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Research Note

Unraveling trait relationships in maize inbred lines

D. Sravani*[1], D. Bharathi[2], M. Reddi Sekhar[1] and A. R. Nirmal Kumar[3]

[1]Department of Genetics and Plant Breeding, S.V. Agricultural College, Tirupati- 517502, Andhra Pradesh, India
[2]Department of Genetics and Plant Breeding, RARS, Tirupati- 517502, Andhra Pradesh, India
[3]Department of Crop Physiology, S.V. Agricultural College, Tirupati- 517502, Andhra Pradesh, India
***E-Mail**: sravanidevagudi20@gmail.com

Abstract

An experiment was carried out during *Kharif* 2020 at wetland farm of Sri Venkateswara Agricultural College, Tirupati using 30 inbred lines of maize to assess the trait association for 16 yield and yield attributes. It revealed that ear length, number of kernels per row, plant height, ear girth, SPAD chlorophyll meter reading, 100 kernel weight, number of kernel rows per ear, specific leaf area, harvest index and tassel length had notable positive correlation with kernel yield per plant suggesting that selecting these characters simultaneously lead to an increase in kernel yield per plant. Path analysis revealed a significant and positive direct influence of ear length on the kernel yield per plant. Hence, ear length could be considered during selection in maize for improving kernel yield.

Keywords: maize, correlation, path analysis, inbred, direct effects

Maize (*Zea mays* L.) stands as a vital cereal crop on a global scale, playing an essential role in ensuring food security and supporting agricultural economies. It has got the sobriquet "Queen of cereals" because of its highest yield potential and wider adaptability. Its adaptability to various climates and growing conditions, coupled with advancements in breeding and agricultural practices, has led to its cultivation across a wide spectrum of regions. It stands as the third-highest producer after wheat and rice. Although maize serves as a staple food in many nations, the global average yield falls short of satisfying the growing food demands of the world's increasing population. To address this rising need, maize productivity must be raised by developing cultivars with higher yields and other desired agronomic and phenological characteristics to fulfil the needs of an ever-increasing population.

Due to the quantitative nature of kernel yield in maize, which is influenced by a complex network of interconnected traits, relying solely on the grain yield trait for selection is typically ineffective and inefficient (Dutta *et al.,* 2017). Therefore, understanding the association both direct and indirect effects between kernel yield and its related traits is crucial when choosing advantageous plant varieties for efficient maize breeding initiatives. Correlation coefficients unveil connections between independent traits and the extent of their linear interrelationship. However, correlation analysis lacks the capacity to estimate the relative relevance of each character in terms of cause and effect that can be obtained through path analysis. Path analysis aims to ascertain whether the relationship between independent and dependent traits results from their direct influences or is a result of their indirect influences through intermediary traits. The present research aims to gain a deeper understanding of the correlation between kernel yield and various constituent characteristics. It also intends to evaluate the relative importance of both direct and indirect effects of these characteristics on yield in maize inbreds.

The experiment was carried out using 30 inbred lines of maize during *Kharif,* 2020 at Sri Venkateswara Agricultural College, Tirupati. A total of thirty maize inbred lines were assessed using a Randomized Block Design (RBD) replicated three times. Within each replication, each genotype was planted in individual rows measuring 3 meters in length, with 60 centimeters of spacing between the rows and 20 centimeters between the plants. All recommended agronomical and plant protection practices were followed to raise the healthy crop.

Biometric traits such as the days to 50% tasseling, the anthesis-silking interval, days to 50% silking and days to maturity were assessed at the plot level. In contrast, characteristics including SPAD chlorophyll meter readings, specific leaf area, tassel length, plant height, ear length, 100 kernel weight, ear girth, number of kernels per row, number of kernel rows per ear, kernel yield per plant, protein content and harvest index were recorded based on observations from five randomly selected plants. Correlation coefficients, both genotypic and phenotypic, were calculated using the methodology described in the work of Johnson *et al*. (1955). Additionally, Path coefficient analysis was conducted using the procedure initially introduced by Wright (1921) and further refined by Dewey and Lu (1959).

Grain yield is a multifaceted trait, significantly affected by environmental factors, and arises from the interplay of several yield-related components (Grafius, 1960). Thus, knowledge on phenotypic and genotype correlation coefficients among various plant traits aids in determining the extent to which these are related to economic productivity. Phenotypic correlation expresses the degree to which two traits are genetically connected whereas genotypic correlation quantifies the genetic relationship between two traits, genotypic and phenotype correlations within and between variables in a crop breeding program enable indirect selection (Pavan *et al.,* 2011). Hence, a sound knowledge of traits association is necessary in order to select the traits for developing high yielding hybrids. The calculated phenotypic and genotypic correlations between kernel yield and traits that contribute to yield across a group of 30 maize inbred lines are presented in **Table 1**. The association analysis indicated that genotypic correlation coefficients exceeded phenotypic correlation coefficients, underscoring a substantial inherent relationship between the studied traits and their observable phenotypic expression. Similar results were observed by Dar *et al.* (2015), Begum *et al.* (2016), Reddy and Jabeen, (2016), Pandey *et al.* (2017) and Dash *et al*. (2020).

In the current study, ear length demonstrated the highest positive correlation with kernel yield per plant, number of kernels per row, SPAD chlorophyll meter reading, ear girth, plant height, number of kernel rows per ear, 100 kernel weight, harvest index, specific leaf area, and tassel length. These correlations were significant and consistent at both phenotypic and genotypic levels, highlighting the vital role of these traits in selecting and enhancing kernel yield. These results were consistent with the discoveries of Tulu (2014) and Begum *et al.* (2016) for ear length, ear girth and number of kernels per row, Huda *et al.* (2016) for plant height, ear length, ear girth and 100 kernel weight, Synrem *et al.* (2016) for SPAD chlorophyll meter reading, Pandey *et al*. (2017) for ear length, number of kernels per row and 100 kernel weight, Prakash *et al.* (2019) for tassel length and Verma *et al.* (2020) for harvest index.

In contrast, days to 50% tasseling, days to maturity and days to 50% silking exhibited significant negative association with kernel yield per plant which is desirable in that direction. These results were in close proximity with the results of Kanagarasu *et al.* (2013) and Varaprasad and Shivani (2017) for days to 50% tasseling, Tulu (2014) for days to 50% silking Pandey *et al.* (2017) and Prakash *et al.* (2019) for days to maturity. Therefore, it could be suggested that selection of early maturing inbred lines with more ear length, number of kernels per row, ear girth, plant height, SPAD chlorophyll meter reading, number of kernel rows per ear and harvest index ultimately increases kernel yield per plant.

In order to devise an effective breeding strategy for improving crop yield, it is crucial not only to identify the traits that positively and significantly influence grain yield but also to understand how these attributes relate to each other. The interrelationships among these yield-related characteristics were unveiled in present study. Days to 50% tasseling displayed a significant positive association with both days to 50% silking and days to maturity. Additionally, days to 50% silking exhibited a positive connection with days to maturity. Furthermore, the SPAD chlorophyll meter readings demonstrated positive correlations with ear length, plant height, the number of kernels per row, and 100 kernel weight. Lastly, specific leaf area was found to be linked with the number of kernel rows per ear, 100 kernel weight, ear girth, and ear length. These findings shed light on the interdependencies among these traits, offering valuable insights for the development of more effective breeding strategies aimed at enhancing crop yield. Hence, these traits should also be taken into consideration during the selection process to facilitate improvements in achieving both higher yield and earlier maturity in maize.

Moreover, plant height demonstrated a notable positive correlation with ear length, tassel length, 100 kernel weight, number of kernels per row and ear girth. Tassel length showed positive correlation with ear length, the number of kernels per row, and protein content. In the case of ear length, it demonstrated positive correlations with ear girth, the number of kernels per row, the number of kernel rows per ear, and 100-kernel weight. Ear girth was positively associated with the number of kernels per row, the number of kernel rows per ear, and 100 kernel weight. The number of kernels per row correlated

Table 1. Phenotypic (r_p) and genotypic (r_g) correlation coefficients among yield and yield attributes in 30 maize inbred lines

		DFT	DFS	ASI	DM	SCMR	SLA	PH	TL	EL	EG	KPR	KRPE	100KW	HI	PC	KYP
DFT	r_p	**1.000**	0.979**	-0.062	0.823**	-0.111	-0.196	-0.322**	-0.088	-0.457**	-0.178	-0.345**	-0.111	-0.271**	-0.126	-0.032	-0.390**
	r_g	**1.000**	0.989**	0.002	0.911**	-0.124	-0.251*	-0.318**	-0.052	-0.484**	-0.133	-0.411**	-0.095	-0.335**	-0.157	-0.026	-0.449**
DFS	r_p		**1.000**	0.135	0.860**	-0.120	-0.185	-0.315**	-0.074	-0.443**	-0.171	-0.311**	-0.087	-0.279**	-0.104	-0.028	-0.365**
	r_g		**1.000**	0.151	0.937**	-0.124	-0.258*	-0.310**	-0.045	-0.460**	-0.140	-0.377**	-0.085	-0.348**	-0.153	-0.022	-0.412**
ASI	r_p			**1.000**	0.195	-0.090	0.032	0.038	0.089	0.067	0.057	0.197	0.140	-0.049	0.123	0.015	0.117
	r_g			**1.000**	0.264*	-0.010	-0.157	0.055	0.057	0.152	-0.049	0.184	0.069	-0.084	0.074	0.024	0.242*
DM	r_p				**1.000**	-0.007	-0.165	-0.150	0.083	-0.332**	-0.109	-0.194	-0.146	-0.202	-0.177	-0.092	-0.286**
	r_g				**1.000**	0.003	-0.184	-0.143	0.101	-0.338**	-0.168	-0.230*	-0.223*	-0.237*	-0.248*	-0.084	-0.327**
SCMR	r_p					**1.000**	-0.001	0.315**	0.051	0.328**	0.150	0.289**	-0.177	0.252*	0.108	-0.276**	0.407**
	r_g					**1.000**	0.060	0.408**	0.081	0.392**	0.266*	0.464**	-0.191	0.303**	0.163	-0.302**	0.474**
SLA	r_p						**1.000**	0.161	0.140	0.256*	0.302**	0.158	0.333**	0.311**	-0.052	0.034	0.342**
	r_g						**1.000**	0.227*	0.163	0.310**	0.384**	0.141	0.416**	0.565**	-0.017	0.036	0.424**
PH	r_p							**1.000**	0.353**	0.645**	0.406**	0.578**	0.126	0.476**	0.094	0.088	0.580**
	r_g							**1.000**	0.414**	0.705**	0.503**	0.713**	0.124	0.641**	0.140	0.102	0.618**
TL	r_p								**1.000**	0.447**	0.166	0.276**	0.161	0.067	-0.151	0.234*	0.220*
	r_g								**1.000**	0.520**	0.141	0.306**	0.107	0.023	-0.147	0.236*	0.245*
EL	r_p									**1.000**	0.567**	0.769**	0.365**	0.355**	0.195	0.125	0.793**
	r_g									**1.000**	0.631**	0.867**	0.388**	0.481**	0.248*	0.141	0.837**
EG	r_p										**1.000**	0.694**	0.649**	0.270*	0.121	-0.078	0.596**
	r_g										**1.000**	0.795**	0.711**	0.389**	0.151	-0.111	0.736**
KPR	r_p											**1.000**	0.404**	0.283**	0.265*	0.109	0.747**
	r_g											**1.000**	0.397**	0.449**	0.376**	0.107	0.860**
KRPE	r_p												**1.000**	-0.049	0.095	0.134	0.379**
	r_g												**1.000**	-0.057	0.113	0.147	0.462**
100KW	r_p													**1.000**	0.231*	0.022	0.358**
	r_g													**1.000**	0.333**	-0.013	0.480**
HI	r_p														**1.000**	0.470**	0.357**
	r_g														**1.000**	0.548**	0.412**
PC	r_p															**1.000**	0.054
	r_g															**1.000**	0.058
KYP	r_p																**1.000**
	r_g																**1.000**

*Significant at 5 % level; **Significant at 1 % level

DFT : Days to 50% tasseling; DFS : Days to 50% silking; ASI : Anthesis silking interval; DM : Days to maturity; SCMR : SPAD chlorophyll meter reading; SLA : Specific leaf area (cm^2 g^{-1}); PH : plant height (cm); TL : Tassel length (cm); EL: Ear length (cm); EG: Ear girth (cm); KPR : Number of kernels row^{-1} ; KRPE: Number of kernel rows ear^{-1} ; 100KW: 100 Kernel weight (g); KYP: Kernel yield $plant^{-1}$ (g); HI : Harvest index (%); PC : Protein content (%)

positively with the number of kernel rows per ear, 100 kernel weight, and harvest index. Furthermore, 100 kernel weight showed a positive relationship with harvest index, and harvest index was positively associated with protein content. Consequently, inbred lines exhibiting these traits could be considered in the selection process to enhance the respective characteristics, leading to simultaneous improvements in kernel yield per plant.

Correlations alone may not offer a comprehensive understanding of the significance of each component in influencing grain yield, given that yield components are interconnected and develop sequentially during distinct growth stages. In contrast, path coefficient analysis furnishes a richer dataset regarding the relationships among variables compared to correlation coefficients. (Aycicek and Yildirim, 2006).

Significant correlation coefficients between kernel yield per plant and its constituent traits were dissected into direct and indirect impacts using path coefficient analysis. Hence, path analysis was conducted with kernel yield as the dependent variable, and thirteen independent variables were considered. These variables included days to 50% tasseling, days to 50% silking, days to maturity, plant height, SPAD chlorophyll meter reading, specific leaf area, ear girth, tassel length, ear length, number of kernels per row, number of kernel rows per ear, 100-kernel weight, and harvest index. These variables had displayed significant phenotypic correlations with kernel yield per plant, and the results presented in **Table 2**. The phenotypic path diagram illustrating the traits contributing to yield is provided in **Fig. 1**.

Traits with a strong positive association and a high positive direct effect can be employed effectively as crop improvement selection criteria (Pavan *et al.,* 2011). Path analysis revealed that the residual effect was 0.475 indicating that the traits examined in the study collectively

Table 2. Phenotypic (P) and Genotypic (G) path coefficients for yield and yield attributes in 30 maize inbred lines

		DFT	DFS	DM	SCMR	SLA	PH	TL	EL	EG	KPR	KRPE	100KW	HI	KYP
DFT	P	**-0.1960**	0.2087	-0.0328	-0.0194	-0.0361	-0.0367	0.0074	-0.1967	-0.0137	-0.0640	-0.0040	0.0164	-0.0231	**-0.390****
	G	**-4.0396**	7.0268	-2.7909	0.1975	-1.0404	-0.8438	0.0785	-1.2382	-0.5420	0.4433	0.5889	1.9697	-0.2592	**-0.449****
DFS	P	-0.1920	**0.2130**	-0.0343	-0.0210	-0.0340	-0.0359	0.0062	-0.1910	-0.0132	-0.0576	-0.0031	0.0169	-0.0190	**-0.365****
	G	-3.9945	**7.1061**	-2.8704	0.1981	-1.0699	-0.8241	0.0678	-1.1780	-0.5705	0.4068	0.5238	2.0438	-0.2514	**-0.412****
DM	P	-0.1613	0.1832	**-0.0399**	-0.0012	-0.0303	-0.0171	-0.0069	-0.1430	-0.0084	-0.0359	-0.0052	0.0122	-0.0325	**-0.286****
	G	-3.6784	6.6551	**-3.0650**	-0.0054	-0.7604	-0.3802	-0.1534	-0.8654	-0.6829	0.2484	1.3751	1.3939	-0.4088	**-0.327****
SCMR	P	0.0218	-0.0256	0.0003	**0.1746**	-0.0002	0.0359	-0.0043	0.1413	0.0116	0.0535	-0.0063	-0.0153	0.0198	**0.407****
	G	0.5008	-0.884	-0.0104	**-1.5926**	0.2465	1.0830	-0.1220	1.0038	1.0815	-0.5010	1.1779	-1.7785	0.2688	**0.474****
SLA	P	0.0385	-0.0394	0.0066	-0.0002	**0.1838**	0.0183	-0.0118	0.1101	0.0233	0.0292	0.0119	-0.0189	-0.0095	**0.342****
	G	1.0151	-1.8363	0.5629	-0.0948	**4.1403**	0.6025	-0.2467	0.7934	1.5593	-0.1526	-2.5710	-3.3205	-0.0273	**0.424****
PH	P	0.0631	-0.0671	0.0060	0.0551	0.0295	**0.1138**	-0.0297	0.2779	0.0313	0.1071	0.0045	-0.0289	0.0173	**0.580****
	G	1.2837	-2.2053	0.4388	-0.6495	0.9395	**2.6554**	-0.6274	1.8057	2.0440	-0.7697	-0.7625	-3.7653	0.2307	**0.618****
TL	P	0.0173	-0.0157	-0.0033	0.0089	0.0257	0.0402	**-0.0841**	0.1925	0.0128	0.0511	0.0057	-0.0041	-0.0276	**0.220***
	G	0.2091	-0.3179	-0.3102	-0.1282	0.6737	1.0989	**-1.5160**	1.3322	0.5723	-0.3304	-0.6601	-0.1367	-0.2414	**0.245***
EL	P	0.0895	-0.0945	0.0132	0.0573	0.0470	0.0734	-0.0376	**0.4308**	0.0438	0.1425	0.0131	-0.0215	0.0357	**0.793****
	G	1.9541	-3.2703	1.0362	-0.6246	1.2833	1.8732	-0.7890	**2.5597**	2.5630	-0.9357	-2.3967	-2.8248	0.4085	**0.837****
EG	P	0.0348	-0.0365	0.0044	0.0262	0.0554	0.0462	-0.0140	0.2443	**0.0773**	0.1286	0.0232	-0.0163	0.0222	**0.596****
	G	0.5387	-0.9975	0.5150	-0.4238	1.5885	1.3355	-0.2135	1.6142	**4.0643**	-0.8573	-4.3895	-2.2876	0.2488	**0.736****
KPR	P	0.0677	-0.0662	0.0077	0.0504	0.0289	0.0658	-0.0232	0.3312	0.0536	**0.1853**	0.0144	-0.0171	0.0485	**0.747****
	G	1.6597	-2.6792	0.7056	-0.7396	0.5856	1.8942	-0.4642	2.2198	3.2292	**-1.0790**	-2.4493	-2.6418	0.6190	**0.860****
KRPE	P	0.0218	-0.0184	0.0058	-0.0309	0.0612	0.0143	-0.0135	0.1574	0.0502	0.0748	**0.0357**	0.0030	0.0173	**0.379****
	G	0.3853	-0.6029	0.6827	0.3039	1.7242	0.3280	-0.1621	0.9937	2.8897	-0.4280	**-6.1737**	0.3346	0.1868	**0.462****
100KW	P	0.0532	-0.0595	0.0080	0.0441	0.0572	0.0542	-0.0056	0.1529	0.0208	0.0524	-0.0018	**-0.0606**	0.0423	**0.358****
	G	1.3537	-2.4709	0.7268	-0.4819	2.3389	1.7010	-0.0353	1.2301	1.5818	-0.4849	0.3515	**-5.8779**	0.5475	**0.480****
HI	P	0.0248	-0.0221	0.0071	0.0189	-0.0096	0.0107	0.0127	0.0840	0.0094	0.0491	0.0034	-0.0140	**0.1830**	**0.357****
	G	0.6359	-1.0851	0.761	-0.2601	-0.0687	0.372	0.2223	0.6351	0.6143	-0.4057	-0.7004	-1.9549	**1.6463**	**0.412****

* Significant at 5 % level; ** Significant at 1 % level

DFT : Days to 50% tasseling; DFS : Days to 50% silking; ASI : Anthesis silking interval; DM : Days to maturity; SCMR : SPAD chlorophyll meter reading; SLA : Specific leaf area (cm^2 g^{-1}); PH : plant height (cm); TL : Tassel length (cm); EL: Ear length (cm); EG: Ear girth (cm); KPR : Number of kernels row^{-1} ; KRPE: Number of kernel rows ear^{-1} ; 100KW: 100 Kernel weight (g); KYP: Kernel yield $plant^{-1}$ (g); HI : Harvest index (%); PC : Protein content (%)

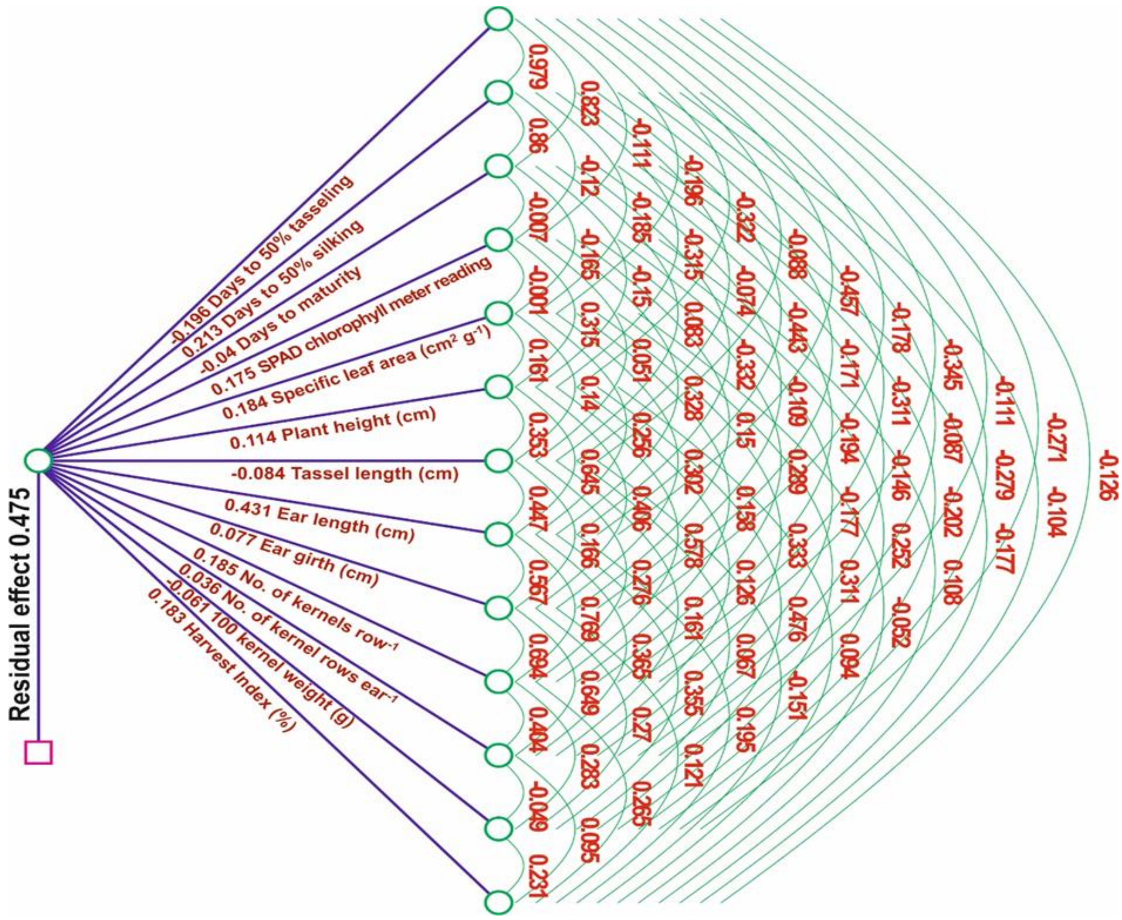

Fig. 1. Phenotypic path diagram for yield and yield attributes in 30 maize inbred line

account for over 52 percent of the variability observed in the dependent variable, which is the kernel yield per plant. Ear length displayed a notably strong and positively direct influence on kernel yield per plant due to its direct contribution, This implies that these correlations are significant and can be considered as elements for enhancing yield. These results align with the discoveries of Zarei *et al.* (2012), Kinfe and Tsehaye, (2015), Begum *et al.* (2016), Alhussein and Idris (2017), Shengu (2017), Belay (2018), Jilo and Tulu (2019).

It was observed that 100 kernel weight had a negative direct impact, but its association with kernel yield per plant remained positive and significant. This positive association could be attributed to its indirect influence through ear length, specific leaf area, plant height, days to 50% tasseling, and the number of kernels per row, resulting in a mutual offsetting of negative effects. Kumar *et al.* (2011), Panwar *et al.* (2013), Kinfe and Tsehaye, (2015) and Alhussein and Idris (2017) also found that 100 kernel weight had negative direct effect on kernel yield per plant. Likewise, the negative impact of tassel length was counteracted by its favourable indirect impacts through ear length and the number of kernels per row, a pattern previously noted by Meena *et al.* (2016). In contrast, days to 50% tasseling and days to maturity displayed a negative direct impact and were negatively correlated with kernel yield per plant. This suggests that favouring a negative association of these traits would be more advantageous when selecting early maturing inbred lines.

By and large to conclude, the path analysis conducted in this study has shown that ear length has a true and significant positive relationship with kernel yield per plant, indicating a substantial positive direct effect on kernel yield. Consequently, it is recommended that ear length be given considerable importance during the selection process to enhance kernel yield in maize breeding programs.

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