525**	0.112	-0.192	0.130	-0.004	-0.166	1.000	0.373**	0.160	0.128	0.178	0.182
Grain filling period normal	-0.503**	-0.593**	0.215*	-0.512**	0.388**	0.248*	0.125	0.373**	1.000	0.419**	0.345**	0.421**	0.504**
Grains/plant	-0.140	-0.245*	0.558**	-0.509**	0.743**	0.295**	0.202	0.160	0.419**	1.000	0.342**	0.663**	0.866**
500-grain weight	-0.094	-0.205	0.445**	-0.523**	0.534**	0.205	0.301**	0.128	0.345**	0.342**	1.000	0.569**	0.668**
Shelling %	-0.104	-0.232*	0.739**	-0.605**	0.815**	0.352**	0.355**	0.178	0.421**	0.663**	0.569**	1.000	0.814**
Grain yield/plant	-0.166	-0.305**	0.642**	-0.664**	0.816**	0.372**	0.389**	0.182	0.504**	0.866**	0.668**	0.814**	1.000

* and ** statistically significant at the 5 % and 1 % probability levels, respectively.

Table 2. Coefficient of genotypic correlation for 13 quantitative traits in heat-stressed maize

Character	Days to 50 % anthesis	Days to 50 % silking	Pollen viability	Anthesis silking interval	Cell membrane thermostability (%)	Plant height (cm)	Ear height (cm)	Days to 50 % physiological maturity	Grain filling period normal	Grains/ plant	500-grain weight	Shelling %	Grain yield/ plant
Days to 50 % anthesis	1.000	0.982**	-0.025	0.152	-0.126	-0.218*	-0.245*	0.679**	-0.535*	-0.149	-0.107	-0.112	-0.189
Days to 50 % silking	0.982**	1.000	-0.101	0.335	-0.282*	-0.245*	-0.291*	0.588**	-0.642*	-0.267*	-0.230*	-0.249*	-0.339*
Pollen viability	-0.025	-0.101	1.000	-0.405*	0.658**	0.654*	0.548*	0.164	0.277	0.590**	0.465*	0.773**	0.677**
Anthesis silking interval	0.152	0.335*	-0.405*	1.0000	-0.854**	-0.196	-0.304*	-0.311*	-0.698*	-0.653**	-0.670**	-0.747*	-0.834*
Cell membrane thermostability (%)	-0.126	-0.282*	0.658**	-0.854**	1.000	0.139	0.182	0.189	0.518*	0.796**	0.571*	0.870**	0.870**
Plant height (cm)	-0.218	-0.245*	0.654**	-0.196	0.139	1.000	0.785**	0.024	0.317*	0.292	0.219	0.369*	0.384*
Ear height (cm)	-0.245*	-0.291*	0.548**	-0.304*	0.182	0.785*	1.000	-0.154	0.203	0.214	0.326*	0.381*	0.414*
Days to 50% Physiological maturity	0.679**	0.588**	0.164	-0.311*	0.189	0.024	-0.154	1.000	0.242	0.184	0.156	0.207	0.212
Grain filling period normal	-0.535**	-0.642**	0.277	-0.697**	0.518*	0.317	0.203	0.242	1.000	0.494*	0.423*	0.495*	0.607**
Grains/ plant	-0.149	-0.267*	0.590**	-0.653**	0.796**	0.292	0.214	0.184	0.494*	1.000	0.381*	0.685**	0.877**
500-grain weight	-0.107	-0.230	0.465*	-0.670**	0.571*	0.219	0.326*	0.156	0.423*	0.381*	1.000	0.586*	0.708**
Shelling %	-0.112	-0.249*	0.773**	-0.747**	0.867**	0.369*	0.381*	0.207	0.495*	0.685**	0.586*	1.000	0.833**
Grain yield/ plant	-0.189	-0.339*	0.677**	-0.834**	0.870**	0.384*	0.414*	0.212	0.607**	0.877**	0.708**	0.833**	1.000

* and ** statistically significant at the 5 % and 1 % probability levels, respectively.

Table 3. Coefficient of phenotypic path for the characteristics being studied

Character	Days to 50 % anthesis	Days to 50 % silking	Pollen viability	Anthesis silking interval	Cell membrane thermostability %	Plant height (cm)	Ear height (cm)	Days to 50 % Physiological maturity	Grain filling period normal	Grains/ plant	500-grain weight	Shelling %
Days to 50 % anthesis	0.0040	0.0039	-0.0001	0.0003	-0.0004	-0.0008	-0.0009	0.0024	-0.0020	-0.0006	-0.0004	-0.0004
Days to 50 % silking	-0.0357	-0.0366	0.0037	-0.0111	0.0089	0.0084	0.0095	-0.0192	0.0217	0.0090	0.0075	0.0085
Pollen viability	0.0021	0.0073	-0.0725	0.0238	-0.0440	-0.0454	-0.0373	-0.0081	-0.0156	-0.0405	-0.0323	-0.0536
Anthesis silking interval	-0.0033	-0.0115	0.0125	-0.0381	0.0252	0.0053	0.0087	0.0073	0.0195	0.0194	0.0199	0.0230
Cell membrane	-0.0074	-0.0176	0.0439	-0.0479	0.0723	0.0092	0.0130	0.0094	0.0281	0.0537	0.0386	0.0589



thermostability (%)												
Plant height (cm)	0.0002	0.0002	-0.0006	0.0001	-0.0001	-0.0010	-0.0008	0.0000	-0.0003	-0.0003	-0.0002	-0.0004
Ear height (cm)	-0.0309	-0.0367	0.0729	-0.0322	0.0254	0.1071	0.1417	-0.0235	0.0178	0.0286	0.0426	0.0503
Days to 50 % physiological maturity	0.0315	0.0279	0.0059	-0.0102	0.0069	-0.0002	-0.0088	0.0531	0.0198	0.0085	0.0068	0.0095
Grain filling period normal	-0.0014	-0.0017	0.0006	-0.0014	0.0011	0.0007	0.0003	0.0010	0.0028	0.0012	0.0010	0.0012
Grains/ plant	-0.0803	-0.1409	0.3204	-0.2922	0.4266	0.1696	0.1160	0.0918	0.2405	0.5743	0.1966	0.3808
500-grain weight	-0.0274	-0.0595	0.1293	-0.1519	0.1552	0.0595	0.0873	0.0373	0.1002	0.0995	0.2905	0.1654
Shelling %	-0.0176	-0.0395	0.1260	-0.1030	0.1389	0.0599	0.0605	0.0304	0.0718	0.1130	0.0970	0.1704
Grain yield/ plant	-0.1663	-0.3047	0.6419	-0.6637	0.8160	0.3724	0.3892	0.1818	0.5042	0.8658	0.6677	0.8136

Residual effects: 0.270.

Table 4. Coefficient of genotypic path for the characteristics being studied

Character	Days to 50 % anthesis	Days to 50 % silking	Pollen viability	Anthesis silking interval	Cell membrane thermostability (%)	Plant height (cm)	Ear height (cm)	Days to 50 % physiological maturity	Grain filling period normal	Grains/ Plant	500-grain weight	Shelling %
Days to 50 % anthesis	-0.1055	-0.1036	0.0026	-0.0160	0.0132	0.0230	0.0258	-0.0716	0.0564	0.0157	0.0113	0.0118
Days to 50 % silking	0.8009	0.8155	-0.0824	0.2735	-0.2302	-0.2001	-0.2372	0.4796	-0.5239	-0.2174	-0.1872	-0.2028
Pollen viability	-0.0177	-0.0715	0.7081	-0.2868	0.4661	0.4627	0.3882	0.1162	0.1959	0.4179	0.3290	0.5475
Anthesis silking interval	-0.1536	-0.3389	0.4094	-1.0107	0.8628	0.1983	0.3071	0.3141	0.7042	0.6597	0.6770	0.7545
Cell membrane thermostability (%)	0.1330	0.2991	-0.6975	0.9046	-1.0597	-0.1468	-0.1928	-0.2007	-0.5490	-0.8438	-0.6052	-0.9215
Plant height (cm)	0.0690	0.0775	-0.2066	0.0620	-0.0438	-0.3161	-0.2481	-0.0075	-0.1002	-0.0924	-0.0692	-0.1167
Ear height (cm)	0.0231	0.0275	-0.0518	0.0287	-0.0172	-0.0741	-0.0944	0.0146	-0.0192	-0.0202	-0.0307	-0.0360
Days to 50 % physiological maturity	-0.5035	-0.4361	-0.1217	0.2305	-0.1404	-0.0177	0.1144	-0.7415	-0.1794	-0.1362	-0.1156	-0.1536
Grain filling period normal	-0.3057	-0.3673	0.1582	-0.3984	0.2962	0.1812	0.1160	0.1383	0.5717	0.2824	0.2420	0.2828
Grains/ plant	-0.1005	-0.1794	0.3972	-0.4393	0.5359	0.1968	0.1439	0.1237	0.3324	0.6731	0.2562	0.4607
500-grain weight	-0.0130	-0.0280	0.0566	-0.0817	0.0696	0.0267	0.0397	0.0190	0.0516	0.0464	0.1219	0.0715
Shelling %	-0.0151	-0.0335	0.1042	-0.1006	0.1172	0.0497	0.0514	0.0279	0.0667	0.0923	0.0790	0.1348
Grain yield/ plant	-0.1887	-0.3388	0.6765	-0.8343	0.8699	0.3837	0.4138	0.2121	0.6074	0.8774	0.7083	0.8330

4. Conclusion

The estimates of genetic parameters revealed that the trait number of grains per plant exhibited the highest

genetic advance (GA) coupled with high heritability, followed by plant height and 500-grain weight, indicating the significance of these characteristics for maize breeding under heat stress conditions. The study



highlights that two important factors that determine grain output under heat stress circumstances are the number of grains per plant and the weight of 500 grains.

The study underscores the importance of number of grains per plant and 500-grain weight as key determining factors of grain yield under heat stress conditions. Both correlation and path coefficient analyses revealed that these traits had substantial positive direct and indirect effects on yield. Therefore, while designing heat-tolerant, high-yielding genotypes, these characteristics should be given priority during selection. The relatively high residual effect also suggests that additional physiological or morphological traits may contribute to yield under heat stress and should be considered in future studies. The present study is focused only on one season's experiment and a limited number of genotypes under study, which calls for further intensive research. Inclusion of marker-based research is another avenue for future work.

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Authors' contributions

NR carried out research work, participated in data collection, analysis and drafting of manuscript. NKC participated in writing, editing and proofreading of manuscript. RBPN conceived the study and participated in its design, data collection, analysis and drafting of manuscript. DM participated in proofreading of the manuscript. All authors have read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest

Authors do not have any conflict of interests to declare.

Ethical issues

None

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