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CORRELATION AND PATH COEFFICIENT ANALYSIS FOR GRAIN YIELD AND STARCH CONTENT IN DOUBLED HAPLOID DERIVED CROSSES OF MAIZE (*Zea mays* L.)

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ABSTRACT

Doubled haploid (DH) technology allows rapid fixation of homozygosity in maize and is increasingly used to generate parental lines for hybrid development. The present study examined phenotypic and genotypic correlations and path coefficients among fourteen agro-morphological and quality traits in 40 single crosses derived from 20 DH lines crossed to two testers, along with five checks, evaluated in a randomized block design at the Agricultural Research Station, Karimnagar, during Vanakalam (*kharif*) 2025. Grain yield per plant showed strong positive phenotypic and genotypic associations with plant height, ear height, ear length, ear girth, kernel rows per ear, kernels per row, test weight, shelling percentage, moisture content and starch content, and negative associations with days to 50 per cent tasseling, silking and maturity. Path coefficient analysis revealed that plant height exerted the highest positive direct effect on grain yield at both levels (0.890 phenotypic; 0.942 genotypic), whereas starch content, despite its positive correlation with yield, showed a high negative direct effect (–0.539 phenotypic; –0.652 genotypic), indicating that its association with yield was largely mediated through other traits rather than a direct causal contribution. Residual effects of 0.354 (phenotypic) and 0.324 (genotypic) indicated that the traits studied together explained a substantial share of the variation in grain yield. Plant height, ear height and test weight, used jointly with starch content in an index-based approach, are suggested as reliable simultaneous selection criteria for improving both yield and grain quality in DH-derived maize hybrids.

Keywords: Doubled haploid, maize, correlation, path coefficient, direct effect, grain yield, starch content.

Introduction

Maize (*Zea mays* L.), often called the "Queen of Cereals", is among the most widely adapted and economically important cereal crops in the world, valued as food, feed and industrial raw material. In India it ranks third among cereals after rice and wheat, with a national average productivity of about 3,940 kg/ha (Anonymous, 2025), and Telangana has emerged as a high-productivity maize-growing state, with average yields of around 5,998 kg/ha, well above the national mean (PJTAU, 2025). Grain yield in maize is a complex, polygenic character that is the end product of several interacting component traits, so direct selection for yield alone is often unreliable and inefficient (Mohammadi *et al*., 2003).

Doubled haploid (DH) technology has transformed inbred line development in maize by compressing the time needed to reach full homozygosity from several generations of selfing to a single generation (Longin *et al*., 2007). Because DH lines are completely homozygous, they permit more precise phenotyping and combining ability evaluation, and single-cross hybrids or experimental crosses derived from them are being evaluated as an efficient route to identify superior parental combinations for grain yield and quality traits such as starch content (Spitko *et al*., 2010).

Correlation analysis quantifies the strength and direction of association between grain yield and its component traits, and between the component traits themselves, but by itself it cannot distinguish a trait's direct contribution to yield from contributions that are merely mediated through other, correlated traits. Path coefficient analysis, developed by Wright (1921) and adapted for crop improvement work by Dewey and Lu (1959), partitions each correlation coefficient into direct and indirect effects, thereby providing a clearer basis for choosing effective selection criteria. This is particularly relevant when a quality trait such as starch content is being improved simultaneously with grain yield, since traits that are positively correlated with yield are not always the traits that causally drive it.

The present study was conducted to elucidate the relationships among grain yield, its component traits and starch content through phenotypic and genotypic correlation analyses, and to determine the direct and indirect contributions of these traits to grain yield using path coefficient analysis. Such information is valuable for identifying efficient selection criteria for the simultaneous improvement of yield and grain quality in doubled haploid-derived maize hybrids.

Material and Methods

Experimental Material and Design

The experimental material comprised 40 single crosses generated from 20 doubled haploid (DH) derived maize lines crossed on to two testers, along with five standard checks. The material was evaluated in a Randomized Block Design (RBD) with a plot size of 4.8 m² (spacing 60 × 20 cm, two rows of 4 m length) at the Agricultural Research Station, Karimnagar, during Vanakalam (*kharif*) 2025.

Characters Studied

Observations were recorded on five randomly selected competitive plants per replication for fourteen characters: days to 50 per cent tasseling (DT), days to 50 per cent silking (DS), days to maturity (DM), plant height (PH, cm), ear height (EH, cm), ear length (CL, cm), ear girth (CG, cm), number of kernel rows per ear (NKR), number of kernels per row (NKPR), test weight (TW, g), starch content (SC, %), moisture content (MC, %), shelling percentage (SP, %) and grain yield per plant (GY).

Statistical Analysis

Phenotypic (rp) and genotypic (rg) correlation coefficients between all pairs of characters were computed from the respective phenotypic and genotypic variance–covariance components, following standard procedures for randomized block design data (Panse and Sukhatme, 1985; Singh and Chaudhary, 1985). The significance of the correlation coefficients was tested against tabulated values (Fisher and Yates, 1963) at the appropriate degrees of freedom.

Path coefficient analysis, as proposed by Wright (1921) and elaborated for crop data by Dewey and Lu (1959), was carried out with grain yield per plant as the dependent variable and the remaining thirteen characters as causal (independent) factors, separately at the phenotypic and genotypic levels. This procedure partitions each correlation coefficient of a component character with grain yield into a direct effect (the diagonal path coefficient) and a set of indirect effects mediated through every other character in the model. The residual effect, representing the contribution of factors not included in the model, was estimated as PRY = √(1 − Σ Piy·riy), where Piy is the direct effect and riy the correlation of the ith character with grain yield. The relative magnitude of direct and indirect effects was interpreted following the scale of Lenka and Misra (1973): negligible (0.00–0.09), low (0.10–0.19), moderate (0.20–0.29), high (0.30–0.99) and very high (>1.00).

Results and Discussion

Phenotypic and Genotypic Correlation of Grain Yield and its Component Traits

The pooled phenotypic and genotypic correlation coefficients among the fourteen characters are presented in Table 1 and Table 2, respectively. In general, the genotypic correlation coefficients were of a higher magnitude than the corresponding phenotypic coefficients for most trait pairs, suggesting that the observed associations were largely under genetic control, with the phenotypic expression being only marginally moderated by the environment. This pattern is consistent with earlier reports on correlation studies in maize (Nataraj *et al*., 2014; Mallikarjuna *et al*., 2020; Rajesh *et al*., 2015).

Grain yield per plant showed highly significant positive associations, at both phenotypic and genotypic levels, with plant height (rp = 0.897**, rg = 0.903**), ear height (rp = 0.891**, rg = 0.898**), ear length (rp

= 0.881**, rg = 0.888**), ear girth (rp = 0.892**, rg = 0.900**), number of kernel rows per ear (rp = 0.757**, rg = 0.763**), number of kernels per row (rp = 0.870**, rg = 0.878**), test weight (rp = 0.883**, rg = 0.890**), shelling percentage (rp = 0.873**, rg = 0.880**), moisture content (rp = 0.824**, rg = 0.883**) and, notably, starch content (rp = 0.680**, rg = 0.703**). These results agree with the widely reported positive association of plant stature, ear dimensions, kernel number and test weight with grain yield in maize (Pavan *et al*., 2011; Begum *et al*., 2016; Kuchanur *et al*., 2014; Praveen Kumar *et al*., 2022; Gogoi *et al*., 2025). The positive correlation between starch content and grain yield is a favourable indication for this material, since it suggests that selection need not necessarily trade off yield against starch, a relationship also reported in quality-oriented maize studies (Ramesh Kumar *et al*., 2017).

In contrast, grain yield was significantly and negatively associated with the flowering and maturity traits — days to 50 per cent tasseling (rp = –0.602**, rg = –0.654**), days to 50 per cent silking (rp = –0.602**, rg = –0.654**) and days to maturity (rp = –0.427**, rg = –0.484**) — indicating that the earlier-flowering and earlier-maturing crosses in this DH-derived set tended to be the higher yielding ones. This is consistent with the findings of Badu-Apraku and Oyekunle (2012) and Mohammadi *et al*. (2003), who reported that late flowering and extended maturity duration are generally associated with reduced grain yield in maize. Days to tasseling and days to silking were almost perfectly correlated with each other (r = 1.00) and showed near-identical association patterns with every other trait, indicating a very narrow anthesis–silking interval and synchronous flowering across this set of DH-derived crosses; in practical terms, days to tasseling alone can be used to represent both traits in future selection work on this material.

Nearly all vegetative and ear traits (PH, EH, CL, CG, NKR, NKPR, TW, MC, SP) were also very strongly and positively inter-correlated with one another (r generally between 0.84 and 0.99), reflecting the coordinated development of plant stature, ear size and kernel traits typical of high-yielding maize genotypes. The high inter-correlation among the predictor traits suggests the presence of multicollinearity, and therefore the path coefficients should be interpreted with appropriate caution (Dewey and Lu, 1959; Mohammadi *et al*., 2003).

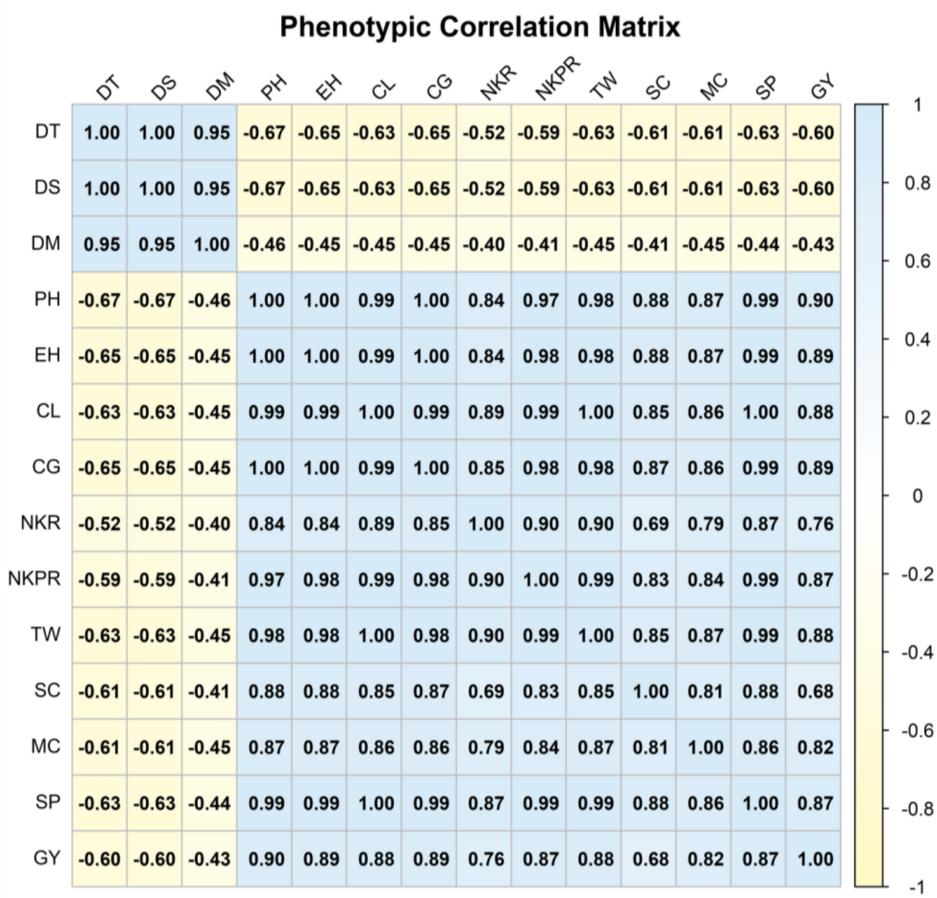

Fig. 1 : Heat map of pooled phenotypic correlation coefficients among 14 characters.

Table 1 : Pooled phenotypic correlation coefficients among 14 characters in DH-derived maize crosses

Trait	DT	DS	DM	PH	EH	CL	CG	NKR	NKPR	TW	SC	MC	SP	GY
DT	1	1	0.951**	-0.668**	-0.655**	-0.630**	-0.649**	-0.520**	-0.588**	-0.628**	-0.609**	-0.612**	-0.629**	-0.602**
DS		1	0.951**	-0.668**	-0.655**	-0.630**	-0.649**	-0.520**	-0.588**	-0.628**	-0.609**	-0.612**	-0.629**	-0.602**
DM			1.000	-0.464**	-0.450**	-0.451**	-0.446**	-0.404**	-0.412**	-0.452**	-0.412**	-0.447**	-0.442**	-0.427**
PH				1.000	0.999**	0.987**	0.997**	0.842**	0.973**	0.983**	0.878**	0.871**	0.989**	0.897**
EH					1.000	0.988**	0.997**	0.842**	0.975**	0.984**	0.879**	0.868**	0.991**	0.891**
CL						1.000	0.988**	0.890**	0.993**	0.997**	0.853**	0.861**	0.995**	0.881**
CG							1.000	0.854**	0.976**	0.984**	0.866**	0.865**	0.988**	0.892**
NKR								1.000	0.897**	0.895**	0.693**	0.788**	0.873**	0.757**
NKPR									1.000	0.994**	0.825**	0.842**	0.989**	0.870**
TW										1.000	0.846**	0.865**	0.993**	0.883**
SC											1.000	0.810**	0.877**	0.680**
MC												1.000	0.862**	0.824**
SP													1.000	0.873**
GY														1.000

Trait abbreviations: DT = Days to 50% tasseling; DS = Days to 50% silking; DM = Days to maturity; PH = Plant height (cm); EH = Ear height (cm); CL = Ear length (cm); CG = Ear girth (cm); NKR = Number of kernel rows per ear; NKPR = Number of kernels per row; TW = Test weight (g); SC = Starch content (%); MC = Moisture content (%); SP = Shelling percentage (%); GY = Grain yield per plant. *, ** = significant at 5% and 1% level, respectively.

Table 2 : Pooled genotypic correlation coefficients among 14 characters in DH-derived maize crosses

Trait	DT	DS	DM	PH	EH	CL	CG	NKR	NKPR	TW	SC	MC	SP	GY
DT	1	1	0.947**	-0.718**	-0.707**	-0.681**	-0.703**	-0.552**	-0.641**	-0.675**	-0.634**	-0.629**	-0.676**	-0.654**
DS		1	0.947**	-0.718**	-0.707**	-0.681**	-0.703**	-0.552**	-0.641**	-0.675**	-0.634**	-0.629**	-0.676**	-0.654**
DM			1.000	-0.519**	-0.507**	-0.509**	-0.506**	-0.443**	-0.472**	-0.505**	-0.427**	-0.444**	-0.495**	-0.484**
PH				1.000	0.999**	0.987**	0.997**	0.843**	0.973**	0.983**	0.907**	0.941**	0.989**	0.903**
EH					1.000	0.988**	0.998**	0.844**	0.976**	0.984**	0.910**	0.942**	0.991**	0.898**
CL						1.000	0.988**	0.892**	0.994**	0.998**	0.884**	0.935**	0.995**	0.888**
CG							1.000	0.856**	0.976**	0.985**	0.899**	0.943**	0.988**	0.900**
NKR								1.000	0.900**	0.896**	0.710**	0.837**	0.874**	0.763**
NKPR									1.000	0.995**	0.861**	0.925**	0.990**	0.878**
TW										1.000	0.872**	0.933**	0.993**	0.890**
SC											1.000	0.821**	0.905**	0.703**
MC												1.000	0.930**	0.883**
SP													1.000	0.880**
GY														1.000

Trait abbreviations: DT = Days to 50% tasseling; DS = Days to 50% silking; DM = Days to maturity; PH = Plant height (cm); EH = Ear height (cm); CL = Ear length (cm); CG = Ear girth (cm); NKR = Number of kernel rows per ear; NKPR = Number of kernels per row; TW = Test weight (g); SC = Starch content (%); MC = Moisture content (%); SP = Shelling percentage (%); GY = Grain yield per plant. *, ** = significant at 5% and 1% level, respectively.

Path Coefficient Analysis

The direct and indirect effects of the thirteen component characters on grain yield, at the phenotypic and genotypic levels, are presented in Table 3 and Table 4 (diagonal values, shaded, are the direct effects; the last column is the correlation coefficient with grain yield, which equals the sum of the direct and all indirect effects in that row).

Plant height recorded the highest positive direct effect on grain yield at both levels (0.890 phenotypic; 0.942 genotypic-classed as ‘high’ on the Lenka and Misra scale), and this direct effect was of almost the same magnitude as its correlation with grain yield (0.897 and 0.903, respectively). This indicates that the strong correlation of plant height with yield is predominantly a true, direct causal relationship rather than one mediated through other traits, in agreement with Pavan *et al*. (2011), Praveen Kumar *et al*. (2022) and Kumar *et al*. (2024), who similarly identified plant height as the principal direct contributor to grain yield in maize. Ear height also exerted a moderate-to-high positive direct effect (0.202 phenotypic; 0.361 genotypic), consistent with Begum *et al*. (2016) and Gogoi *et al*. (2025).

Moisture content (0.312 phenotypic; 0.179 genotypic) and test weight (0.233 phenotypic; 0.130

genotypic) showed positive direct effects of low-to-high magnitude, supporting their use as secondary selection criteria along with plant height. Number of kernels per row (–0.175 phenotypic; –0.224 genotypic) and number of kernel rows per ear (–0.125 phenotypic; –0.119 genotypic) showed negative direct effects despite their strong positive correlation with grain yield, indicating that their contribution to yield in this material was almost entirely indirect – chiefly routed through plant height and ear height, with which they were very strongly correlated (r > 0.84 in both cases). A similar decoupling of direct and correlated effects for kernel-row and kernel-number traits has been reported by Rajesh *et al*. (2015) and Mallikarjuna *et al*. (2020).

Starch content showed the most informative result of this analysis: although it was significantly and positively correlated with grain yield (rp = 0.680**, rg = 0.703**), its direct effect on yield was high and negative (–0.539 phenotypic; –0.652 genotypic). This means the positive correlation of starch content with yield in these DH-derived crosses arises almost entirely through large positive indirect effects via plant height, ear height, moisture content and test weight, which more than compensate for a directly antagonistic physiological relationship between starch accumulation and grain filling. This kind of divergence between correlation and direct effect is precisely the situation path analysis is designed to expose, and has parallel precedent in maize quality studies (Ramesh Kumar *et al*., 2017; Rajesh *et al*., 2015), where starch or protein-related traits combined a favourable correlation with a comparatively smaller or even adverse direct contribution to yield. The practical implication is that direct mass selection for starch content alone, without regard to plant and ear stature, could inadvertently depress yield gain; an index that combines starch content with plant height, ear height and test weight is therefore recommended over single-trait selection.

Days to 50 per cent tasseling and days to 50 per cent silking showed negligible direct effects (–0.021 phenotypic; –0.025 genotypic) but a substantial negative indirect effect through plant height, which explains most of their negative correlation with grain yield; selecting against late flowering (i.e., for earlier tasseling and silking) should therefore continue to improve yield indirectly through its association with plant stature, in line with Badu-Apraku and Oyekunle (2012).

The coefficient of determination (R^2, the sum of Piy × riy over all thirteen characters) was 0.875 at the phenotypic level and 0.895 at the genotypic level, giving residual effects of 0.354 and 0.324, respectively. The residual effects indicate that the traits considered in the present study accounted for a major proportion of the variation in grain yield. Nevertheless, the remaining variation may reflect the influence of additional factors not included in the analysis together with the effects of multicollinearity among the highly correlated predictor traits, which can affect the stability of individual path coefficients (Dewey and Lu, 1959; Mohammadi *et al*., 2003).

Table 3 : Phenotypic direct (diagonal, shaded) and indirect effects of 13 characters on grain yield

Trait	DT	DS	DM	PH	EH	CL	CG	NKR	NKPR	TW	SC	MC	SP	GY
DT	**-0.021**	-0.021	0.03	-0.592	-0.132	-0.004	-0.03	0.065	0.103	-0.145	0.326	-0.19	0.008	**-0.6023****
DS	-0.021	**-0.021**	0.03	-0.592	-0.132	-0.004	-0.03	0.065	0.103	-0.145	0.326	-0.19	0.008	**-0.6023****
DM	-0.019	-0.019	**0.032**	-0.411	-0.091	-0.003	-0.021	0.05	0.072	-0.105	0.221	-0.139	0.005	**-0.4272****
PH	0.014	0.014	-0.015	**0.89**	0.201	0.006	0.046	-0.105	-0.17	0.228	-0.471	0.27	-0.012	**0.8967****
EH	0.013	0.013	-0.014	0.885	**0.202**	0.006	0.046	-0.105	-0.17	0.228	-0.471	0.269	-0.012	**0.8910****
CL	0.013	0.013	-0.014	0.875	0.199	**0.007**	0.045	-0.111	-0.173	0.231	-0.457	0.267	-0.012	**0.8813****
CG	0.013	0.013	-0.014	0.883	0.201	0.006	**0.046**	-0.106	-0.17	0.228	-0.464	0.268	-0.012	**0.8925****
NKR	0.011	0.011	-0.013	0.746	0.17	0.006	0.039	**-0.125**	-0.157	0.207	-0.371	0.244	-0.011	**0.7571****
NKPR	0.012	0.012	-0.013	0.862	0.196	0.007	0.045	-0.112	**-0.175**	0.23	-0.443	0.261	-0.012	**0.8704****
TW	0.013	0.013	-0.014	0.871	0.198	0.007	0.045	-0.112	-0.173	**0.233**	-0.453	0.269	-0.012	**0.8831****
SC	0.013	0.013	-0.013	0.778	0.177	0.006	0.04	-0.086	-0.144	0.196	**-0.539**	0.251	-0.011	**0.6797****
MC	0.013	0.013	-0.014	0.771	0.175	0.006	0.04	-0.098	-0.147	0.2	-0.434	**0.312**	-0.01	**0.8245****
SP	0.013	0.013	-0.014	0.876	0.2	0.007	0.045	-0.109	-0.173	0.23	-0.47	0.267	**-0.012**	**0.8732****

R^2 (phenotypic) = 0.875; Residual effect = 0.354.

Trait abbreviations: DT = Days to 50% tasseling; DS = Days to 50% silking; DM = Days to maturity; PH = Plant height (cm); EH = Ear height (cm); CL = Ear length (cm); CG = Ear girth (cm); NKR = Number of kernel rows per ear; NKPR = Number of kernels per row; TW = Test weight (g); SC = Starch content (%); MC = Moisture content (%); SP = Shelling percentage (%); GY = Grain yield per plant. *, ** = significant at 5% and 1% level, respectively.

Table 4 : Genotypic direct (diagonal, shaded) and indirect effects of 13 characters on grain yield

Trait	DT	DS	DM	PH	EH	CL	CG	NKR	NKPR	TW	SC	MC	SP	GY
DT	**-0.025**	-0.024	0.039	-0.673	-0.254	-0.04	-0.042	0.066	0.143	-0.087	0.412	-0.112	-0.056	**-0.6543****
DS	-0.024	**-0.025**	0.039	-0.673	-0.254	-0.04	-0.042	0.066	0.143	-0.087	0.412	-0.112	-0.056	**-0.6543****
DM	-0.023	-0.023	**0.042**	-0.487	-0.182	-0.03	-0.03	0.052	0.105	-0.065	0.277	-0.079	-0.041	**-0.4841****
PH	0.018	0.018	-0.022	**0.942**	0.359	0.059	0.06	-0.1	-0.217	0.127	-0.589	0.168	0.081	**0.9033****
EH	0.017	0.017	-0.021	0.936	**0.361**	0.059	0.06	-0.1	-0.217	0.127	-0.591	0.168	0.082	**0.8979****
CL	0.017	0.017	-0.021	0.925	0.355	**0.06**	0.059	-0.106	-0.221	0.129	-0.574	0.167	0.082	**0.8881****
CG	0.017	0.017	-0.021	0.934	0.359	0.059	**0.06**	-0.102	-0.217	0.127	-0.583	0.168	0.081	**0.8995****
NKR	0.013	0.013	-0.018	0.79	0.303	0.053	0.051	**-0.119**	-0.2	0.116	-0.461	0.149	0.072	**0.7629****
NKPR	0.016	0.016	-0.02	0.912	0.351	0.059	0.058	-0.107	**-0.224**	0.128	-0.559	0.165	0.082	**0.8779****
TW	0.016	0.016	-0.021	0.922	0.354	0.059	0.059	-0.106	-0.222	**0.13**	-0.566	0.167	0.082	**0.8895****
SC	0.015	0.015	-0.018	0.85	0.327	0.052	0.054	-0.084	-0.192	0.112	**-0.652**	0.146	0.074	**0.7026****
MC	0.015	0.015	-0.018	0.882	0.339	0.056	0.056	-0.099	-0.206	0.12	-0.533	**0.179**	0.077	**0.8834****
SP	0.017	0.017	-0.021	0.927	0.356	0.059	0.059	-0.104	-0.22	0.128	-0.587	0.166	**0.083**	**0.8795****

R^2 (genotypic) = 0.895; Residual effect = 0.324.

Trait abbreviations: DT = Days to 50% tasseling; DS = Days to 50% silking; DM = Days to maturity; PH = Plant height (cm); EH = Ear height (cm); CL = Ear length (cm); CG = Ear girth (cm); NKR = Number of kernel rows per ear; NKPR = Number of kernels per row; TW = Test weight (g); SC = Starch content (%); MC = Moisture content (%); SP = Shelling percentage (%); GY = Grain yield per plant. *, ** = significant at 5% and 1% level, respectively.

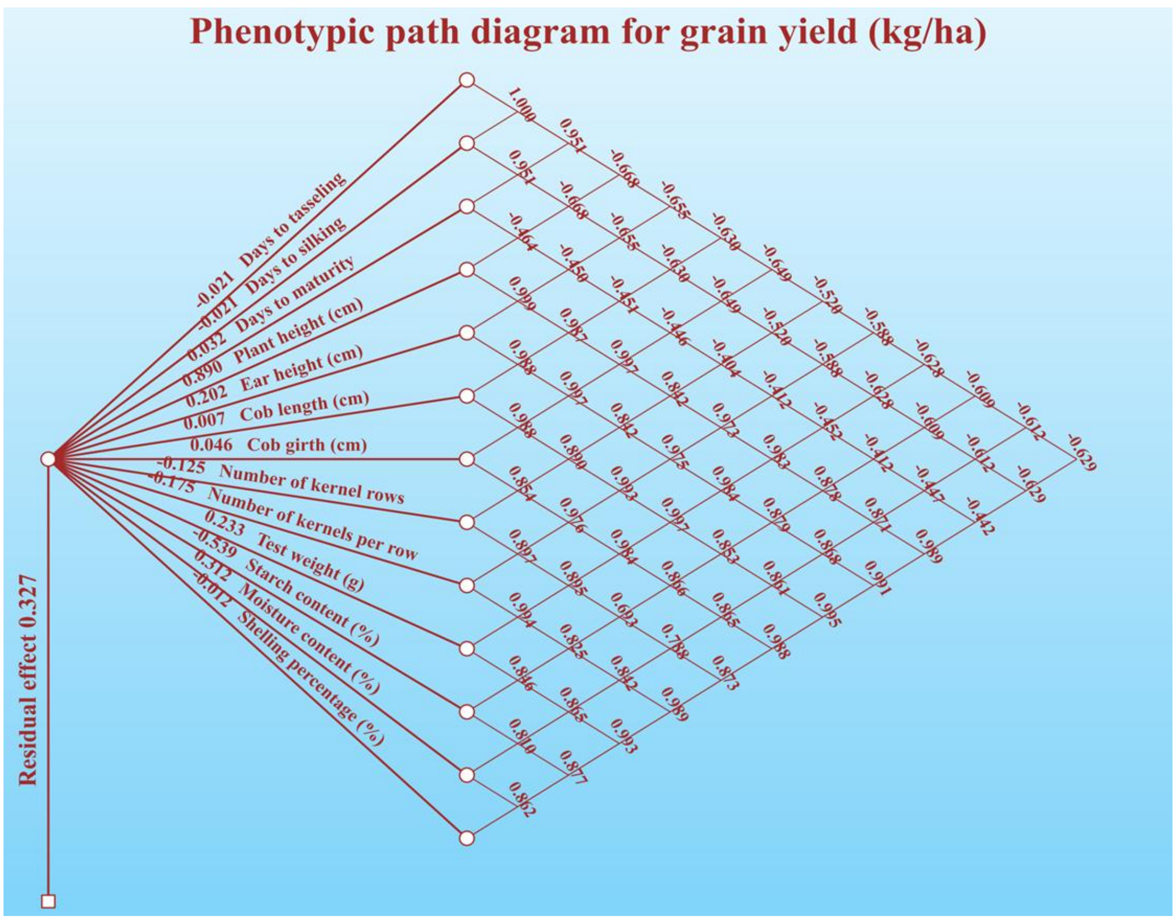

Fig. 2 : Phenotypic path diagram showing the direct effects of component characters on grain yield.

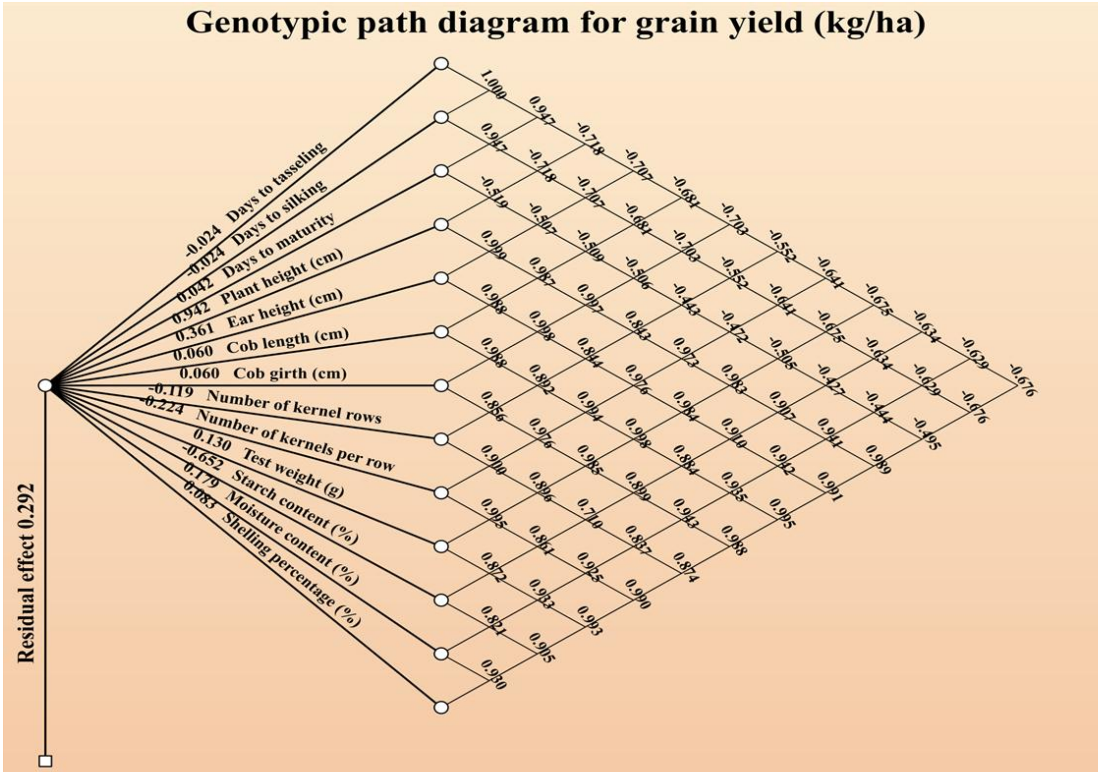

Fig. 3 : Genotypic path diagram showing the direct effects of component characters on grain yield.

Conclusion

In this set of doubled haploid derived maize crosses, plant height emerged as the single most reliable selection criterion for grain yield, combining a strong correlation with an almost equally strong, positive direct effect at both the phenotypic and genotypic levels. Ear height, test weight and moisture content are useful secondary criteria. Starch content presents a more nuanced picture: it is positively correlated with grain yield but acts through indirect pathways rather than a direct causal route, so breeders aiming to improve both yield and starch content in this DH-derived material would be better served by an index combining starch content with plant height, ear height and test weight than by single-trait selection on starch content alone. Selection for earlier tasseling, silking and maturity is also expected to favour higher yield, largely through its association with plant stature. The high residual effects (0.354 phenotypic; 0.324 genotypic) suggest that including additional yield-contributing traits, such as ears per plant or harvest index, in future combining-ability trials on this material could further improve the precision of selection indices developed for these DH-derived hybrids.

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