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RESEARCH ARTICLE

Evaluation of productivity components and their interrelationships in early-maturing inbred maize families

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Abstract

This study aimed to investigate the formation of productivity and the relationships among traits in early-maturing inbred maize families under the conditions of the Northern Steppe of Ukraine. The research methods included the field evaluation of 302 S_4-S_6 families derived from a mixed germplasm pool, as well as multivariate statistical analysis. The highest positive correlation was observed between plant productivity and 1,000-kernel weight (r=0.726) and ear length (r=0.604). Multiple regression confirmed ear length and diameter as the main independent traits for predicting yield. The analysis of main traits explained 69.1% of the phenotypic variance, whilst cluster analysis differentiated the genotypes into eight distinct groups to optimise the selection of parental lines for new hybrids.

Keywords: Maize, Inbreeding, Selection, Productivity, Morphobiological traits, Correlation, Regression and cluster analysis

Introduction

The development of competitive maize hybrids adapted to climatic challenges (in particular, moisture deficiency and extreme temperatures) requires the continuous improvement of the initial breeding material (Bharathi, et al. 2021, Ocwa, et al. 2023). A priority in this process is the development of inbred families based on mixed germplasm, which ensures broad genetic diversity and a high level of recombination variability (Kamara, et al. 2020, Patel, et al. 2024).

The effectiveness of breeding such genotypes depends on the accurate assessment of the morphobiological traits that determine overall productivity (Bhatla, et al. 2025, Bonkoungou, et al. 2024). The level of impact is determined by their genetics and environmental conditions, therefore, optimizing the breeding process requires the use of multidimensional statistical methods (in particular, Principal Component Analysis (PCA) and cluster analysis), which allows the identification of the most reliable indirect selection criteria (Mounika, et al. 2018, Suryanarayana, et al. 2017).

Despite a considerable number of studies, the patterns governing the formation of productivity in early-maturing inbred families of mixed germplasm under the specific conditions of the Northern Steppe of Ukraine remain insufficiently investigated (Badu-Apraku, et al. 2017, Vozhegova, et al. 2022). This highlights the need to establish informative selection criteria for the development of new parental components adapted to this region.

Materials and Methods

The study was conducted at the SE Institute of Grain Crops of the National Academy of Agrarian Sciences (NAAS) of Ukraine (Dnipro) during the 2023-2025 growing seasons. The experimental material included 302 early-maturing inbred maize families (generations S_4-S_6), derived from seven mixed germplasm populations. The early-maturing self-pollinated line DK315SVZM was used as the standard. Field trials were conducted in a breeding nursery (plots measuring 4.9 m^2) within a barley-maize crop rotation. Sowing was carried out from late April to early May. Standard agronomic practices for the Northern Steppe of Ukraine were applied, and plant density was adjusted to 60,000 plants ha^{-1} at the Biologische Bundesanstalt, Bundessortenamt and Chemical industry (BBCH) 13-17 stage.

Phenotypic assessment was carried out on 10 plants from each plot in accordance with the national maize descriptors. The following nine traits were recorded: Number of days to 50 % silk emergence, plant height and insertion height of the first productive ear, ear length and diameter, number of kernel rows per ear, number of kernels per row, 1,000-kernel weight and grain yield. Statistical analysis of the data, including Pearson's correlation, multiple linear regression, Principal Component Analysis (PCA) and Ward's hierarchical clustering, was performed using PAST version 4.03 and Microsoft Excel.

Results and Discussion

Plant productivity is determined by complex interactions among yield attributes of the crop. According to the results of the correlation analysis (represented on a heat map, Fig. 1), the strongest positive correlation with yield was found for the 1,000-kernel weight (r=0.726), ear length (r=0.604) and the number of kernels per row (r=0.557). Morphometric parameters (plant height and ear height) showed moderate correlations with yield (r=0.523-0.534).

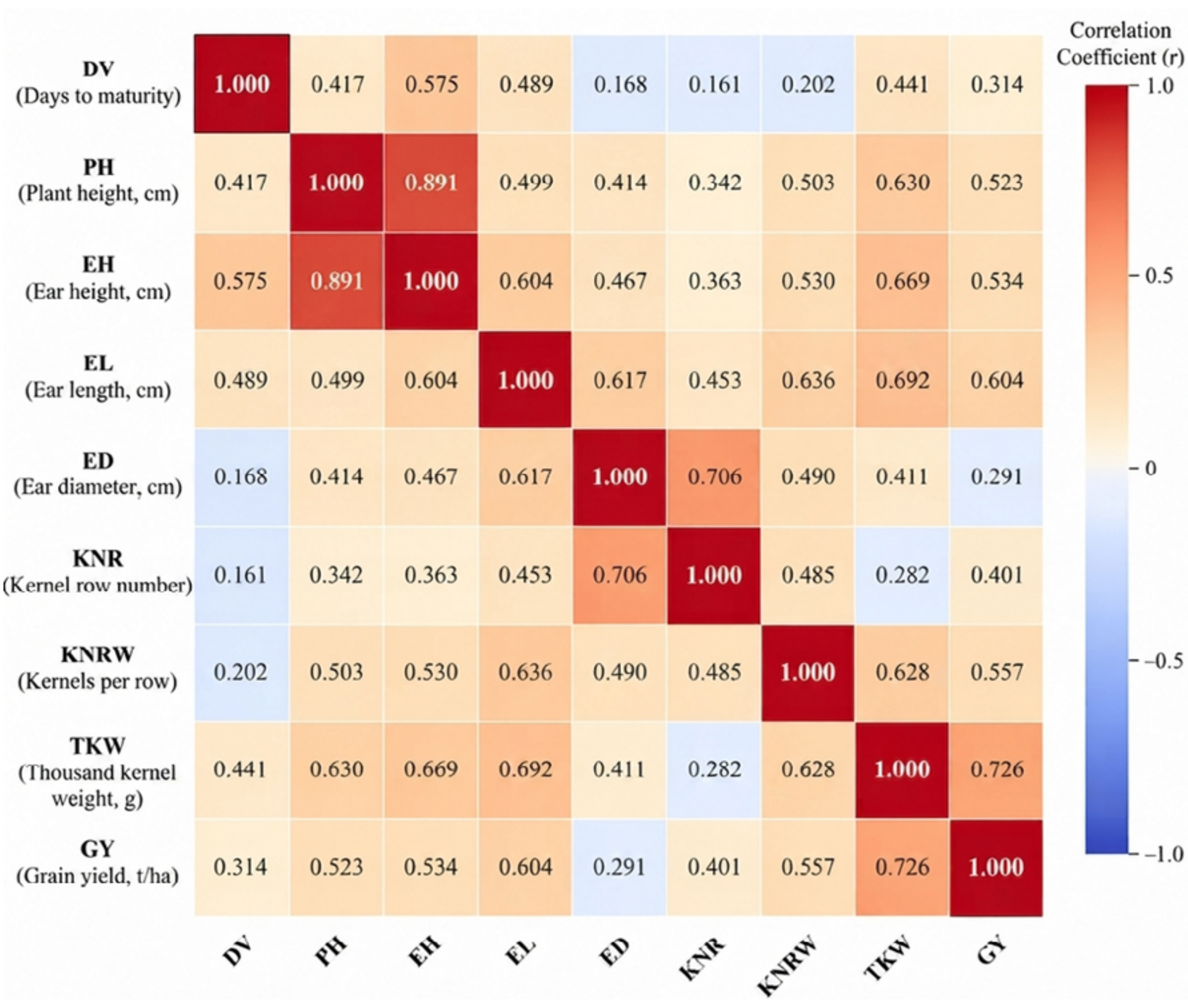

Figure 1. Heat map of correlations between traits of inbred maize lines (2023-2025), n=302. Method: Pearson's correlation. Positive values (red) indicate a direct relationship; negative values (blue) indicate an inverse relationship.

The visual analysis of the heat map revealed the integration of traits: The morphometric parameters are closely interrelated (r=0.891), and strong correlation was found between ear length and the 1,000-kernel weight (r=0.692). No strong negative relationships were identified, suggesting the feasibility of enhancing these traits through the breeding process.

Multiple regression analysis was used to assess the independent contribution of each trait (Tab. 1).

Table 1. Multiple regression parameters for the productivity of inbred families.

Variable	Standardized β	SE	t	p-value	VIF
Growing season duration, days	0.31	0.27	0.27	0.78	1.80
Plant height, cm	0.52	1.71	0.01	0.99	5.06
Ear height, cm	0.53	1.07	0.03	0.98	4.89
Ear length, cm	0.60	0.13	2.19	0.03	2.82
Ear diameter, cm	0.29	0.02	43.30	<0.001	1.77
Number of kernel rows per ear	0.40	0.14	1.43	0.22	1.99
Number of kernels per row	0.56	0.31	0.38	0.70	2.75
1,000-kernel weight, g	0.72	6.63	0.00	0.99	5.02

Note: β: Standardised regression coefficient; SE: Standard Error of the regression coefficient; t: Student's test; p: level of statistical significance; VIF: Variance Inflation Factor.

Multiple regression analysis showed that, after adjusting for the interdependence of the traits, the primary components of productivity are ear length (β=0.60; p=0.03) and ear diameter (β=0.29; p<0.001). At the same time, the 1,000-kernel weight, which had the strongest correlation with yield (r=0.726), did not reveal a significant independent contribution. This is explained by its excessive interdependence with other traits (VIF=5.02) and the redistribution of explanatory power due to strong relationships with other model predictors.

Principal Component Analysis (PCA) confirmed a two-factor model of variability (Fig. 2). The first two components explain 69.1 % of the total variance. The first component (PC1-54.0 %) characterises the integrated level of plant development and productivity (the largest contributions being 1,000-kernel weight, plant height and ear length). The second (PC2-15.1 %) determines the ear architecture (ear diameter, and number of kernel rows).

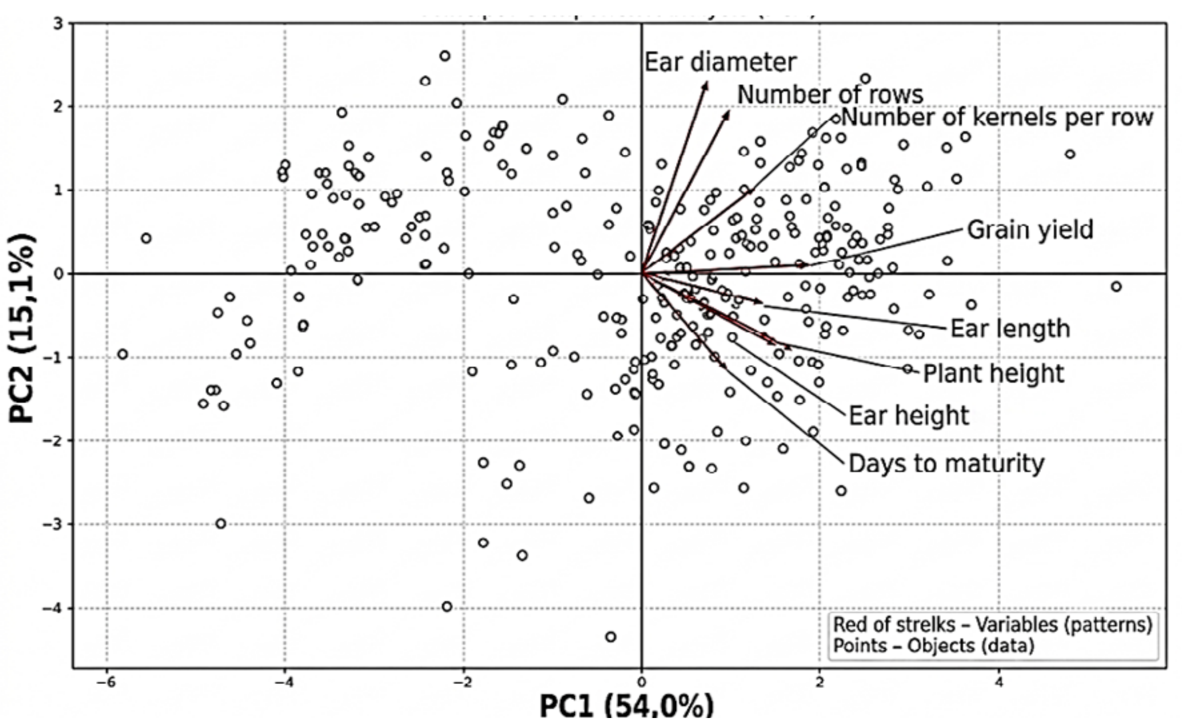

Figure 2. PCA biplot of agronomic traits of early-maturing maize inbred lines (2023-2025).

The Ward's method of cluster analysis allowed us to classify 302 genotypes into eight phenotypically distinct groups. The most isolated clusters (VII and VIII) accumulate specific effects of breeding value and represent the most promising donors for the development of highly heterozygous hybrids.

Conclusion

The synthesis of early-maturing inbred families based on mixed germplasm resulted in the formation of a wide range of phenotypic variability of a complex of economically important traits, indicating the high breeding potential of the developed source material.

Comprehensive correlation and multiple regression analysis revealed that the most informative criteria for indirect selection for improving plant productivity are ear length and diameter, the 1,000-kernel weight, and the number of kernels per row. Therefore, these traits should be used as breeding indicators during the early stages of evaluating inbred material.

Principal component analysis found that the phenotypic structure of the sample under study is determined by two principal components, which account for 69.1 % of the total variance and characterise the integral productivity and morphological architecture of the ear.

Cluster analysis highlighted contrasting groups of genotypes, which are promising sources for the selection of parental components for the development of high-yielding, early-maturing maize hybrids adapted to the soil and climatic conditions of the Northern Steppe of Ukraine.

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