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Path Coefficient Analysis in *Zea mays* L.

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ABSTRACT

In a diallel cross experiment, ratio of growing degree days to reproductive phase and vegetative phase had the maximum positive direct contribution to grain yield per plant followed by growing degree days to tasseling and growing degree days to maturity. Therefore, these traits turned up to be important for selecting high yielding genotypes in maize. On the other hand, growing degree days to reproductive phase had highest negative direct effect followed by growing degree days to silking.

Key Words: Maize; Correlations; Path analysis; Growing degree days; Heat units; Grain yield

INTRODUCTION

The efficiency of a breeding programme depends mainly on the direction and magnitude of the association between yield and its components and also the relative importance of each factor involved in contributing to grain yield. Dwyer *et al*. (1994b) found the grain yield in maize was linearly related to the cumulative heat units (CHU) required to reach physiological maturity at the time of hailstorm. Liang *et al.* (1991) found grain yields directly proportional to the product of heat units (HU) and total water inputs during the growing season. At the normal rate of fertilization, stover yields depended only on HU. The effect of HU on stover yields was quadratic. HU values greater than 3000 resulted in lower stover yields. Seo and Lee (1996) reported high correlations of stover yields with silk growing degree days.

Agrama (1996) studied path analysis of five yield components, which revealed that number of grains per ear and grain size serve as potential characters in breeding for superior lines for grain yield in maize. According to Annapurna *et al.* (1998) seed yield was positively and significantly correlated with plant height, number of seeds per row, number of seed rows per ear, number of seeds per ear and test weight. Path coefficient analysis revealed that number of seeds per ear and test weight had the greatest direct effect on yield. Plant height, days to 75% silking and ear length also influenced the yield indirectly via number of seeds/ear.

The cause-effect relationship was studied in maize by Arias *et al.* (1999) for ear weight (the principal trait), plant and ear height, the ratio of ear height/plant height, number of kernel rows and kernels per row on each ear. The direct and indirect effects on ear weight of plant and ear height and its ratio varied according to the evaluated progeny type. Among the other traits, number of kernel rows showed only a small positive indirect effect via ear diameter for all progeny types and populations, and the number of kernels per row showed high positive direct effect. In another study, Khatun *et al.* (1999) found that grain yield per plant was positively and significantly correlated with 1000-grain weight, number of kernels per ear and ear insertion height. Path analysis showed that 1000-grain weight and number of kernels per ear were the most important components determining grain yield.

Mani *et al.* (1999) suggested that grains per row was the best direct contributor to grain yield/plant. Hence, maize breeders should give more importance to grains/row as selection criteria for yield improvement. Gautam *et al.* (1999a) found that grain yield was positively correlated with grain rows, 1000-grain weight, shelling percentage, plant height and ear height. The direct effects of plant height and ear height towards grain yield were small, as was that of days to silking, indicating the possibility of developing high yielding plant types with short plant height, medium ear placement and early maturity. In another study on popcorn, Gautam *et al.* (1999b) reported that number of kernels/row imparted maximum positive direct effect towards grain yield followed by plant height. Rather *et al.* (1999) estimated positive correlation between days to 50% silking and ear height and grain yield. Plant height had no association with grain yield. The direct and indirect effects of different quantitative traits on grain yield were studied in 90 hybrids by Geetha and Jayaraman (2000) and they reported that number of grains per row exerted a maximum direct effect on grain yield. Hence, selection for number of grains per row will be highly effective for improvement of grain yield. Kumar and Kumar (2000) put emphasis on plant height with greater ear weight, number of seed rows per ear and number of seeds per ear for better grain yield.

A quantitative trait expresses itself in close association with many other traits. Alteration in the expression of one trait is usually associated with a change in the expression of other traits. Therefore, a plant breeder has to study the degree of characters association. Present studies were conducted with view to find out the nature and extent of character association at genotypic level and criterion for indirect selection for grain yield in maize.

MATERIALS AND METHODS

The study was carried out in the Department of Plant Breeding and Genetics, University of Agriculture, Faisalabad. Six maize inbred lines i.e. T-232, FD-7, Mo-17, Pa-91, TZI-4001 and TZI-7103 were crossed in all possible combinations in a diallel fashion during Kharif, 1996. The F_1s were sown and selfed in the coming planting season (Spring, 1997) to produce seed for F_2 generation. During Kharif, 1997 F_2s and parental inbred lines were sown according to a Randomized Complete Block Design with three replications. Two seeds of each entry were planted in each of 25 hills 20 cm apart in ten-row plots keeping 75 cm row-to-row distance. After emergence, each hill was thinned to single plant. The data were recorded on ten guarded plants for inbred parents and on 200 guarded plants for F_2 generation on following traits:-

- Growing degree days to tasseling (vegetative phase) (GDDTA)
- Growing degree days to silking (GDDSL)
- Growing degree days to maturity (GDDMT)
- Growing degree days between tasseling & silking (GDDTS)
- Growing degree days between tasseling & maturity (reproductive phase) (GDDREP)
- Ratio of growing degree days to reproductive phase and vegetative phase (GDD R/V)
- Plant height (cm)
- Ear height (cm)
- Kernel rows per ear
- Kernels per row
- 1000-kernel weight (g)
- Grain yield per plant (g)

Daily maximum and minimum temperatures were recorded to calculate the growing degree days for different physiological stages according to Gilmore and Rogers (1958) and Cross and Zuber (1972). The data on all the parameters for the parents and F_2 generation were subjected to the analysis of variance according to Steel and Torrie (1980). Genotypic correlations were calculated by formulas given by Kwon and Torrie (1964) and path coefficient analysis was conducted according to Dewey and Lu (1959) on F_2 generation data. Genotypic correlation coefficients were tested against their standard errors (SE). The value r_g was considered to be significant if it exceeds twice of the value of its standard error. The SE was calculated following Lothrop *et al.* (1985).

RESULTS AND DISCUSSION

The results of analysis of variance were significant for all the traits (Table I). A critical review of Table II revealed that GDD R/V had the maximum positive direct contribution (6.527) to grain yield per plant followed by GDDTA (5.378) and GDDMT (1.951). Therefore, these traits turned up to be important for selecting high yielding genotypes in maize. On the other hand, GDDREP had highest negative direct effect of -6.005 followed by GDDSL with direct contribution of –2.369.

The results of path analysis are discussed in the following paragraphs.

GDDTA and grain yield per plant. GDDTA had a high positive direct effect (5.378) on grain yield per plant. The genotypic correlation coefficient between the traits was also positive and significant. Therefore, correlation explains the true relationship between the two traits and a direct selection through GDDTA in early stages of plant growth will be effective. Moreover, the positive indirect contributions of GDDTA to grain yield per plant were through GDDMT, GDDREP, 1000-kernel weight and kernels per row. The indirect effect through GDD R/V was negative and high (-4.554).

GDDSL and grain yield per plant. The genotypic correlation coefficient was significant and positive between two traits, but the direct effect of GDDSL was negative and high. The indirect effects via GDDTA and GDDMT are seemed to be the cause of positive correlation between GDDSL and grain yield per plant. Therefore, these traits must be considered if selection is made through GDDSL. Results from the study of Kang *et al.* (1983) indicated that selection for a reduced number of growing degree days to mid-silking would be effective in increasing grain yield. Qin and Li (1991) also stressed on reduced period between emergence and silking for high yielding genotypes. Tyagi *et al.* (1988), in an analysis of data on days to silking, revealed that early maturing plants had relatively low yields. Seo and Lee (1996) reported high correlations of stover yields with silk growing degree days.

GDDTS and grain yield per plant. The genotypic correlation between GDDTS and grain yield per plant was negative and statistically significant, while the direct effect of GDDTS was positive and high. Under these circumstances, a restricted simultaneous selection model should be followed i.e. restrictions should be imposed to nullify the undesirable indirect effects (GDDTA, GDDREP, GDDMT, kernels per row, 1000-kernel weight and ear height) in order to make use of direct effect of GDDTS (Singh & Kakar, 1977).

GDDREP and grain yield per plant. The situation was the same as for previous trait. The magnitude of direct effect was very high and negative, while genotypic correlation between GDDREP and grain yield per plant was significant and positive. The positive indirect effects through GDD R/V, GDDMT, 1000-kernel weight, GDDTS, ear height and kernels per row nullified the negative direct effect of GDDREP and caused the genotypic correlation to be positive. Dwyer *et al.* (1994a) reported significant correlations between grain yield and time to develop between silking and maturity (reproductive phase).

GDD R/V and grain yield per plant. The direct contribution of GDD R/V towards grain yield per plant was

Table I. Estimates of mean squares for various traits of maize (*Zea mays* L.) in 6 x 6 diallel cross experiment

SOV	df	GDDTA	GDDSL	GDDTS	GDDREP	GDD R/V	GDDMT	PHT	EHT	KR/E	K/R	KW	YLD
Reps	2	1317.6**	546.6^{NS}	349.4^{NS}	91.7^{NS}	0.0003^{NS}	1403.7^{NS}	84.7^{NS}	3.2^{NS}	46.7**	203.3**	398.8**	435.5**
Genotypes	35	6870.3**	4520.4**	1187.9**	5983.8**	0.0062**	11013.9**	372.8**	111.5**	3.8**	32.0**	2193.4**	542.8**
Error	70	249.3	220.0	261.8	604.5	0.0006	485.0	35.9	18.9	0.8	0.6	43.7	46.4

NS, *, **, denote non-significant, significant ($P<0.05$) and highly significant ($P<0.01$), respectively.

Table II. Direct (bold diagonal) and indirect effect matrix

Traits	GDDTA	GDDSL	GDDTS	GDDREP	GDD R/V	GDDMT	PHT	EHT	KR/E	K/R	KW	Genotypic Correlations with Yield
GDDTA	**5.378**	-2.203	-0.666	0.706	-4.554	1.368	-0.006	-0.005	-0.223	0.101	0.177	0.073 ± 0.004
GDDSL	4.999	**-2.369**	-0.326	-0.291	-3.484	1.496	0.007	-0.007	-0.162	0.035	0.199	0.097 ± 0.005
GDDTS	-3.465	0.748	**1.033**	-1.569	3.834	-0.614	0.030	-0.005	0.275	-0.213	-0.092	-0.038 ± 0.007
GDDREP	-0.632	-0.115	0.270	**-6.005**	5.175	1.222	-0.029	0.028	-0.057	0.015	0.353	0.225 ± 0.004
GDD R/V	-3.753	1.265	0.607	-4.761	**6.527**	0.043	-0.017	0.023	0.085	-0.066	0.154	0.107 ± 0.135
GDDMT	3.772	-1.817	-0.325	-3.761	0.143	**1.951**	-0.027	0.016	-0.221	0.099	0.394	0.224 ± 0.003
PHT	0.321	0.151	-0.297	-1.690	1.070	0.505	**-0.103**	0.060	-0.068	0.094	0.256	0.299 ± 0.008
EHT	-0.332	0.189	-0.055	-1.948	1.762	0.357	-0.072	**0.086**	0.047	0.089	0.402	0.525 ± 0.009
KR/E	-1.892	0.599	0.447	0.539	0.875	-0.678	0.013	0.006	**0.635**	-0.070	-0.258	0.216 ± 0.028
K/R	0.713	-0.103	-0.289	-0.125	-0.566	0.255	-0.013	0.010	-0.058	**0.760**	0.034	0.618 ± 0.010
KW	1.295	-0.643	-0.131	-2.886	1.374	1.046	-0.037	0.047	-0.223	0.035	**0.734**	0.611 ± 0.003

the maximum of all the traits. However, the genotypic correlation was positive and statistically non-significant. The genotypic correlation gives the true picture of the association between these traits. Therefore, the genotypes which accumulate more degree days during grain filling period (reproductive phase) than during vegetative phase are higher yielder. In other words higher the value of GDD R/V, higher will be the yield. Therefore, It is suggested that in breeding for higher yield, emphasis should be placed on an increased grain filling period (reproductive phase), and reduced period between emergence and tasseling (Qin & Li, 1991; Dwyer *et al.*, 1994a).

GDDMT and grain yield per plant. GDDMT had a high positive direct effect (1.951) on grain yield per plant, ranking third after GDD R/V and GDDTA. The genotypic correlation coefficient between the traits was also positive and significant. Therefore, direct path and correlation explain the true association between the two traits. The high positive indirect contributions of GDDMT to grain yield per plant were through GDDTA (3.772) and 1000-kernel weight (0.394). Singh *et al.* (1995) also estimated high direct effect of days to maturity on yield.

Plant height and grain yield per plant. The genotypic correlation coefficient was significant and positive between two traits, but the direct effect of plant height was negative and low. Parh *et al.* (1986) also reported negative direct effect of plant height on yield. The indirect positive effects through GDD R/V, GDDMT, GDDTA, 1000-kernel weight and GDDSL are the possible cause of positive correlation between plant height and grain yield per plant. Therefore, these traits must be considered if selection is made through plant height.

Ear height and grain yield per plant. The magnitude of direct effect of ear height on grain yield per plant was very small, while the genotypic correlation was positive and statistically significant. Therefore, if selection is made through ear height then the traits like GDD R/V and 1000-kernel weight should also be considered simultaneously as indirect effects through them were high and positive. The result confirms the earlier findings of Gautam *et al.* (1999a). They have also reported small direct effect of ear height towards yield.

Kernel rows per ear and grain yield per plant. The genotypic correlation coefficient was significant and positive between kernel rows per ear and grain yield per plant. The direct effect on grain yield per plant was also positive and greater in magnitude than that of genotypic correlation. Therefore, correlation explains the true relationship between the two traits. Trifunovic (1988), Ivakhnenko and Klimov (1991), Singh and Singh (1993), Han *et al.* (1994), Singh *et al.* (1995), and Kumar and Kumar (2000) suggested that indirect selection for grain yield through number of kernel rows would be effective.

Kernels per row and grain yield per plant. The genotypic correlation between kernels per row and grain yield per plant and direct effect of kernels per row were both positive and almost equal in magnitude. Therefore, selection for more number of kernels per row will definitely increase grain yield per plant. Mahajan *et al.* (1990), Singh and Singh (1993), Han *et al.* (1994), Kumar and Mishra (1995), Singh *et al.* (1995), Agrama (1996), Annapurna *et al.* (1998), Arias *et al.* (1999), Gautam *et al.* (1999b), Khatun *et al.* (1999), Mani *et al.* (1999), Geetha and Jayaraman (2000), and Kumar and Kumar (2000) advocated the importance of more number of kernels in breeding for higher grain yield in maize.

1000-kernel weight and grain yield per plant. 1000-kernel weight had a positive direct effect of 0.734 on grain yield per plant. The genotypic correlation coefficient between the traits was also positive and significant. Therefore, direct path and correlation explain the true association between the two traits and selection for heavier grain will improve grain yield. Parh *et al.* (1986), Dash *et al.* (1992), Han *et al.* (1994), Rahman *et al.* (1995) and Khatun *et al.* (1999) have also reported high positive direct contribution of kernel weight towards grain yield.

Residual effect. The residual effect determines how best the causal variables (GDDTA, GDDSL, GDDTS, GDDREP, GDD R/V, GDDMT, plant height, ear height, kernel rows per ear, kernels per row and 1000-kernel weight) account for the variability of the dependent variable i.e. grain yield per plant. Its estimate of 0.15 indicated that the causal variables explained about 85% of the variability in grain yield per plant and only 15% of the variability remained unexplored.

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