Pak. J. Bot., 56(3): 863-869, 2024. DOI: http://dx.doi.org/10.30848/PJB2024-3(33)

CORRELATION AND PATH COEFFICIENT ANALYSES OF DIFFERENT MORPHO-PHYSIOLOGICAL TRAITS IN DOUBLED HAPLOID MAIZE HYBRIDS UNDER NORMAL AND DROUGHT STRESS

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Abstract

In this research, the problem of drought stress and its impact on maize crops was addressed. Different morpho-physiological traits were recorded in fifteen doubled haploid maize hybrids and their parents, under normal conditions and drought stress. Based on the RCBD (Randomized Complete Block Design), two factors of factorial structure treatments were used for the experiment. In order to investigate the correlation between traits, correlation coefficients were calculated at both genotypic and phenotypic levels. Path coefficient analysis was used to determine direct and indirect effects on grain yield per plant. Genotypic correlation coefficients were generally higher than phenotypic correlation coefficients, suggesting that the impact of environmental effects was minimal. Traits such as leaf area, leaf number, and plant height, showed positive correlations with grain yield under both normal and drought stress conditions. Path coefficient analysis revealed the direct and indirect effects of various traits on grain yield. Leaf area and 100-grain weight had the highest positive direct effects on grain yield. These findings provide valuable insights for breeding maize cultivars with improved drought tolerance by selecting traits such as leaf area, plant height, and leaf number. This research focuses on the negative effects of drought stress on maize crops and the importance of developing drought-tolerant hybrids to mitigate yield losses and enhance food security. The study aims to uncover the genetic basis and correlation between grain yield and green yield-related traits under normal and drought stress conditions, with the goal of selecting genotypes that indirectly maximize yield and improve drought tolerance in maize cultivars.

Key words: Biotic and abiotic stress, Drought-tolerant hybrids, Grain yield, Genetic variability, Maize production.

Abbreviations used in the paper: Plant height = PH; Cob length = CL; Leaf angle = LAn; Leaf area = LA; NOL = NOL; Stem diameter = SD; Leaf temperature = LT; Cob diameter = CD; Grain rows per ear = GRE; Grains per ear = GPE; 100-grain yield = 100 GY; Grain yield per plant = GYP; Harvest index = HI.

Introduction

Metabolic changes in plants are affected by a variety of abiotic and biotic stresses (Vemanna *et al*., 2019) which results in the reduction of growth and yield (Pandey *et al*., 2017). Crop production is threatened by these stresses in most agricultural areas around the world. The most crucial abiotic factor limiting maize production is drought in tropical and subtropical zones (Messmer *et al*., 2011). Drought stress greatly reduces agricultural crop productivity across the globe, making it one of the biggest abiotic stresses (Bruce *et al*., 2002).

In terms of global production, maize ranks third among staple food crops. Over the past decade, it has grown in semi-arid, arid, semi-humid, and humid regions throughout the hemispheres on an average of 157 million hectares, resulting in an average yield of 781 Mt (Ramirez *et al*., 2017). Maize grain is used for the extraction of corn oil, the production of corn flour, the extraction of starch, and the manufacture of corn flakes and corn syrup. Maize cob powder is used for explosive fillers in plastics, adhesives, glues, resins, artificial leather, and vinegar production. Additionally, it is used as a diluent and carrier in the formulation of pesticides and insecticides, as well as for hardboard, pulp, and paper production.

Increasing maize yields is vital to future food security, particularly in food-insecure countries. Drought stress is one of the major environmental constraints that negatively affects growth, yield, quality, quantity and nutritional profile of various crops (Perveen *et al.,* Darynato *et al*., 2016 analyzed data from 35 years (1980-2015) to show that water stress reduced maize yield by 40% globally. It is revealed that loss in maize yield under drought stress is specifically related to the severity of the drought level and at which growth stage, the drought stress was applied. Drought drastically reduced the plant biomass at the seedling stage and affects morphology such as plant height, leaf area, and yield at the vegetative and milk stage (Luqman *et al.*, 2023). Maize yield loss is influenced by the severity of the drought, the exposure period, and the growth stage. Severe and prolonged drought will severely affect the flowering, and grain-filling stages of maize, leading to grain yield losses of 30 to 90% (Sah *et al*., 2020). For morpho-physiological markers that promote stress tolerance in maize on the basis of genetic variability is vital for development of water stress tolerant cultivars at initial and late periods of growth (Tahir *et al.*, 2023). .The drought stress had a significant impact on the total biomass at the vegetative and tasselling stages (Cakir, 2004). The key component to stabilize maize production is the understanding of genetics and applying it for the improvement and development of maize drought-tolerant hybrids.

The correlation of a specific character with the other related traits contributing to grain yield is of considerable significance for the selection of genotypes via indirect means for maximum grain yield. Correlation coefficients are partitioned by path coefficient analysis into direct and indirect effects. Under normal and drought stress conditions, phenotypic and genotypic correlations were examined as well as the direct and indirect effects of various traits on grain yield.

There is a positive correlation between certain morpho-physiological traits (such as leaf area, leaf number, and plant height) and grain yield in maize crops under both normal and drought stress conditions and selecting for these traits can lead to the development of drought-tolerant maize cultivars with improved grain yield.

The objectives of this study were:

1) To assess the genetic variability of various traits related to grain yield in maize doubled haploid hybrids under normal and drought stress conditions.
2) To determine the genetic and phenotypic correlations between different traits and grain yield in maize under normal and drought stress conditions.
3) To identify the direct and indirect effects of specific traits on grain yield in maize under normal and drought stress conditions.
4) To provide insights into the traits that could be targeted for breeding drought-tolerant maize cultivars and improving grain yield.

Material and Methods

The study utilized a genetic material that was created by crossing five maize-doubled haploid lines with three phenotypically diverse testers in a line × tester mating design. The parents and developed crosses were subjected to two-factor factorial treatments in a randomized complete block design. Each entry was sown as a single row with a plant-to-plant spacing of 25 cm and a row-to-row spacing of 75 cm. All necessary cultural and agronomic practices were followed during the crop cultivation.

Under normal conditions, the genetic material received twelve irrigations, while alternate irrigations were omitted for the genetic material grown under drought conditions. Data were recorded for twelve traits: Plant height, cob length, leaf angle, leaf area, stem diameter, leaf temperature, cob diameter, grains rows per ear, grains per ear, 100-grain weight, grain yield per plant, and harvest index. For each replication and treatment, a random sample of five plants was selected from each entry, and the data was collected by averaging the measurements.

To assess the genetic variability, a plot of averages based on five observations was used, following the method outlined by Steel *et al*., (1997). The association between genotypic and phenotypic traits was determined according to the approach described by Kwon & Torrie (1964).

Results

This study aimed to analyze the correlation and path analysis of different morpho-physiological traits in doubled haploid maize hybrids under normal and drought stress conditions.

Analysis of variance: Analysis of variance for the studied traits is displayed in (Table 1). All traits under normal conditions showed significant differences except CD. Parents were significantly different for all the traits except the NOL, LT, and CD. Significant differences were found among crosses, lines, testers, and parents vs crosses for all the studied traits other than CD. The interaction among line × tester was significantly different for all the studied traits except LT and CD.

Analysis of variance for studied traits under drought stress is presented in (Table 2). All the studied traits other than CD and 100-grain weight were found to be significantly different among all entries and parents under drought stress. Parents vs crosses differed significantly for all the traits except CD, SD, and 100GW. All traits except CD and 100GW showed significant differences among crosses, lines, and testers.

The analysis of variance showed significant genetic variability among the studied traits. This variability suggests that there is potential for exploiting heterosis (hybrid vigor) for the development of maize hybrids with improved traits related to grain yield. The observed variability among parents and crosses indicates the possibility of selecting superior genotypes for breeding programs.

Association: In this research, correlation coefficients at both genotypic and phenotypic levels to investigate the relationship between different morpho-physiological traits. The genotypic coefficient correlation of studied traits was greater than the phenotypic correlation coefficients both under normal conditions and under drought stress, which showed that the impact of environmental effects was less. The genotypic and phenotypic correlation coefficients among the studied traits under normal conditions are displayed in (Table 3). Grain yield was positively and significantly correlated with SD, LA, CB, and GRE at the genotypic level only. The significant positive correlations between certain traits, such as genotypic variation in grain GYP and PH, NOL, LA, and SD under both normal and drought conditions indicate a strong association between these traits. This suggests that these traits may influence grain yield directly or indirectly.

Correlation coefficients among all the studied traits both at a genotypic and phenotypic level under drought stress are displayed in (Table 4). Grain yield showed positive and significant phenotypic and genotypic correlation coefficients with LA, PH, SD, CB, and HI.

Under both normal and stress conditions, two traits LA and SD showed positive and significant correlations with grain yield at both phenotypic and genotypic levels.

The study found that genotypic correlation coefficients were generally greater than phenotypic correlation coefficients for the studied traits under both normal and drought stress conditions. This indicates that genetic factors rather than environmental effects primarily influenced the observed correlations between traits. This finding suggests that genetic control plays a significant role in the association between traits and grain yield.

Path coefficient analysis: Path analysis showed direct and indirect effects of studied traits on GYP under the normal condition that is displayed in (Fig. 1). A maximum positive direct effect on grain yield could be found with LA, SD, and 100-grain weight. NOL had positive and highest indirect effects on GYP via PH, ,LAn, GPE and SD. NOL, LA, CB, HI, GRE and GPE had the highest positive indirect effect on GYP through SD. LT, PH, GPE, LAn and grains rows per ear showed the highest positive indirect effects on grain yield via NOL. NOL, SD, LA, HI and GRE had the highest positive indirect effects on GYP through PH. SD, CB, HI and GPE had the highest positive indirect effects on grain yield through LA.

Table 1. Mean square values from analysis of variance for field traits in maize doubled haploid hybrids under normal conditions.

Source of variance	df	PH	LT	LA	LAn	NOL	SD	CB	CD	GRE	GPE	100 GW	GYP	HI
Replications	1	15.09	4.91	3.52	3.58	2.17	0.97	0.10	0.49	3.13	25.68	1.98	42.09	0.009*
Treatments	22	281.47*	27.43*	14052.93*	87.77*	25.45*	2.05*	25.80*	0.31	9.34*	10734.33*	11.91*	355.24*	0.053*
Parents	7	197.91*	4.47	965.14*	89.48*	1.29	2.24*	6.63*	0.19	3.82*	2087.71*	2.82*	311.83*	0.023*
Parents vs crosses	1	650.95*	212.00*	102941.08*	222.82*	69.16*	3.09*	61.01*	0.82	24.26*	68321.08*	120.58*	212.97*	0.700*
Crosses	14	296.86*	25.72*	14247.67*	77.27*	34.40*	1.88*	32.87*	0.34	11.03*	10944.31*	8.70*	387.10*	0.022*
Lines	4	195.96*	35.17*	3599.79*	94.58*	17.42*	0.86*	35.72*	0.10	4.28*	3899.98*	8.22*	202.70*	0.013*
Testers	2	1316.94*	89.02*	21943.63*	144.07*	147.63*	4.62*	39.68*	0.31	8.23*	34898.95*	18.20*	478.13*	0.009*
Lines x Testers	8	92.28*	5.17	17647.62*	51.91*	14.59*	1.71*	29.74*	0.47	15.11*	8477.82*	6.56*	456.55*	0.030*
Error	22	2.41	2.34	24.70	4.27	1.08	0.27	2.15	0.23	1.40	503.08	0.40	5.82	0.001
Total	**45**													

Table 2. Mean square values from analysis of variance for field traits in maize doubled haploid hybrids under drought conditions.

Source of variance	df	PH	LT	LA	LAn	NOL	SD	CB	CD	GRE	GPE	100 GW	GYP	HI
Replications	1	3.08	0.03	23.37	2.50	1.761	0.11	0.07	0.003	1.39	809.76	6.89	39.88	0.00004
Treatments	22	228.27*	44.98*	7185.36*	7.22*	2.30*	0.27*	4.68*	0.039	6.66*	10465.04*	5.73*	262.76*	0.0051*
Parents	7	236.02*	20.67*	2135.72*	6.21*	3.70*	0.33*	4.68*	0.063	8.25*	6568.43*	2.21*	113.24*	0.0089*
Parents vs crosses	1	278.85*	205.66*	613.54*	32.88*	7.00*	0.05	3.91*	0.046	5.48*	55513.40*	10.71*	363.25*	0.0018*
Crosses	14	220.78*	45.66*	10179.60*	5.90*	1.27*	0.26*	4.74*	0.026	5.94*	9195.60*	7.13*	330.34*	0.0034*
Lines	4	84.65*	30.25*	10472.92*	5.12*	1.86*	0.29*	6.09*	0.023	7.13*	5755.45*	8.77*	327.64*	0.0035*
Testers	2	5.13*	118.67*	38198.61*	2.54*	0.90	0.55*	1.74*	0.011	3.60*	4504.63*	5.13*	815.89*	0.0046*
Lines x Testers	8	6.81*	35.11*	3028.19*	7.13*	1.06*	0.17*	4.81*	0.031	5.93*	12088.43*	6.81*	210.31*	0.0030*
Error	22	5.25	0.52	3.20	0.46	0.397	0.03	0.79	0.029	0.66	312.62	5.85	24.87	0.000544
Total	**45**													

Table 3. Genotypic (bold) and phenotypic correlation of studied traits in maize doubled haploid under normal conditions.

	LT	LA	LAn	NOL	SD	CB	GRE	GPE	100-grain weight	HI	GYP
PH	**0.53***	**-0.24**	**0.28**	**-0.41***	**-0.63***	**-0.24**	**-0.34***	**-0.19**	**0.36***	**0.19**	**-0.31***
	0.50*	-0.24	0.27	-0.38*	-0.38*	-0.24*	-0.31*	-0.18	0.34*	-0.30*	0.19
LT		**-0.02**	**0.12**	**-0.06**	**-0.31***	**-0.33***	**-0.38***	**-0.18**	**0.56***	**0.12**	**0.002**
		-0.01	0.14	-0.006	-0.25	-0.29	-0.41*	-0.16	0.50*	-0.007	0.12
LA			**-0.25**	**0.08**	**0.49***	**0.17**	**-0.09**	**0.31***	**-0.06**	**0.09**	**0.48***
			-0.23	0.095	0.42*	0.16	-0.07	0.31*	-0.06	0.47*	0.09
LAn				**-0.34***	**-0.31***	**0.14**	**0.11**	**0.02**	**-0.13**	**-0.09**	**-0.09**
				-0.29*	-0.28*	0.10*	0.06	0.01	-0.10	-0.09	-0.09
NOL					**0.39***	**0.05**	**-0.05**	**-0.48***	**0.02**	**-0.44***	**-0.005**
					0.28*	0.04	-0.04	-0.44*	0.02	-0.003	-0.42*
SD						**0.17**	**0.24**	**0.24**	**-0.39***	**-0.01**	**0.38***
						0.13	0.18	0.20	-0.29*	0.33*	0.01
CB							**0.54**	**0.23**	**-0.31***	**-0.35***	**0.46***
							0.49*	0.19	-0.27	0.43*	-0.34*
GRE								**0.30***	**-0.46***	**-0.20**	**0.31***
								0.24	-0.39*	0.31*	-0.18
GPE									**-0.35***	**0.12**	**0.25**
									-0.32*	0.25	0.11
100 GW										**0.25**	**-0.14***
										-0.11*	0.24
HI											**-0.31**
											-0.30

Table 4. Genotypic (bold) and phenotypic correlation of studied traits in maize doubled haploid hybrids under drought stress.

	LT	LA	LAn	NOL	SD	Cob length	GRE	GPE	HI	GYP
PH	**-0.66***	**0.51***	**-0.37***	**0.51***	**0.28***	**0.44***	**0.23**	**-0.03**	**0.03**	**0.36***
	-0.64*	0.49*	-0.35*	0.44*	0.23	0.37*	0.21	-0.04	0.05	0.32*
LT		**-0.44***	**0.40***	**-0.05**	**-0.19**	**-0.04**	**0.08**	**0.09**	**-0.04**	**-0.33***
		-0.44*	0.38*	-0.04	-0.17	-0.06	0.06	0.08	-0.02	-0.32*
LA			**-0.17***	**0.29***	**0.38***	**0.11**	**0.05**	**-0.17**	**-0.16**	**0.49***
			-0.16	0.24	0.33*	0.09	0.05	-0.17	-0.15	0.45*
LAn				**-0.08**	**0.21**	**-0.44***	**-0.09**	**-0.05**	**0.04**	**-0.13**
				-0.02	0.17	-0.33*	-0.09	-0.09	0.03	-0.11
NOL					**0.29***	**0.33***	**0.25**	**-0.20**	**-0.44***	**-0.19**
					0.28*	0.19	0.28*	-0.21	-0.35*	-0.16
SD						**0.24**	**0.24**	**-0.32***	**-0.22**	**0.55***
						0.21	0.23*	-0.30*	-0.16	0.50*
CB							**0.37***	**0.05**	**0.33***	**0.39***
							0.29	0.02	0.20	0.33*
GRE								**0.03**	**-0.03**	**-0.05**
								0.03	0.01	-0.04
GPE									**-0.17**	**-0.10**
									-0.14	-0.11
HI										**0.33***
										0.32*

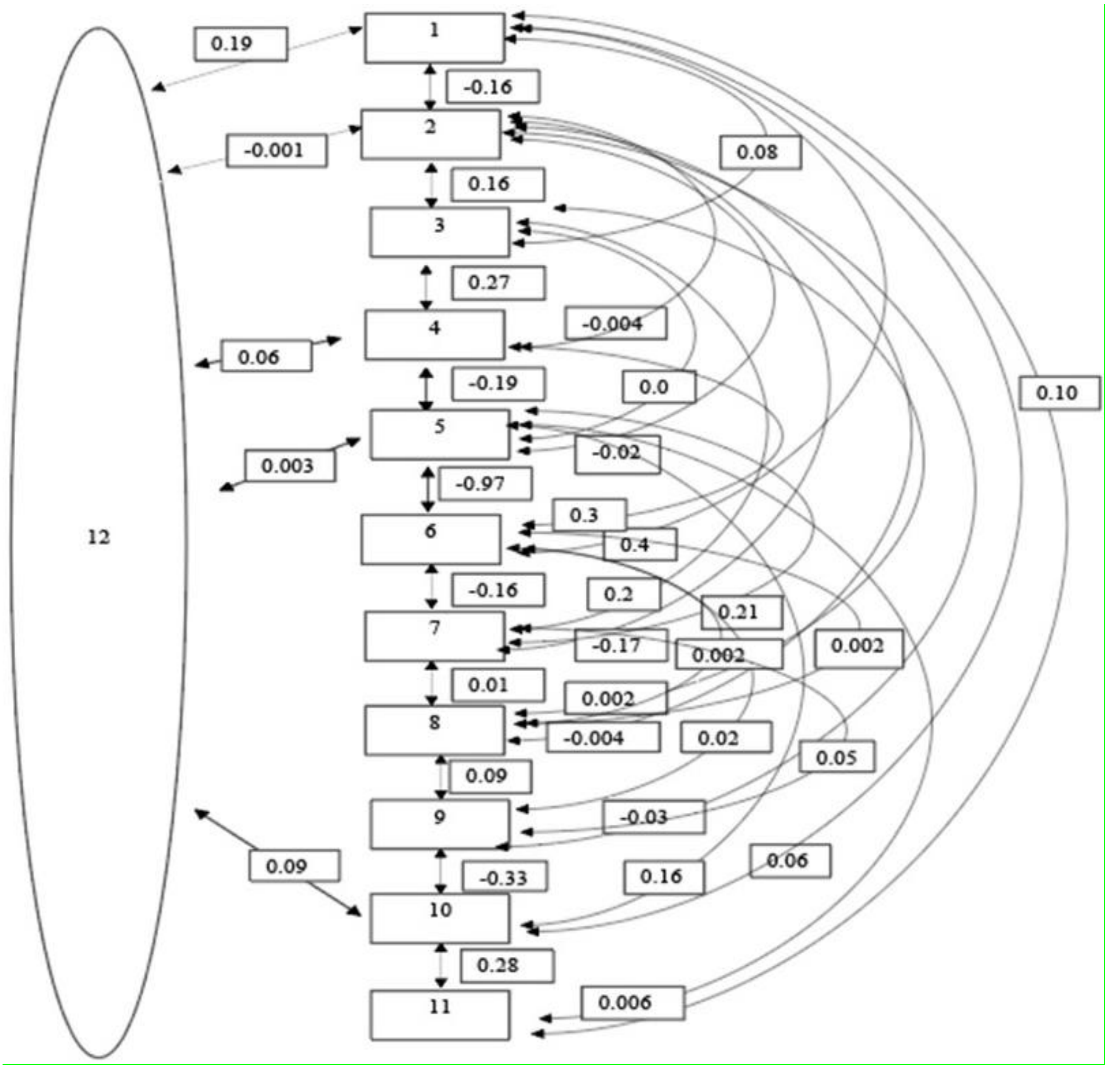

Fig. 1. Nature of causal system of variables for path-coefficient analysis in maize under normal conditions (1) PH, (2) LT, (3) LA, (4) LAn, (5) NOL, (6) SD, (7) CB, (8) GRE, (9) GPE, (10) 100-grain weight, (11) HI, (12) GYP.

Direct and indirect effects of studied traits on GYP under drought stress are displayed in (Fig. 2). LT, NOL, SD, GPE and HI showed the highest positive direct effect on grain yield. SD, PH, SD, NOL and HI had the highest positive indirect effects on grain yield via CB. LA, LAn, NOL, GRE, CB, and GPE showed the highest positive indirect effects on grain yield through LAn. PH, LAn, LA, CB, NOL, CB and GRE had the highest positive indirect effects on grain yield via SD. PH, "SD, LA, CB and GRE had the highest positive indirect effects on GYP via NOL.

The analysis revealed that SD had a direct positive effect on GYP under both normal and drought conditions. This means that an increase in SD directly contributes to an increase in grain yield. Additionally, other traits such as LA, PH, NOL, and SD showed positive indirect effects on GYP through different pathways, indicating their contribution to grain yield through intermediate traits.

Discussion

The objective of the study was to examine the correlation and path analysis of various morpho-physiological traits in doubled haploid maize hybrids under normal conditions and drought stress. Data of different traits were recorded in fifteen doubled haploid maize hybrids and their parents.

Significant genetic variability was observed in parents for all of the traits that have been studied except LT, CD, and NOL. Most of the traits studied showed genetic variability between parents and crosses under both treatments, indicating that heterosis may be exploited for the development of hybrids. The genetic variation in traits related to grain yield among maize accessions has also been studied by Carvalho *et al*., (2010); Khodarahmpour (2011); Iqbal *et al*., (2012); Chohan *et al*., (2012).

Correlation coefficients were calculated at both the genotypic and phenotypic levels to investigate the correlation between traits. A majority of the traits studied under normal conditions and drought stress conditions showed greater genotypic correlation coefficients than phenotypic correlation coefficients. The environment rarely affected studied traits, according to the study. Positive and significant correlations between genotypic variation in GYP and traits such as PH, NOL, LA, LT, and SD under both normal and drought conditions. Under normal and drought stress conditions, gene expression of grain yield was positively correlated with LT, LA, PH, SD, and leaf number (Bolanos *et al*., 1993; Ahsan 1999; Mehdi & Ahsan, 2000).

Path coefficient analysis was used to determine the direct and indirect effects on GYP. Positive and significant correlations between genotypic variation in GYP and traits such as PH, NOL, LA, LT, and SD under both normal and drought conditions. The path coefficient analysis revealed that SD had a direct effect on GYP under both normal and drought conditions. Positive and direct effects of SD on grain yield were observed under both normal and drought stress conditions. These results were in accordance with Yuan *et al*., 2016; Patel & Shelke, 1984; Oktem, 2008; Munawar *et al*., 2013. LA, LT, PH, NOL, SD, LAn, GRE, GPE, and HI had a positive indirect effect on grain yield under both normal and drought stress conditions. The same results were also found by Ilker, 2011; Jakhar *et al*., 2017; Jilo & Tulu, 2019; Shikha *et al*., 2020 and Aman *et al*., 2020.

The study highlighted the importance of understanding the correlation between different traits and their contributions to grain yield. By analyzing the direct and indirect effects, the researchers identified traits that could be targeted for breeding maize cultivars with improved drought tolerance. The research findings have implications for maize production, particularly in areas prone to drought stress. Maize is a staple food crop and plays a crucial role in global food security. Developing drought-tolerant maize hybrids can help mitigate the negative impact of drought on crop productivity and ensure food availability.

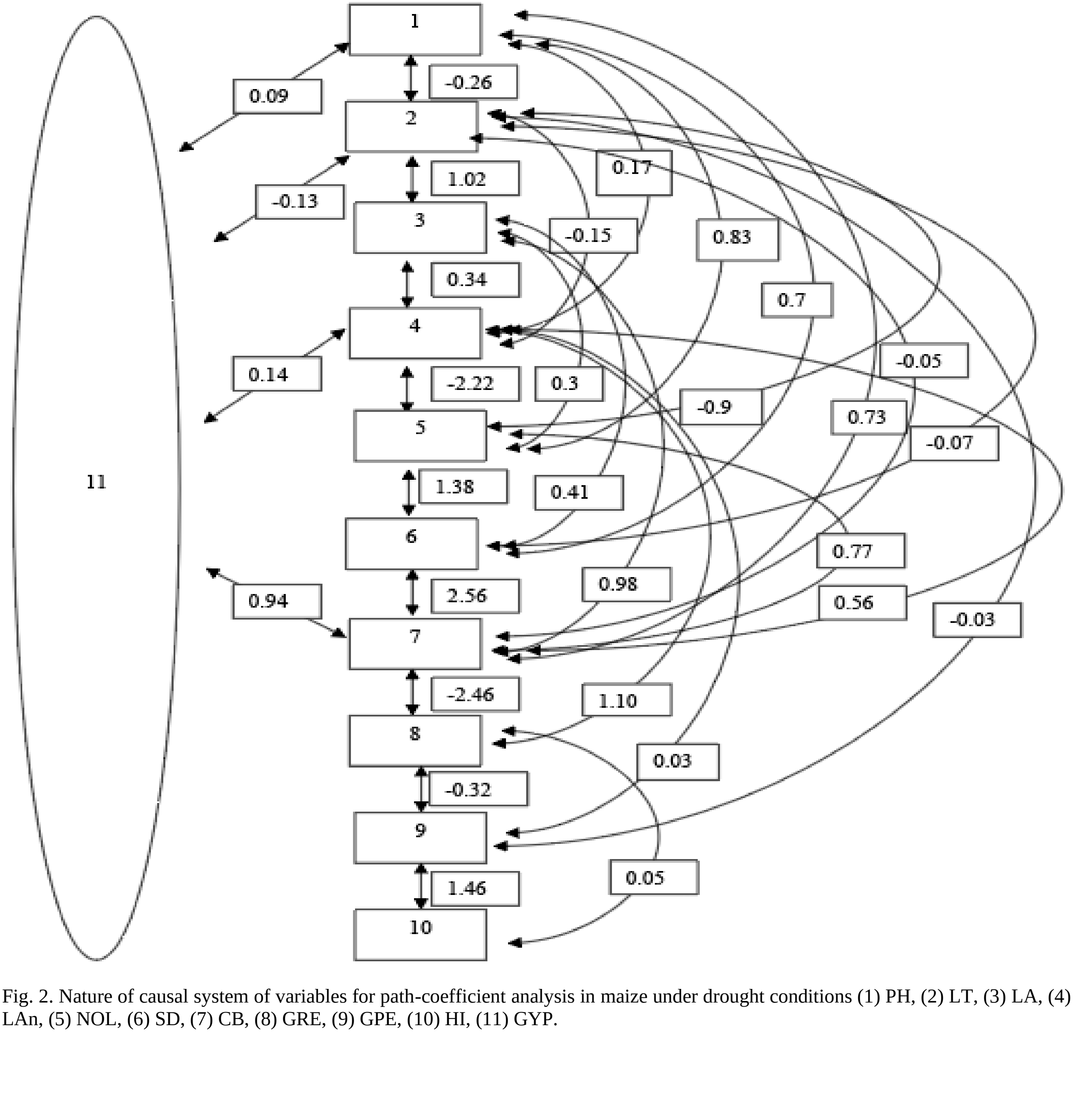

Fig. 2. Nature of causal system of variables for path-coefficient analysis in maize under drought conditions (1) PH, (2) LT, (3) LA, (4) LAn, (5) NOL, (6) SD, (7) CB, (8) GRE, (9) GPE, (10) HI, (11) GYP.

Conclusions

The genetic correlation showed that GYP under normal and drought conditions was positively correlated with LT, PH, LA, NOL, and SD. It depicts that these traits could prove most effective for being used in breeding maize cultivars for drought tolerance. It was observed that "SD" has a direct impact on "GYP" under normal and drought stress conditions. Developing hybrid maize under normal and drought stress would be more successful by selecting these traits.

Acknowledgement

The funds provided by Higher Education Commission are acknowledged. Special thanks to Dr. Muhammad Ahsan (late) who supervised and planned the research during his lifetime.

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(Received for publication 20 March 2023)