

Character Associations and Correlation Networks for Yield-Related and Vegetative Traits in Open-Pollinated and Hybrid Maize (*Zea Mays* L.) Genotypes in Contrasting Savannah Ecologies

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<https://doi.org/10.56201/ijaes.vol.12.no9.2026.pg81.90>

Abstract

Crop yield in maize (*Zea mays* L.) is a complex quantitative trait, making character associations crucial for developing indirect selection criteria. This study evaluated the phenotypic and genotypic associations among 22 growth, phenological, and yield traits across 10 elite maize genotypes. Field trials were conducted during the 2023 cropping season under contrasting environments in Gombe State, Nigeria: Dadin-Kowa (dry semi-arid, 350 mm annual rainfall) and Billiri (humid, 1,600 mm annual rainfall), using a Randomized Complete Block Design with three replications. Under dry semi-arid conditions at Dadin-Kowa, grain yield exhibited highly significant positive genotypic correlations with thousand-grain weight ($rg = 0.865^{**}$) and field weight ($rg = 0.931^{**}$). Conversely, under wet sub-humid conditions at Billiri, grain yield was strongly and positively correlated with vegetative traits, including number of leaves ($rp = 0.890^{**}$; $rg = 0.946^{**}$) and leaf area ($rp = 0.925^{**}$; $rg = 0.999^{**}$), indicating that canopy dimensions are primary yield drivers in high-moisture regimes. In the combined multi-environment analysis, grain yield was positively correlated with number of grains per row ($rp = 0.790^{**}$; $rg = 0.999^{**}$) and field weight ($rp = 0.949^{**}$; $rg = 0.999^{**}$). A notable physiological source-sink trade-off emerged, as harvest index was significantly negatively correlated with leaf area ($rp = -0.795^{**}$) and above-ground biomass ($rp = -0.814^{**}$). Maize selection must be environment-specific; breeders should prioritize thousand-grain weight for dry savannahs, leaf dimensions and ear diameter for humid zones, and grains per row for general regional cultivation.

Keywords: *Zea mays* L.; Phenotypic correlation; Genotypic correlation; Source-sink trade-offs; Dadin-Kowa; Billiri; Indirect selection index

1.0 Introduction

Maize (*Zea mays* L.) represents one of the most widely cultivated coarse grains and vital staple crops across sub-Saharan Africa, serving as a primary source of human food, industrial confectionery flours, starch, and animal feed constituents (Mamud, 2021; Magar et al., 2021). In Nigeria, which ranks as Africa's second-largest producer, maize is grown extensively across diverse ecological savannahs (PwC, 2021). Given that nearly 45.5% of the national maize crop is absorbed by the poultry and aquaculture feed manufacturing industries, and demand continues to rise exponentially due to rapid population growth, substantial productivity enhancements per unit land area are urgently required (Olaniyi & Adewale, 2012).

However, grain yield is a classic quantitative, polygenic attribute characterized by complex inheritance and high environmental sensitivity. Direct selection for grain yield in breeding nurseries is often highly inefficient and slow, as phenotypic expression is heavily masked by environmental noise and G×E interactions (Oluwagbenga & Fayeun, 2020). To circumvent this challenge, crop breeders rely on indirect selection indices, targeting highly heritable and easily measurable secondary vegetative and reproductive components that possess robust, positive correlation networks with economic yield (Maruthi & Jhansi Rani, 2015). Understanding the character associations among vegetative traits (such as leaf area, plant height, and stem diameter), phenological traits (days to silking and anthesis), and yield-attributing components (ear dimensions, grain rows, and kernel weights) is fundamental to designing highly efficient breeding schemes (Magar et al., 2021). Correlation analysis separates these relationships into phenotypic and genotypic dimensions. While phenotypic correlations quantify the observed physical associations between traits under field conditions, genotypic correlations delve into the inherent genetic relationships governed by linkage, pleiotropy, and physiological source-sink balances (Oluwagbenga & Stephen, 2020; Khan & Mahmud, 2021). Gombe State presents an exceptionally ideal breeding laboratory, spanning a sharp rainfall and climate gradient from the dry, northern semi-arid ecological zone of Dadin-Kowa (350 mm annual rainfall) to the wet, humid southern zone of Billiri (1,600 mm annual rainfall) (Kowal & Knabe, 1973; Butu et al., 2020). Thus, this study was initiated to analyze the character associations and correlation networks among twenty-two growth and yield traits of ten elite maize varieties across these contrasting environments, to identify precise, ecologically targeted indirect selection criteria.

2.0 Materials and Methods

2.1 Experimental Environments and Germplasm

Field trials were executed concurrently during the 2023 cropping season across two agro-climatic extremes in Gombe State, Nigeria. Location A was the Federal College of Horticulture Research Farm in Dadin-Kowa (Gombe Central), representing a dry semi-arid savannah ecology with a mean annual rainfall of only 350 mm and average temperatures ranging from 30°C to 32°C. Location B was the Gombe State College of Education Teaching and Research Farm in Billiri (Gombe South), representing a humid, sub-humid savannah climate with an average rainfall of 1,600 mm and sandy loam soils. The genetic materials comprised ten elite maize genotypes: nine open-pollinated Sammaz varieties (Sammaz 15, 17, 18, 29, 51, 52, 53, 54, 55) and one commercial early white hybrid variety (Oba-98), all sourced from the Institute for Agricultural Research (IAR), Zaria.

2.2 Experimental Design and Crop Management

At each site, the experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. Individual plot sizes were 3.0 m × 2.0 m (6.0 m²), comprising four rows. Spacing was maintained at 75 cm between rows and 25 cm within rows. Sowing was done manually at two seeds per hill and thinned to one robust seedling per hill at the 4–5 leaf stage (two weeks after planting) to establish uniform crop stands. Weeding was conducted manually using hand hoes at two-week intervals. Inorganic fertilizers were applied uniformly across all plots: N.P.K. (15:15:15) was applied as a basal dressing at 100 kg/ha one week after planting, and Urea was applied at 100 kg/ha in two equal split applications (the first half six weeks after planting and the remaining half at tassel emergence).

2.3 Biometric Measurements and Data Collection

A total of twenty-two agronomic, vegetative, phenological, and yield traits were recorded from ten randomly selected plants per plot. These included: number of leaves (NL), plant height (PH, cm), ear height (EH, cm), leaf length (LL, cm), leaf width (LW, cm), leaf area (LA, cm²), number of tassel branches (NTB), stem diameter (SD, mm), days to 50% anthesis (DTA), days to 50% silking (DTS), number of ears per plant (NEP), ear length (EL, cm), ear diameter (ED, mm), number of grain rows per ear (NOGRPE), number of grains per row (NOGPR), 1000-grain weight (THOGW, kg), field weight per plot and converted to tons/hectare (FWTPH), grain yield per plot and converted to tons/hectare (GYTPH), above-ground biomass yield per plot and tons/hectare (AGBYTPH), and harvest index (HI, %) calculated using the formula: $HI (\%) = [\text{Grain Yield (kg/ha)} / \text{Above-ground Biomass (kg/ha)}] \times 100$.

2.4 Biometrical Analysis

Phenotypic and genotypic correlation coefficients were calculated using the standard formulas adapted by Magar et al. (2021) and Fekadu et al. (2024). Phenotypic correlation (r_p) was determined as: $r_p = \text{Covp}(x, y) / [\text{Varp}(x) * \text{Varp}(y)]^{0.5}$, where $\text{Covp}(x, y)$ represents the phenotypic covariance between traits x and y , and $\text{Varp}(x)$ and $\text{Varp}(y)$ are the respective phenotypic variances. Genotypic correlation (r_g) was computed as: $r_g = \text{Covg}(x, y) / [\text{Varg}(x) * \text{Varg}(y)]^{0.5}$, where $\text{Covg}(x, y)$ represents the genotypic covariance, and $\text{Varg}(x)$ and $\text{Varg}(y)$ are the respective genotypic variances. All biometric computations and statistical significance tests at the 5% and 1% levels of probability were executed using SPSS version 23.

3.0 Results

3.1 Core Yield Associations and Correlation Networks across Climates

The calculated phenotypic and genotypic correlation coefficients of grain yield (t/ha) with growth, phenological, and yield-related attributes revealed distinct patterns across Dadin-Kowa, Billiri, and the combined environments (Table 1). In the dry semi-arid climate of Dadin-Kowa, where severe water scarcity (350 mm/annum) governed growth, grain yield exhibited highly significant positive phenotypic correlations with only field weight ($r_p = 0.801^{**}$) and grain yield per plot ($r_p = 0.995^{**}$). There were no significant phenotypic correlations between grain yield and other growth or phenological characteristics, demonstrating that vegetative structures had limited direct association with yield under drought. However, at the genotypic level in Dadin-Kowa, thousand-grain weight ($r_g = 0.865^{**}$) and field weight ($r_g = 0.931^{**}$) exhibited highly significant positive correlations with grain yield, indicating a strong, inherent genetic relationship.

In stark contrast, under the humid, high-moisture climate of Billiri (1,600 mm/annum), grain yield displayed highly significant positive phenotypic and genotypic correlations with almost all vegetative, morphological, and reproductive traits. Highly significant positive phenotypic and genotypic correlations were recorded with number of leaves ($r_p = 0.890^{**}$; $r_g = 0.946^{**}$), leaf width ($r_p = 0.965^{**}$; $r_g = 0.999^{**}$), leaf area ($r_p = 0.925^{**}$; $r_g = 0.999^{**}$), leaf length ($r_p = 0.814^{**}$; $r_g = 0.999^{**}$), plant height ($r_p = 0.782^{**}$), ear height ($r_p = 0.781^{**}$; $r_g = 0.999^{**}$), ear diameter ($r_p = 0.864^{**}$; $r_g = 0.999^{**}$), number of grains per row ($r_p = 0.958^{**}$; $r_g = 0.999^{**}$), and field weight ($r_p = 0.989^{**}$; $r_g = 0.999^{**}$). Grain yield in Billiri showed non-significant phenotypic associations with number of tassel branches, stem diameter, 1000-grain weight, days to 50% anthesis, and days to 50% silking, though at the genotypic level, stem diameter was stable and non-significant. For the combined locations (Table 1), grain yield was positively and highly significantly correlated phenotypically and genotypic with number of grains per row ($r_p = 0.790^{**}$; $r_g = 0.999^{**}$), field weight ($r_p = 0.949^{**}$; $r_g = 0.999^{**}$), grain yield per plot ($r_p = 0.997^{**}$), and grain yield kg/ha ($r_p = 0.999^{**}$). Significant positive phenotypic correlations were also recorded with number of leaves ($r_p = 0.751^*$), ear length ($r_p = 0.708^*$; $r_g = 0.646^*$), and ear diameter ($r_p = 0.737^*$). In contrast, leaf length, leaf width, leaf area, plant height, ear height, tassel branches, and stem diameter showed non-significant associations with yield in the combined phenotypic analysis, highlighting environmental confounding.

Table 1: Phenotypic (r_p) and Genotypic (r_g) Correlation of Grain Yield with Selected Agronomic Traits

Traits	Dadin-Kowa (r_p)	Dadin-Kowa (r_g)	Billiri (r_p)	Billiri (r_g)	Combined (r_p)	Combined (r_g)
No. of leaves (NL)	0.274	0.155	0.890**	0.946**	0.751*	0.999**
Plant height (PH)	-0.503	0.676*	0.782**	0.676*	-0.199	0.676*
Ear Height (EH)	0.037	0.272	0.780**	0.978**	-0.012	0.999**
Leaf length (LL)	-0.078	-0.239	0.814**	0.999**	0.459	0.999**
Leaf width (LW)	-0.084	0.999**	0.965**	0.999**	0.531	0.999**
Leaf Area (LA)	-0.070	0.999**	0.925**	0.999**	0.516	0.999**
Ear length (EL)	0.183	-0.171	0.899**	0.999**	0.708*	0.646*
Ear diameter (ED)	0.150	0.391	0.864**	0.999**	0.737*	0.999**
No of Grains per Row	0.290	0.300	0.958**	0.999**	0.790**	0.999**

1000-grain weight	0.353	0.865**	0.594	0.999**	0.566	0.999**
Field weight (t/ha)	0.801**	0.931**	0.989**	0.999**	0.949**	0.999**
Grain yield/plot	0.995**	0.999**	0.999**	0.999**	0.997**	0.999**
Above-ground biomass	0.236	0.318	0.922**	0.999**	0.865**	0.999**
Harvest index (HI)	0.427	1.244	-0.128	0.999**	-0.449	-0.389

3.2 Correlation Networks among Vegetative and Reproductive Components

Beyond direct grain yield associations, complex correlation networks exist among growth, vegetative source, and reproductive sink parameters. At Dadin-Kowa (Table 2), phenotypic networks revealed that number of grain rows per ear exhibited highly significant positive phenotypic correlations with ear diameter ($r_p = 0.846^{**}$) and number of ears per plant ($r_p = 0.805^{**}$). Additionally, leaf area index was strongly and positively linked with number of leaves per plant ($r_p = 0.754^*$), leaf length ($r_p = 0.956^{**}$), and leaf width ($r_p = 0.962^{**}$), confirming that leaf area is a direct function of physical leaf dimensions. Stem diameter was highly correlated with ear height ($r_p = 0.815^{**}$) and leaf width ($r_p = 0.826^{**}$). A major physiological trade-off was identified at the phenotypic level, where harvest index exhibited a highly significant negative correlation with above-ground biomass yield per plot ($r_p = -0.749^*$) and above-ground biomass in tons/hectare ($r_p = -0.746^*$), confirming that excessive biomass load under dry environments reduces relative harvest index. At the genotypic level in Dadin-Kowa, the number of grain rows per ear displayed tight positive genetic linkages with number of leaves ($r_g = 0.999^{**}$), ear length ($r_g = 0.999^{**}$), and leaf width ($r_g = 0.999^{**}$). Above-ground biomass exhibited highly significant positive genetic correlations with number of leaves ($r_g = 0.995^{**}$), days to 50% anthesis ($r_g = 0.999^{**}$), and number of grains per row ($r_g = 0.676^*$), while exhibiting negative genetic correlations with leaf length ($r_g = -0.399^{**}$) and number of ears per plant ($r_g = -0.399^{**}$).

Table 2: Key Morphological and Yield-Component Inter-trait Correlation Coefficients in Dadin-Kowa

Associated Trait Pair	Phenotypic (rp)	Genotypic (rg)	Breeding Implication
Grain Rows per Ear × Ear Diameter	0.841**	0.846**	Direct selection for row number increases ear girth.
Leaf Area × Leaf Length	0.956**	0.999**	High genetic linkage; leaf expansion driven by leaf elongation.
Leaf Area × Leaf Width	0.962**	0.999**	Strict genetic pleiotropy controlling leaf source dimensions.

Stem Diameter × Ear Height	0.815**	0.999**	Sufficient stem thickness supports high ear placement against lodging.
Harvest Index × Above-ground Biomass	-0.749*	-0.483	Drought-induced trade-off; high biomass reduces grain-filling index.
Grain Rows per Ear × Number of Leaves	0.362	0.999**	Cryptic genetic correlation; larger source supports more kernel rows.

3.3 Trait Interrelationships under Humid Climate (Billiri)

In the humid, resource-rich climate of Billiri, different trait associations emerged. Phenotypically, ear diameter was highly significantly and positively correlated with number of leaves ($r_p = 0.733^{**}$), plant height ($r_p = 0.664^*$), leaf width ($r_p = 0.781^{**}$), ear length ($r_p = 0.727^*$), and leaf area ($r_p = 0.714^*$). This indicates that well-developed vegetative source canopies directly supported reproductive sink sizing (ear thickness). Furthermore, number of grains per row exhibited highly significant positive phenotypic correlations with number of leaves ($r_p = 0.848^{**}$), plant height ($r_p = 0.772^{**}$), ear height ($r_p = 0.784^{**}$), leaf length ($r_p = 0.802^{**}$), and ear length ($r_p = 0.956^{**}$). At the genotypic level in Billiri, ear diameter showed highly significant positive genetic correlations with leaf length ($r_g = 0.778^{**}$), leaf width ($r_g = 0.948^{**}$), and leaf area ($r_g = 0.825^{**}$). Crucially, phenological parameters, specifically days to 50% anthesis ($r_g = -0.999^{**}$) and days to 50% silking ($r_g = -0.999^{**}$), exhibited highly significant negative genotypic correlations with ear diameter and other vegetative growth traits, confirming that early-maturing genotypes suffer a significant vegetative growth penalty and smaller ear capacities under unlimited humid cropping seasons.

Table 3: Key Morphological and Yield-Component Inter-trait Correlation Coefficients in Billiri

Associated Trait Pair	Phenotypic (r_p)	Genotypic (r_g)	Breeding Implication
Ear Diameter × Leaf Width	0.781**	0.948**	Strong genetic/physical link between leaf width and ear girth.
Grains per Row × Ear Length	0.956**	0.999**	Elongated ears directly dictate the number of grains per row.
Grains per Row × Plant Height	0.772**	0.999**	Taller plants provide a larger source capacity to fill long ears.
Ear Diameter × Leaf Area	0.714*	0.825**	Adequate leaf canopy area directly feeds ear sink development.
Ear Diameter × Days to 50% Anthesis	-0.146	-0.999**	Early-flowering genotypes have a shorter vegetative cycle and smaller ears.

Above-ground Biomass × Ear Length	0.840**	0.999**	High biomass indicates high source output driving ear elongation.
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3.4 Character Associations across Combined Multi-Environments

The combined phenotypic correlation analysis across both contrasting climates (Table 4) revealed that number of grains per row exhibited highly significant positive correlations with number of leaves ($r_p = 0.734^*$), leaf area ($r_p = 0.590^*$), ear length ($r_p = 0.897^{**}$), and ear diameter ($r_p = 0.652^{**}$). Above-ground biomass yield per plot was highly significantly and positively correlated with number of leaves ($r_p = 0.752^*$), ear length ($r_p = 0.708^*$), ear diameter ($r_p = 0.737^*$), number of grains per row ($r_p = 0.828^{**}$), and grain yield per plot ($r_p = 0.864^{**}$).

Crucially, a prominent and highly significant negative phenotypic correlation network was identified for harvest index with vegetative growth traits: harvest index correlated negatively with number of leaves ($r_p = -0.734^*$), leaf length ($r_p = -0.777^{**}$), leaf width ($r_p = -0.756^*$), leaf area ($r_p = -0.795^{**}$), number of grains per row ($r_p = -0.694^*$), and above-ground biomass yield per plot ($r_p = -0.814^{**}$). At the genotypic level, the number of grains per row exhibited strong positive genetic correlations with number of leaves ($r_g = 0.999^{**}$), ear diameter ($r_g = 0.894^{**}$), leaf width ($r_g = 0.999^{**}$), and ear length ($r_g = 0.999^{**}$), while maintaining a highly significant negative genetic correlation with number of ears per plant ($r_g = -0.981^{**}$).

Table 4: Key Morphological and Yield-Component Inter-trait Correlation Coefficients in Combined Analysis

Associated Trait Pair	Phenotypic (r_p)	Genotypic (r_g)	Breeding Implication
Grains per Row × Ear Length	0.897**	0.999**	Perfect genetic and phenotypic link driving grain row filling.
Biomass per Plot × Grains per Row	0.828**	0.999**	High biomass accumulation supports more grains per row.
Harvest Index × Above-ground Biomass	-0.814**	-0.814**	Physiological conflict: excessive biomass reduces economic conversion.
Harvest Index × Leaf Area	-0.795**	-0.795**	Shaded, dense canopies can lower relative economic harvest index.
Grains per Row × Number of Ears/Plant	-0.505	-0.981**	Strong genetic trade-off between ear number and grain number per row.
Grains per Row × Ear Diameter	0.652**	0.894**	Ear thickness supports higher grain capacities per row.

4. Discussion

The stark contrasts in correlation profiles between Dadin-Kowa and Billiri highlights that physical environmental stressors fundamentally reorganize crop character associations and physiological networks. In Dadin-Kowa, where water availability is extremely limited (350 mm/annum), vegetative growth traits showed complete non-significance phenotypically with grain yield. Environmental moisture stress restricted leaf area expansion and plant height development, decoupled vegetative development from final productivity, and made vegetative size a poor predictor of yield. This aligns with the findings of Gopalakrishna et al. (2023) and Kumsa et al. (2020), who noted that under drought stress, plant morphological traits fail to correlate significantly with yield due to radical changes in assimilate partitioning to female reproductive structures. In contrast, in the high-moisture sub-humid climate of Billiri, where resources are non-limiting, and the physiological sink capacity was completely supported by source sizing. Vegetative traits such as leaf area ($r_p = 0.925^{**}$), leaf length, leaf width, and plant height demonstrated extremely high, positive, and significant phenotypic correlations with grain yield. Under these conditions, larger, well-exposed leaf canopies maximize solar light interception, promoting substantial photo-assimilate synthesis and strong source-sink conversion to grain filling. These results are in full agreement with those of Magar et al. (2021) and Oyekola and Fayeun (2019), who observed that vegetative traits exhibit high positive correlations with yield under optimal, unrestricted tropical environments, making vegetative canopy characteristics effective selection tools. A highly significant finding in this study is the genotypic correlation profile. When genotypic correlations exceed their corresponding phenotypic counterparts (as seen in Table 1 across traits like leaf area, ear diameter, and grains per row), it indicates a strong, inherent genetic relationship among the studied traits that is partially masked by environmental noise. Breeders can successfully exploit these high genotypic correlations for selection because they are governed by linkage and pleiotropic gene actions rather than temporary environmental benefits, agreeing with reports by Fekadu et al. (2024) and Khan and Mahmud (2021). For instance, the highly positive genotypic correlation of thousand-grain weight with yield in Dadin-Kowa ($r_g = 0.865^{**}$) highlights that breeding for grain weight is a highly effective genetic pathway for improving drought yield.

However, our results also reveal critical physiological trade-offs. The highly significant negative correlation of harvest index with above-ground biomass ($r_p = -0.814^{**}$) and leaf area ($r_p = -0.795^{**}$) in the combined analysis demonstrates a common biological conflict in intensively bred crops. Excessive vegetative biomass expansion, while increasing absolute biological yield, leads to mutual shading, lodging, and reduced relative allocation of assimilates to the grain, ultimately depressing the harvest index. This trade-off is well-documented by Echarte et al. (2013) and Richards (2017), who caution that continually breeding for larger plant structures can be counterproductive if the harvest index collapses due to source-sink imbalance. Thus, breeders must target an optimal balance between leaf area and harvest index to maximize stable yields across Gombe State.

5. Conclusions and Recommendations

This study concludes that phenotypic and genotypic character associations in maize are highly dependent on the agro-climatic evaluation environment, requiring distinct selection strategies for Gombe State's contrasting climates. Under dry semi-arid northern savannah conditions (Dadin-Kowa), vegetative growth parameters are decoupled from yield, and breeders must prioritize thousand-grain weight and field weight as indirect selection criteria. Under high-rainfall, sub-

humid southern conditions (Billiri), grain yield is heavily driven by vegetative source size, making leaf area index, leaf width, and ear diameter highly effective selection targets. For state-wide stability, selection should focus on number of grains per row and above-ground biomass, while carefully managing the physiological trade-off where excessive biomass load depresses the economic harvest index.

Based on these findings, the following recommendations are put forward:

- **Environment-Specific Selection Indices:** Avoid using unified selection criteria across Gombe State. Prioritize thousand-grain weight and ear diameter for dry northern savannahs (Dadin-Kowa) and vegetative canopy traits (leaf area, leaf width) for wet southern ecologies (Billiri).
- **Target Yield-Related Attributes:** Breeders targeting general regional maize improvement should select for number of grains per row and ear diameter, as these yield-components exhibited highly stable positive correlations with yield across environments.
- **Optimize Source-Sink Balancing:** Breeding programs must manage the biomass trade-off by selecting genotypes with moderate plant height and high harvest index (such as Sammaz 51 and Oba 98) to prevent mutual shading and yield depression.
- **Exploit Genotypic Covariation:** Utilize parent lines like Sammaz 18 and Sammaz 15 in crossing blocks to introgress stable vegetative development and robust genetic trait correlations into high-yielding local composite varieties.

Declarations

Ethical Approval: Not applicable as this study did not involve human or animal subjects.

Competing Interests: The authors declare that they have no competing interests.

Funding: This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Authors' Contributions: This work was conceptualized, designed, and executed in collaboration with the researchers.

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