

# **Influence of mating systems on trait associations in segregating populations of maize (*Zea mays* L.) double cross**

## **ABSTRACT**

In the present challenging scenario of climate change, it is essential to breed maize cultivars that sustain biotic and especially abiotic stresses in a broader sense. Diversification of existing germplasm is invariable to harness the actual potential of maize hybrids which are generally bred for specific agroecosystems. Double crosses interact less with environment compared to single crosses and their broad parentage enables better performance under varied scenarios of cultivation. In the present study, impact of mating systems *ie.*, self pollination, sib mating and open pollination was studied in a high yielding double cross of maize so as to identify robust and diverse recombinants. The present study focused on comparing the effects of mating type on genetic correlations among the agronomically important characters along with their direct and indirect effects on grain yield. It was observed that sib mating established stronger and highest number of positive correlations among the yield and its attributing traits in its progenies. Results of path analysis, however, did not significantly vary with the mating type though sib mating showed lowest residual effect.

*Key words: Maize, self pollination, sib mating, open pollination, mating system, correlation, path analysis*

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## **1. INTRODUCTION**

Maize (*Zea mays* L.) is one of the major cereal food crops besides rice and wheat providing nutrition to a vast portion of population. Maize and wheat are the primary providers of dietary energy, indispensable proteins, micronutrients, and a wide range of non-nutritional bioactive compounds in our diets [17]. Global crop production faces mounting pressure driven by three primary factors: the expanding global population, elevated meat and dairy consumption due to rising affluence, and the growing demand for biofuels [15]. To fulfill the escalating demands, it might be necessary to raise global agricultural production by 60 to 110% by the year 2050 [16]. The global average rate of yield increase is 1.6 % against a required rate of 2.4% per year which is insufficient to meet the goal of doubling crop production by 2050 for ensuring food security [18].

Maize yields are affected by an array of biotic and environmental stresses especially in rainfed ecosystem thereby limiting the accrued on-farm yield levels. In spite of commendable improvement in maize productivity over the past two decades, the increasing vulnerability of cultivars to various stresses keeps alive the challenge of reaping sustainable benefits amidst changing climatic patterns [11]. It is therefore crucial to develop climate smart maize cultivars that are tolerant to drought, heat, water logging in addition to resistance for biotic constraints so as to stabilize the yields over a broad regime of environmental conditions. The concept of double cross hybrids emerged commercially when there was difficulty to meet the seed demands from single cross hybrids because of weak and inferior inbreds. Although, modern inbreds are much superior comparatively in terms of yield potential and stress tolerance, performance of single cross hybrids is mostly restrained to a specific environment and subject to best management conditions. Double crosses exhibit a lower degree of interaction with environments compared to single crosses, and they surpass single crosses in terms of maintaining stable performance across varying conditions [21]. Double crosses are made from four inbreds, hence retain more heterozygosity and variability, unlike single crosses. It is a well-established fact that heterozygous and heterogeneous populations interact less with environments and have broader adaptability to diverse environments resulting in high rate of stability and increased resilience against stresses through population buffering [1]. As per Sprague and Federer (1951) [21], double crosses excel in maintaining performance stability, making them particularly effective in adverse conditions when compared to single crosses. Double crosses possess more variability in plant and ear traits resulting in lesser yields than single crosses but more consistent performance under challenging climatic conditions [9]. Three way and double crosses where the female parent is a high yielding single cross are more fetching in terms of resistance to pests and diseases [22].

In cross-pollinated crops like maize which do not have self-incompatibility concerns, inbred lines used as parents for producing hybrids are developed through self pollination. Extensive studies on inbreeding depression in maize have indicated that selfing is important in inbred development because it leads to rapid gene homozygosity and desirable favourable genes can be accumulated while the undesirable ones are eliminated. However, the performance of inbred lines or lines produced from selfing decrease drastically, resulting in yield reduction, increase in the number of stunted plants, reduced plant resistance to pests and diseases and reduced growth rate [4,5]. Sib mating becomes a viable option while considering

less severe inbreeding systems. Less restrictive forms of inbreeding which would permit less rapid fixation of deleterious genes as compared to selfing have been suggested for producing more vigorous inbred lines [22]. The third approach is random mating of the segregating populations. The expected gains from this method would be breakup of linkage blocks that are maintained intact due to lack of recombination. Comparison of the three methods for their ability to generate superior recombinants is an interesting study that can assist during inbred line development programmes.

Correlation studies in plant breeding programs play a crucial role in understanding the relationships between different traits and identifying potential markers for desired characteristics. By analyzing the correlation between traits, plant breeders can make more informed decisions on which traits to focus on during the breeding process. Additionally, correlation studies can uncover unexpected relationships between traits, providing valuable insights that may not be immediately apparent. This can lead to innovative approaches in plant breeding, ultimately contributing to the development of improved and resilient crop varieties. Likewise understanding the direction of effect of each trait on grain yield helps the breeder in making selections. The present study was taken up in the  $S_3$  generation populations of two maize double crosses generated *via* three systems of mating viz., selfing, sib mating and random mating to make a comparative assessment of the trait relationships among the individuals as influenced by different mating systems.

## 2. MATERIALS AND METHODS

The experiment was initiated during *kharif* 2016 at Regional Agricultural Research Station, Palem, Telangana State, India with  $F_1$  crop of the double cross *ie.*, (BML-32 x BML-6) x (BML-10 x BML-7). The crop was divided into three equal sections to impose three matings *ie.*, selfing, sib mating and open pollination. The resultant seed was harvested individually mating-wise to raise the  $S_1$  crop in the ensuing season. Likewise, the progenies were imposed with the same mating system for three continuous seasons while advancing the generations till  $S_3$ . The three  $S_3$  ( $F_4$ ) populations thus generated were sown in three replications in randomized block design during *rabi* 2017-18 to study and compare the effects of mating type on trait relationships. Data was collected for twelve agronomical traits *viz.*,

days to 50% tasseling, days to 50% silking, days to maturity, plant height (cm), ear height (cm), ear length(cm), ear circumference (cm), number of kernel rows, number of kernels row<sup>-1</sup>, 100 seed weight (g), shelling percentage (%) and grain yield plant<sup>-1</sup> (g). Statistical analysis for calculating Pearson's correlation coefficients was conducted using R software (version 4.0.2) while OPSTAT was used for the path analysis.

### 3. RESULTS AND DISCUSSION

After three selfing generations, the progenies of the double cross (BML-32 x BML-6) x (BML-10 x BML-7) were evaluated for trait interrelationships. All the yield attributing characters such as ear length (0.637\*\*), ear circumference (0.864\*\*), number of kernel rows (0.425\*), number of kernels row<sup>-1</sup> (0.814\*\*), 100 seed weight (0.805\*\*) and shelling percentage (0.719\*\*) were strongly and positively correlated with grain yield plant<sup>-1</sup> including plant height (0.054) and ear height (0.392\*) indicating an effective selection system with these traits for line development programmes. Similar findings were reported by Munawar et al. (2013)[13], Aman et al. (2020)[2], Yahaya et al. (2021)[28], Reddy et al. (2022)[19] and Verma et al. (2020)[26]. The traits days to 50% tasseling (-0.250), days to 50% silking (-0.277) and days to maturity (-0.235) showed negative associations with grain yield indicating the opportunities for selection of early maturing and high yielding lines [10, 14] (Table 1, Figure 1).

Sib mated progenies of the cross exhibited similar results with ear length (0.761\*\*), ear circumference (0.778\*\*), number of kernel rows (0.844\*), number of kernels row<sup>-1</sup> (0.615\*\*), 100 seed weight (0.776\*\*) and shelling percentage (0.018) showing positive associations with grain yield plant<sup>-1</sup> [12, 2]. However the traits plant height (-0.279) and ear height (-0.184) exhibited negative correlations with grain yield plant<sup>-1</sup> in addition to days to 50% tasseling (-0.470\*\*), 50% silking (-0.145) and maturity (-0.161). High plant height and ear height require higher investment of resources towards vegetative growth and therefore can negatively affect the yields. Hence selection for short genotypes should be made for earliness and better yield performance. The characters ear length, ear circumference, number of kernel rows ear<sup>-1</sup>, number of kernels row<sup>-1</sup>, 100 seed weight and shelling percentage showed highly significant positive associations with each other though shelling percentage exhibited non-significant positive associations with the aforementioned traits in addition to displaying a negative correlation with ear length (-0.270) (Table 1, Figure 2).

Open pollinated populations revealed a mixture of positive and negative correlations between yield and its attributing traits many of them being weak associations. Only two traits

ie., days to 50% silking (0.520\*\*) and days to maturity (0.585\*\*) exhibited significant positive correlation with grain yield plant<sup>-1</sup> whereas plant height (0.328), ear height (0.179), ear circumference (0.270), number of kernel rows ear<sup>-1</sup> (0.155), 100 seed weight (0.136), shelling percentage (0.096) and days to 50% tasseling (0.020) showed non-significant positive associations. In contrary, negative association with grain yield plant<sup>-1</sup> was observed for ear length (-0.089) and number of kernels row<sup>-1</sup>(-0.329) (Table 1, Figure 3).

Comparison of the three mating systems indicates that sib mating manifested seven and twelve additional positive associations with grain yield over self and open pollination systems respectively. The new positive correlations exhibited by sib mating may have been a result of new recombinations reinforced by the mating system resulting in conversion of repulsion type of linkages into coupling type for these character combinations. Thomas (1998)[24] opined that genetic correlation between traits may be due to linkage or/and pleiotropic effect of the genes. While pleiotropic effect cannot be manipulated, association due to linkage can be affected by deploying appropriate breeding programmes. He further reported that biparental mating produced additional desirable correlations in sunflower compared to selfing and open pollination methods. Singh and Murty (1973)[20] reported additional twelve favourable associations in biparental mated progenies than selfs in a study made in pearl millet. The negative or non-significant correlations observed in open pollination indicate that these populations are in linkage disequilibrium and any linkage observed may be due to prevalence of repulsion type linkage. Humphrey et al. (1969)[6] observed a decrease in yield in *Nicotiana* with increased generations of random mating due to disruption of internally balanced chromosomal effects.

Path coefficient analysis was conducted to assess the contribution of various factors by breaking down the correlation coefficients into direct and indirect effects in order to propose a more robust selection criterion. In the selfed progeny, 100 seed weight (0.697) exhibited highest direct positive effect on grain yield plant<sup>-1</sup> followed by ear circumference (0.606), ear length (0.347), number of kernel rows (0.155), plant height (0.102), number of kernels row<sup>-1</sup>(0.053) and days to 50% tasseling (0.052). These results are in accordance with Vishnu et al. (2023) [27] and Verma et al. (2020) [26]. In contrast direct negative effects on grain yield plant<sup>-1</sup> were shown by shelling percentage (-0.491), ear height (-0.388), days to 50% silking (-0.117) and days to maturity (-0.247) [12, 7]. Shelling percentage showed direct negative effect inspite of significant positive correlation with grain yield which may be an implication of high weight of de-shelled cob in contrary to the findings of Devasree et al. (2020) [3]. However, shelling percentage continued to influence the grain yield through other

yield attributing traits like ear length, ear circumference, number of kernel rows, number of kernels row<sup>-1</sup> and 100 seed weight in addition to days to 50% silking, days to 50% tasseling and days to maturity (Table 2, Figure 1).

Dissection of trait contributions towards grain yield among the sib mated progenies suggested that 100 seed weight had highest direct positive effect on grain yield (0.391) followed by number of kernels row<sup>-1</sup> (0.359) and days to maturity (0.302) which was also reflected as significant correlations of these traits with grain yield. In addition, the traits ear length (0.289), shelling percentage (0.142) and ear circumference (0.107) have also shown direct positive effects on grain yield [13, 25]. In contrary, direct negative effects on grain yield were exhibited by plant height (-0.317), ear height (-0.075), number of kernel rows (-0.096), days to 50% tasseling (-0.069) and days to 50% silking (-0.335). Matin et al. (2017)[12] reported indirect negative effects of days to 50% tasseling, days to 50% silking, ear height and days to maturity on yield implying the effectiveness of indirect selection. However, these traits influenced grain yield through other factors. For instance, number of kernel rows manifested high positive indirect effects on grain yield through 100 seed weight (0.305), number of kernels row<sup>-1</sup> (0.359) and ear length (0.202) besides ear circumference (0.072) and shelling percentage (0.028). This was also indicated by the strong positive correlation exhibited by this trait with grain yield ( $rg=0.844^{**}$ ) (Table 2, Figure 2).

In open mated progeny, highest direct positive effect on grain yield was exhibited by days to 50% silking (4.456) followed by number of kernels row<sup>-1</sup> (2.463), 100 seed weight (1.045), days to 50% tasseling (0.426), ear circumference (0.281) and shelling percentage (0.026) while plant height (-1.94), ear length (-1.792), number of kernel rows (-0.536) and days to maturity (-1.687) showed direct negative effects in contrary to the findings of Yahaya et al. (2021) [28] who observed highest direct effect of plant height on maize grain yield. This suggests that higher grain yield was due to high cob girth, more number of kernels, high 100 seed weight [8] and high shelling percentage inspite of having smaller cob size and fewer kernel rows (Table 2, Figure 3).

It is therefore implied that 100 seed weight, number of kernels row<sup>-1</sup> and ear circumference have profound direct and positive influence on the grain yield in all the three mating systems. However, the residual effect which denotes the unexplained variance is lowest in sib mating (0.158) suggesting its comparative advantage over other systems.

#### **4. CONCLUSION**

The results on influence of three mating systems on  $S_3$  ( $F_4$ ) population of the maize double cross on trait correlations have shown that higher number of positive correlations with grain yield was manifested through sib mating. The traits ear length, ear circumference, number of kernel rows, number of kernels row<sup>-1</sup>, 100 seed weight and shelling percentage played a key role in influencing the grain yield and hence should be focused while making selections. Path analysis indicated that 100 seed weight, number of kernels row<sup>-1</sup> and ear circumference have strong direct and positive effects on grain yield. While the mating systems did not much influence the direction of influence of these traits on grain yield, most of the variance was contributed by the traits studied in sib mating while the magnitude of unexplained variance was higher in self and open pollination systems. Therefore it can suggested that sib mating may be adopted in the line development programmes of maize for obtaining diverse, robust and better inbreds.

## REFERENCES

1. Allard RW, Bradshaw AD. Implications of genotype environment interaction in applied plant breeding. *Crop Science*. 1964; 4:503-508
2. Aman J, Bantte K, Alamerew S, Sbhatu DB. Correlation and path coefficient analysis of yield and yield components of quality protein maize (*Zea mays* L) hybrids at Jimma Western Ethiopia. *International Journal of Agronomy* Volume. 2020; Article ID 9651537, 7 pages <https://doi.org/10.1155/2020/9651537>
3. Devasree S, Ganesan KN, Ravikesavan R, Senthil N, Paranidharan V. Relationship between yield and its component traits for enhancing grain yield in single cross hybrids of maize (*Zea mays* L). *Electronic Journal of Plant Breeding* 2020;11(3):796-802
4. Genter CF. Yields of S1 lines from original and advanced synthetic varieties of maize. *Crop Science*. 1971;11(6): 821-824
5. Good RL, Hallauer AR. Inbreeding depression in maize by selfing and full-sibbing. *Crop Science*.1977;17(6): 935-940. <https://doi.org/10.37992/20201103131>.
6. Humphrey AB, Matzinger DF, Cockerham CC. Effect of random intercrossing in a naturally self-fertilizing species, *N. tabacum* L. *Crop Science*.1969; 9: 495-497.

7. Jakhar DS, Singh R, Kumar A. Studies on path coefficient analysis in maize (*Zea mays* L) for grain yield and its attributes. International Journal of Current Microbiology and Applied Sciences.2017; 6(4): 2851-2856
8. Jambagi BP, Wali MC. Heritability correlation and path coefficient analysis in maize germplasm for starch and oil content. Journal of Farm Science. 2016; 29(2):257-260
9. Jones DF. Heterosis and homeostasis in evaluation and in applied genetics. Am Naturalist. 1958; 92: 321-328
10. Krishna B, Singh B, Mandal SS, Rashmi K, Ranjan T. Association and path coefficient analysis among grain yield and related traits in *kharif* maize (*Zea mays* L). The Pharma Innovation Journal. 2021; 10(7): 1062-1067
11. Mao H, Wang H, Liu S, Li Z, Yang X, Yan J, Li J, Tran LP, Qin F. A transposable element in a *NAC* gene is associated with drought tolerance in maize seedlings. Nature Communications.2015; 6:8326 <https://doi.org/101038/ncomms9326>
12. Matin MQI, Uddin MS, Rohman MM, Amiruzzaman M, Azad AK, Banik BR. Genetic variability and path analysis studies in hybrid maize (*Zea mays* L). American Journal of Plant Sciences. 2017; 8: 3101-3109 <http://www.scirp.org/journal/ajps>
13. Munawar M, Shahbaz M, Hammad G, Yasir M. Correlation and path analysis of grain yield components in exotic maize (*Zea mays* L) hybrids. International Journal of Sciences: Basic and Applied Research. 2013;12(1):22-27
14. Nagaraja D, Nallathambi G. Correlation studies for grain yield and yield attributes in maize (*Zea mays* L). Bulletin of Environment Pharmacology and Life Sciences.2017; 6(7): 65-68
15. Nations U. Department of Economic and Social Affairs Population Division. 2015
16. OECD/FAO. OECD-FAO Agricultural Outlook 2012-2021 OECD Publishing and FAO.2021. [http://dxdoi.org/101787/agr\\_outlook-2012-en](http://dxdoi.org/101787/agr_outlook-2012-en)
17. Poole N, Donovan J, Erenstein O. Viewpoint: Agri-nutrition research: Revisiting the contribution of maize and wheat to human nutrition and health Food Policy. 2021;Vol. 100, 101976.<https://doi.org/101016/jfoodpol2020101976>

18. Ray DK, Mueller ND, West PC, Foley JA. Yield trends are insufficient to double global crop production by 2050. *Plos One*. 2013; 8(6):e66428. <https://doi.org/10.1371/journal.pone.0066428>
19. Reddy SGM, Lal GM, Krishna TV, Reddy Y V S, Sandeep N. Correlation and path coefficient analysis for grain yield components in maize (*Zea mays* L). *International Journal of Plant & Soil Science*. 2022; 34(23): 24-36
20. Singh BB, Murty BR. A comparative analysis of biparental mating and selfing in pearl millet (*P.lyphoides* S and H). *Theoretical and Applied Genetics*. 1973; 43: 18-22
21. Sprague GF, Federer WT. A comparison of variance components in corn yield trials II Error year  $\times$  variety location  $\times$  variety and variety components. *Agronomy Journal*. 1951; 43:535-541
22. Stringfield GH. Developing heterozygous parent stocks for maize hybrids DeKalb AgResearch Inc: DeKalb IL USA. 1974
23. Sumalini K, Sravani D, Pradeep T, Usha Rani G, Rajinikanth E, Manjulatha G, Vijay Bhaskar A, Uma Reddy R. A review on maize hybrid breeding - Importance of multiple crosses in comparison with single crosses in present scenario. *Environment and Ecology*. 2018; 36(4): 1079-1082
24. Thomas G. Studies on effect of mating systems on genetic variability, association and path coefficient analysis in Sunflower (*Helianthus annuus* L.).*Ph.D Thesis*. CCS Haryana Agricultural University, Hisar, India.1998.
25. Vara Prasad BVV, Shivani D. Correlation and path analysis in maize (*Zea mays* L). *Journal of Genetics Genomics & Plant Breeding*. 2017; 1(2): 1-7
26. Verma V, Yadav MS, Kumar A, Gathiye GS. Correlation and path analysis for seed yield and components traits in maize (*Zea mays* L). *Journal of Pharmacognosy and Phytochemistry*. 2020; 9(1): 2278-2280
27. Vishnu SV, Kumar SI, Chandar SRH, Pushpalatha G, Krishnam Raju KK. Genetic variability and association studies for grain yield and its component traits in maize (*Zea mays* L) inbreds. *The Pharma Innovation Journal*. 2023; 12(5): 295-299

28. Yahaya MS, Bello I, Unguwanrimi AY. Correlation and path-coefficient analysis for grain yield and agronomic traits of maize (*Zea mays* L). Science World Journal. 2021;16(1)

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**Table 1: Genotypic correlation coefficients for yield and yield related traits of maize double cross after selfing, sib mating and open pollination for three seasons**

Trait		PH	EH	EL	EC	KR	KPR	SW	GY	SP	DT	DS	DM
PH	Self		0.526**	0.013	0.256	-0.02	-0.140	-0.024	0.054	-0.291	-0.186	-0.058	0.093
	Sib		0.128	-0.102	-0.232	-0.315	0.072	-0.027	-0.279	0.006	0.123	-0.484**	-0.634**
	Open		0.165	0.231	-0.225	-0.082	-0.167	0.005	0.328	-0.359	-0.178	0.268	0.194
EH	Self			0.483**	0.557**	0.130	0.393*	0.205	0.392*	0.158	-0.370	-0.156	-0.139
	Sib			-0.051	-0.05	-0.095	0.041	-0.079	-0.184	0.147	0.336	0.029	-0.207
	Open			-0.533**	-0.065	0.311	0.120	0.400*	0.179	-0.007	0.165	-0.035	0.275
EL	Self				0.498**	0.356**	0.531**	0.504**	0.637**	0.631**	-0.217	-0.097	-0.229
	Sib				0.608**	0.672**	0.482**	0.556**	0.761**	-0.270	-0.538**	-0.173	-0.291
	Open				-0.109	0.065	-0.125	-0.180	-0.089	0.235	0.029	0.173	0.117
EC	Self					0.271	0.683**	0.655**	0.864**	0.472**	-0.323	-0.183	-0.081
	Sib					0.636**	0.510**	0.584**	0.778**	0.026	-0.093	-0.008	-0.232
	Open					-0.038	0.146	0.169	0.270	0.068	-0.096	0.374*	0.243
KR	Self						0.396*	0.330	0.425*	0.376*	-0.115	-0.123	-0.449*
	Sib						0.475**	0.589**	0.844**	0.072	-0.501**	-0.257	-0.288
	Open						0.112	0.343	0.155	0.104	0.181	0.295	0.323

<b>KPR</b>	<b>Self</b>							0.724 <sup>**</sup>	0.814 <sup>**</sup>	0.697 <sup>**</sup>	-0.194	-0.135	-0.225
	<b>Sib</b>							0.458 <sup>*</sup>	0.615 <sup>**</sup>	0.038	-0.134	-0.136	-0.247
	<b>Open</b>							0.363 <sup>*</sup>	-0.329	0.015	0.455 <sup>*</sup>	-0.043	-0.088
<b>SW</b>	<b>Self</b>								0.805 <sup>**</sup>	0.745 <sup>**</sup>	-0.034	-0.179	-0.104
	<b>Sib</b>								0.776 <sup>**</sup>	0.231	-0.274	-0.214	-0.319
	<b>Open</b>								0.136	0.064	0.261	0.168	0.597 <sup>**</sup>
<b>GY</b>	<b>Self</b>									0.719 <sup>**</sup>	-0.250	-0.277	-0.235
	<b>Sib</b>									0.018	-0.470 <sup>**</sup>	-0.145	-0.161
	<b>Open</b>									0.096	0.020	0.520 <sup>**</sup>	0.585 <sup>**</sup>
<b>SP</b>	<b>Self</b>										-0.07	-0.118	-0.272
	<b>Sib</b>										0.330	0.140	-0.081
	<b>Open</b>										0.091	0.147	0.341
<b>DT</b>	<b>Self</b>											0.116	0.190
	<b>Sib</b>											0.535 <sup>**</sup>	0.160
	<b>Open</b>											-0.01	0.055
<b>DS</b>	<b>Self</b>												0.260
	<b>Sib</b>												0.543 <sup>**</sup>
	<b>Open</b>												0.468 <sup>**</sup>

\*\* Significant at 1 per cent

\* Significant at 5 per cent

DT - Days to 50% tasseling; DS - Days to 50% silking; DM - Days to maturity; PH - Plant height (cm); EH - Ear height (cm);  
 EL - Ear length (cm); EC - Ear circumference (cm); KR - Number of kernel rows<sup>-1</sup>; KPR - Number of kernels row<sup>-1</sup>; SW - 100 seed weight (g);  
 SP - Shelling percentage (%); GY - Grain yield plant<sup>-1</sup> (g)

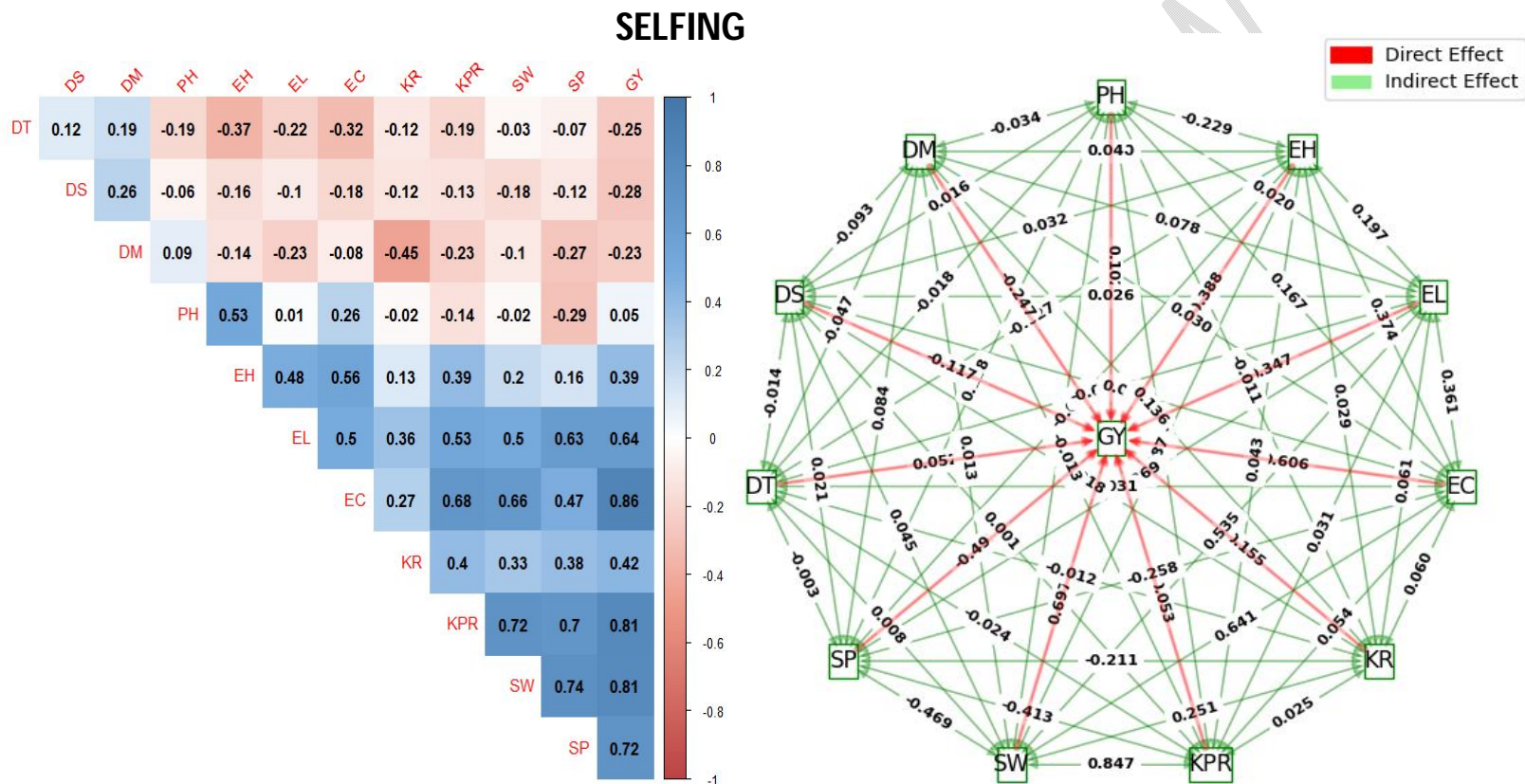
**Table 2: Direct (diagonal) and indirect effects of yield related traits on grain yield plant<sup>-1</sup> in maize double cross after selfing, sib mating and open pollination for three seasons**

Trait	Mating System	PH	EH	EL	EC	KR	KPR	SW	SP	DT	DS	DM	GY
PH	Self	<b>0.102</b>	-0.229	0.020	0.167	-0.011	0.002	-0.045	0.158	-0.018	0.016	-0.034	0.054
	Sib	<b>-0.317</b>	-0.013	-0.036	-0.027	0.035	0.012	-0.001	0.020	-0.009	0.213	-0.183	-0.279
	OP	<b>-1.940</b>	-0.162	-0.286	-0.062	-0.028	1.266	-0.330	-0.020	-0.123	3.171	-1.184	0.328
EH	Self	0.060	<b>-0.388</b>	0.197	0.374	0.029	0.043	0.187	-0.082	-0.027	0.032	0.040	0.392
	Sib	-0.055	<b>-0.075</b>	-0.020	-0.003	0.012	0.039	-0.054	0.038	-0.032	-0.024	-0.033	-0.184
	OP	0.572	<b>0.548</b>	1.257	-0.057	-0.206	-1.197	0.407	0.002	0.179	-0.353	-0.895	0.179
EL	Self	0.006	-0.221	<b>0.347</b>	0.361	0.061	0.031	0.535	-0.369	-0.023	0.026	0.078	0.637 <sup>**</sup>
	Sib	0.039	0.005	<b>0.289</b>	0.069	-0.067	0.267	0.269	-0.047	0.057	0.058	-0.052	0.761 <sup>**</sup>
	OP	-0.310	-0.385	<b>-1.792</b>	0.046	-0.317	1.694	-0.145	0.020	0.072	1.352	-0.466	-0.089
EC	Self	0.028	-0.239	0.207	<b>0.606</b>	0.060	0.054	0.641	-0.258	-0.031	0.038	0.030	0.864 <sup>**</sup>
	Sib	0.079	0.002	0.187	<b>0.107</b>	-0.065	0.212	0.313	0.010	0.003	0.027	-0.029	0.778 <sup>**</sup>
	OP	0.426	-0.112	-0.296	<b>0.281</b>	0.042	-1.339	0.300	0.014	-0.035	2.452	-1.401	0.270
KR	Self	-0.007	-0.072	0.137	0.236	<b>0.155</b>	0.025	0.251	-0.211	-0.012	0.018	0.136	0.425 <sup>**</sup>
	Sib	0.115	0.009	0.202	0.072	<b>-0.096</b>	0.255	0.305	0.028	0.052	0.097	-0.053	0.844 <sup>**</sup>
	OP	-0.100	0.211	-1.058	-0.022	<b>-0.536</b>	0.003	0.543	0.010	0.103	2.301	-0.997	0.155
KPR	Self	0.004	-0.319	0.203	0.623	0.072	<b>0.053</b>	0.847	-0.413	-0.024	0.001	-0.013	0.814 <sup>**</sup>
	Sib	-0.011	-0.008	0.215	0.063	-0.068	<b>0.359</b>	0.337	0.006	0.012	0.058	-0.073	0.615 <sup>**</sup>
	OP	-0.997	-0.266	-1.232	-0.153	-0.001	<b>2.463</b>	-0.194	-0.002	-0.242	0.548	0.219	-0.329
SW	Self	-0.007	-0.104	0.266	0.556	0.056	0.064	<b>0.697</b>	-0.469	0.008	0.045	0.013	0.805 <sup>**</sup>
	Sib	0.001	0.010	0.199	0.085	-0.075	0.309	<b>0.391</b>	0.039	0.047	0.077	-0.097	0.776 <sup>**</sup>
	OP	0.613	0.213	0.249	0.081	-0.279	-0.457	<b>1.045</b>	0.004	0.342	0.669	-2.309	0.136

<b>SP</b>	<b>Self</b>	-0.033	-0.065	0.261	0.318	0.067	0.044	0.667	<b>-0.491</b>	-0.003	0.021	0.084	0.719 <sup>**</sup>
	<b>Sib</b>	-0.046	-0.020	-0.096	0.008	-0.019	0.016	0.109	<b>0.142</b>	-0.050	-0.100	-0.072	0.018
	<b>OP</b>	1.535	0.044	-1.417	0.159	-0.209	-0.203	0.173	<b>0.026</b>	0.321	1.438	-1.518	0.096
<b>DT</b>	<b>Self</b>	-0.035	0.202	-0.153	-0.357	-0.035	-0.024	0.102	0.024	<b>0.052</b>	-0.014	-0.047	-0.250
	<b>Sib</b>	-0.042	-0.035	-0.237	-0.005	0.072	-0.061	-0.268	0.103	<b>-0.069</b>	-0.377	0.152	-0.470 <sup>**</sup>
	<b>OP</b>	-0.042	-0.035	-0.237	-0.005	0.072	-0.061	-0.268	0.103	<b>-0.069</b>	-0.377	0.152	0.020
<b>DS</b>	<b>Self</b>	-0.014	0.106	-0.077	-0.196	-0.024	-0.000	-0.269	0.088	0.006	<b>-0.117</b>	-0.093	-0.277
	<b>Sib</b>	0.202	-0.005	-0.050	-0.009	0.028	-0.062	-0.090	0.043	-0.078	<b>-0.335</b>	0.181	-0.145
	<b>OP</b>	-1.381	-0.043	-0.544	0.155	-0.277	0.303	0.157	0.008	-0.066	<b>4.456</b>	-1.564	0.520 <sup>**</sup>
<b>DM</b>	<b>Self</b>	0.014	0.062	-0.110	-0.075	-0.085	0.003	-0.036	0.167	0.010	-0.044	<b>-0.247</b>	-0.235
	<b>Sib</b>	0.192	0.008	-0.050	-0.010	0.017	-0.087	-0.126	-0.034	-0.035	-0.200	<b>0.302</b>	-0.161
	<b>OP</b>	-1.362	0.291	-0.495	0.233	-0.317	-0.320	1.430	0.023	-0.055	4.131	<b>-1.687</b>	0.585 <sup>**</sup>

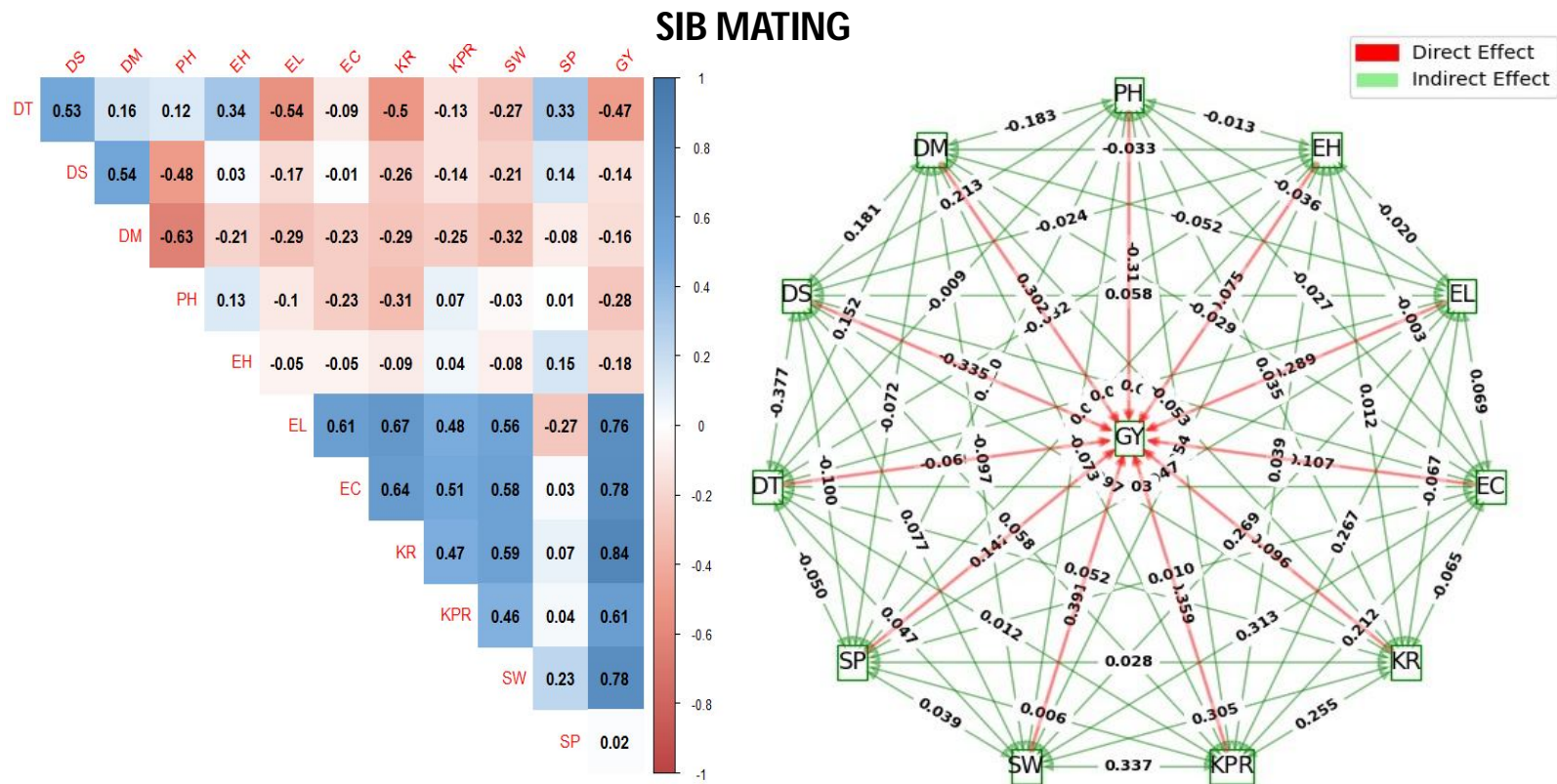
r = 0.460 (self); 0.158(sib); 1.455 (op)

DT - Days to 50% tasseling; DS - Days to 50% silking; DM - Days to maturity; PH - Plant height (cm); EH - Ear height (cm);  
 EL - Ear length (cm); EC - Ear circumference (cm); KR - Number of kernel rows<sup>-1</sup>; KPR - Number of kernels row<sup>-1</sup>; SW - 100 seed weight (g);  
 SP - Shelling percentage (%); GY - Grain yield plant<sup>-1</sup> (g)



DT - Days to 50% tasseling; DS - Days to 50% silking; DM - Days to maturity; PH - Plant height (cm); EH - Ear height (cm); EL - Ear length (cm); EC - Ear circumference (cm); KR - Number of kernel rows<sup>-1</sup>; KPR - Number of kernels row<sup>-1</sup>; SW - 100 seed weight (g); SP - Shelling percentage (%); GY - Grain yield plant<sup>-1</sup> (g)

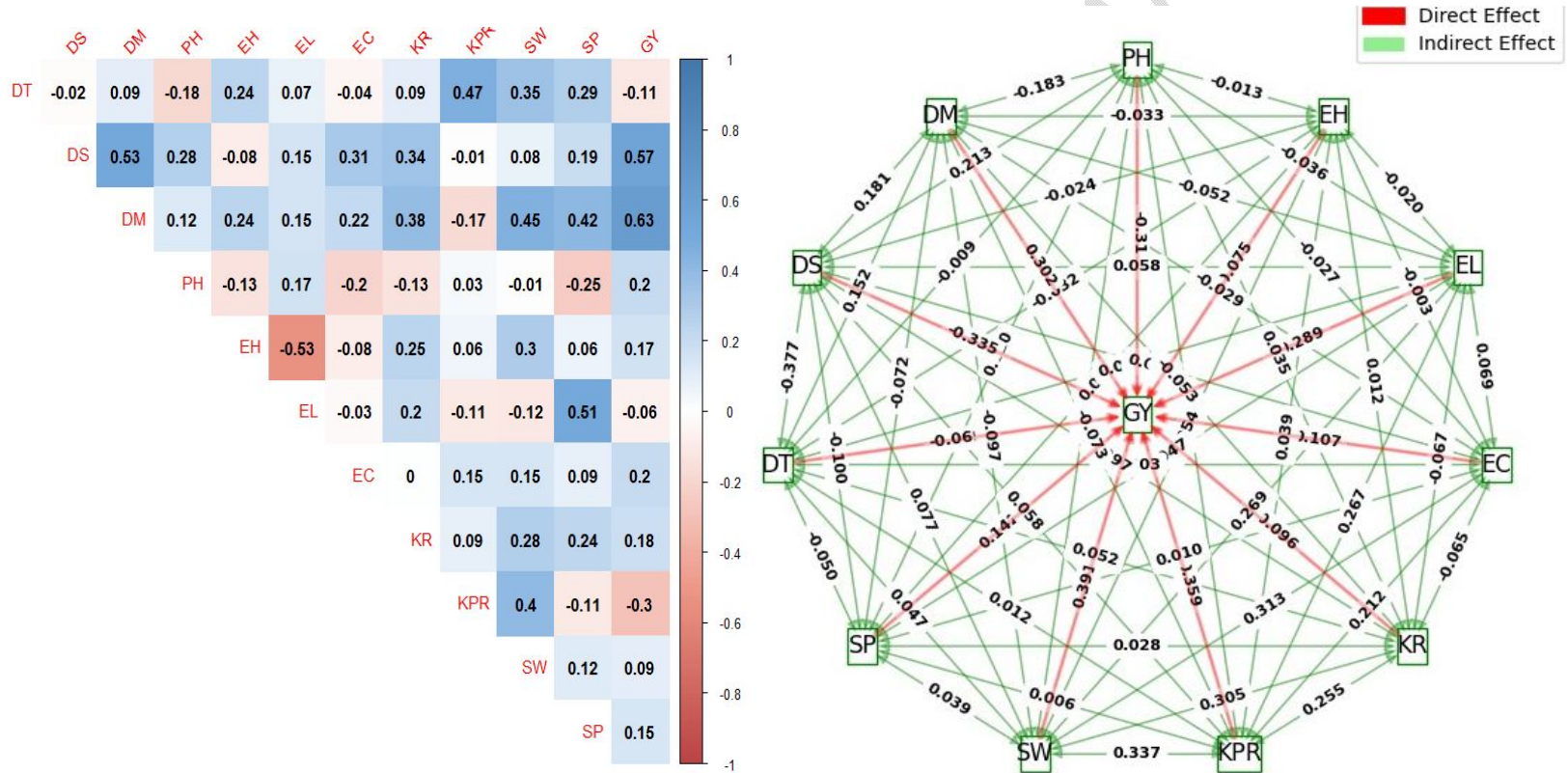
**Figure 1. Graphs showing correlations, direct and indirect effects of yield related traits in maize double cross progenies after selfing**



DT - Days to 50% tasseling; DS - Days to 50% silking; DM - Days to maturity; PH - Plant height (cm); EH - Ear height (cm);  
 EL - Ear length (cm); EC - Ear circumference (cm); KR - Number of kernel rows<sup>-1</sup>; KPR - Number of kernels row<sup>-1</sup>; SW - 100 seed weight (g);  
 SP - Shelling percentage (%); GY - Grain yield plant<sup>-1</sup> (g)

**Figure 2. Graphs showing correlations, direct and indirect effects of yield related traits in maize double cross progenies after sib mating**

## OPEN POLLINATION



DT - Days to 50 per cent tasseling; DS - Days to 50 per cent silking; DM - Days to maturity;  
 PH - Plant height (cm); EH - Ear height (cm); EL - Ear length (cm); EC - Ear circumference (cm); KR - Number of kernel rows /ear; KPR - Number of kernels/row;  
 SW - 100-seed weight (g); SP - Shelling percentage (%); GY - Grain yield /plant (g)

**Figure 3. Graphs showing correlations, direct and indirect effects of yield related traits in maize double cross progenies after open pollination**