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# AI-Driven High-Throughput Phenotyping for Drought-Resilient Maize (*Zea mays* L) in Bangladesh

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**Abstract**

Drought stress is a major limitation for maize productivity in Bangladesh, creating a need for rapid and reliable approaches to identify tolerant genotypes. This study developed an artificial intelligence (AI)-assisted high-throughput phenotyping framework by integrating unmanned aerial vehicle (UAV)-based multispectral imaging, machine learning, and conventional statistical analyses for drought response evaluation in maize. Four elite maize genotypes (BHM-9, BHM-14, BHM-17, and BWMRI-1) were evaluated under managed drought conditions maintained at 40% field capacity. A comprehensive dataset consisting of agronomic, physiological, and UAV-derived spectral traits was generated throughout crop development. Analysis of variance revealed significant differences among genotypes for important drought-related traits, including plant height, grain yield attributes, and relative water content. Multivariate analyses, including principal component analysis (PCA) and hierarchical clustering, effectively differentiated drought-responsive genotypes, with BHM-9 showing superior performance under water-limited conditions. AI-based prediction models combining ResNet-50 and Random Forest algorithms demonstrated strong predictive ability for drought-related phenotypic traits, achieving high accuracy with $R^2$ values above 0.85 and low prediction errors. The findings demonstrate that AI-driven phenotyping can accelerate drought tolerance screening by combining rapid image-based assessment with physiological measurements. The identified tolerant genotype and developed analytical framework may support future maize breeding programs aimed at improving drought resilience in Bangladesh.

**Keywords:** Maize; drought tolerance; high-throughput phenotyping; UAV imaging; artificial intelligence; machine learning.

## Introduction

Maize (*Zea mays* L.) is one of the most important cereal crops in Bangladesh, contributing substantially to food security, livestock feed production, and agricultural diversification. However, maize productivity is increasingly threatened by abiotic stresses, particularly drought, which affects plant growth, reproductive development, and grain yield. Drought stress reduces leaf expansion, disrupts photosynthetic activity, limits nutrient uptake, and accelerates senescence, ultimately causing considerable yield reduction in drought-prone environments (Hoque et al., 2018; Hossain, 2021).

In Bangladesh, drought is particularly severe in the northwestern regions, including the Barind Tract, Rajshahi, and Chapainawabganj areas, where irregular rainfall patterns and limited soil moisture availability create unfavorable conditions for crop production (BARI, 2023). The development and deployment of drought-resilient maize varieties have therefore become important strategies for maintaining productivity under changing climatic conditions.

Drought tolerance is a complex quantitative trait controlled by multiple physiological and morphological mechanisms, including root development, water-use efficiency, chlorophyll retention, canopy temperature regulation, and maintenance of reproductive growth. Accurate identification of drought-tolerant genotypes requires efficient phenotyping approaches capable of measuring multiple traits rapidly and objectively.

Traditional field phenotyping methods are often laborious, time-consuming, and dependent on manual observations. These limitations restrict the evaluation of large breeding populations and slow genetic improvement programs. High-throughput phenotyping (HTP) has emerged as a powerful approach to overcome these limitations by enabling rapid, automated, and non-destructive measurement of plant traits at field scale (Song et al., 2021).

Recent advances in unmanned aerial vehicle (UAV) technology and multispectral imaging have significantly improved crop monitoring and phenotypic evaluation. UAV-based platforms can capture high-resolution spatial and temporal information related to crop growth, canopy structure, vegetation indices, and stress responses. These technologies have been successfully applied for estimating biomass, yield components, and drought-related physiological traits in maize and other crops (Gano et al., 2024; Bongomin et al., 2024).

Artificial intelligence (AI), including machine learning and deep learning algorithms, has further enhanced the capability of HTP systems by extracting complex patterns from large-scale image datasets. Convolutional neural networks (CNNs) can automatically identify image-based features, whereas machine learning models such as Random Forest can establish predictive relationships between spectral information and physiological traits (Farooq et al., 2024; Sheikh et al., 2024).

Recent studies have demonstrated that integrating vegetation indices derived from UAV imagery with computational intelligence models can improve prediction accuracy for complex agronomic traits such as yield, biomass, and drought response indicators in maize (Teodoro et al., 2024). However, the application of AI-assisted HTP for drought screening of maize under Bangladesh environmental conditions remains limited.

Therefore, this study aimed to develop an AI-assisted high-throughput phenotyping framework for drought evaluation in maize by integrating UAV-based multispectral imaging, machine learning algorithms, and conventional statistical approaches. Specifically, this research evaluated phenotypic variation among elite maize genotypes under managed drought stress, predicted physiological traits using AI models, and identified promising drought-resilient genotypes for future breeding applications in Bangladesh.

## Materials and Methods

### Experimental Site and Plant Materials

The field experiment was conducted at the City University Research Farm, Gazipur, Bangladesh, during the Rabi season of 2025–2026. The experimental soil was characterized as sandy loam with moderate organic matter content. Four elite maize genotypes (BHM-9, BHM-14, BHM-17, and BWMRI-1) were selected for evaluation under contrasting water availability conditions (Figure 1).

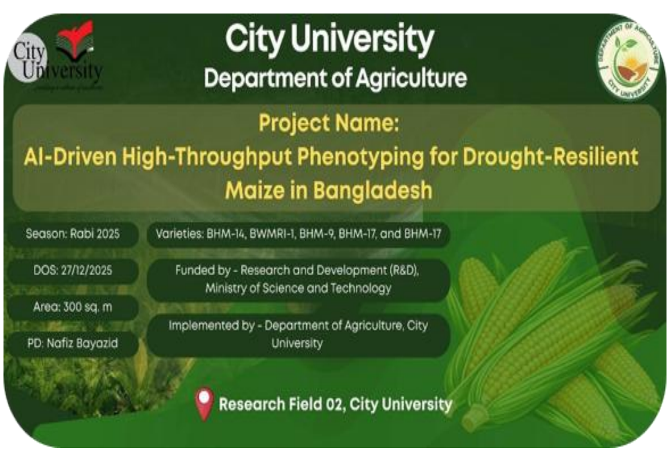


**Figure 1.** Experimental site and project overview of AI-driven high-throughput phenotyping platform for drought assessment in maize.

### Experimental Design and Drought Treatment

The experiment was arranged in a Randomized Complete Block Design (RCBD) with three replications. Each experimental plot measured 4 m × 3 m, maintaining a planting geometry of 60 cm × 20 cm. Crop management practices, including fertilizer application, weed control, and pest management, were applied uniformly across treatments (Figure 2).

**Figure 2.** Seed sowing and experimental establishment activities conducted at the research field.

Two irrigation regimes were imposed: a well-watered control maintained at 100% field capacity and a drought treatment maintained at 40% field capacity. Water stress was initiated at the V8 growth stage and continued until physiological maturity (R6). Soil moisture levels were continuously monitored using IoT-based soil moisture sensors to maintain the targeted stress condition.

### Phenotypic Data Collection

A set of agronomic and physiological traits associated with drought response was recorded (Figure 3 and 4). These included plant height, stem diameter, leaf area index, relative water content (RWC), chlorophyll concentration, root depth, tasseling and silking dates, disease score, cob height, grain number per cob, and yield-related characteristics.

**Figure 3.** Germination assessment and intercultural management practices during crop growth.

### UAV-Based High-Throughput Phenotyping

UAV-based image acquisition was performed weekly from the V5 to R6 growth stages using a DJI Phantom 4 platform equipped with a RedEdge-MX multispectral sensor. The collected images were processed to generate orthomosaic maps and extract vegetation indices, including normalized difference vegetation index (NDVI) and crop water stress index (CWSI).

**Figure 4.** Field data collection, structural trait measurement, canopy assessment, and harvesting activities

Deep learning and machine learning approaches were applied to extract and predict drought-associated traits. A ResNet-50 convolutional neural network was used for automated canopy feature extraction and stress-related image classification, while a Random Forest regression model was developed to estimate relative water content using spectral information.

**Statistical and Machine Learning Analysis**

Phenotypic data were analyzed using R statistical software (version 4.2). A linear mixed model was applied for analysis of variance, considering genotype as a fixed factor and replication as a random effect. Mean comparisons were performed using Tukey's honestly significant difference (HSD) test. Pearson correlation analysis was conducted to evaluate relationships among measured traits. Principal component analysis (PCA) and hierarchical clustering using Ward's method with Euclidean distance were performed on standardized trait values to identify patterns of genetic variation among genotypes. AI model performance was evaluated using coefficient of determination ($R^2$), root mean square error (RMSE), and classification accuracy metrics.

## Results

**Germination and Plant Establishment Performance**

Significant variation was observed among maize genotypes for germination percentage and plant establishment under experimental drought conditions. The establishment performance of all evaluated genotypes is presented in Table 1. BHM-9 showed the highest germination percentage (97.8%) and plant establishment (29.3 plants $plot^{-1}$), followed by BWMRI-1 (96.7%). In contrast, BHM-14 showed relatively poor establishment (62.2%), indicating greater sensitivity during early growth stages (Figure 5). The differences in early establishment among genotypes indicate that genetic variation influenced initial drought adaptation capacity. Better establishment may contribute to improved crop competitiveness and biomass accumulation under moisture-limited conditions.

**Table 1**. Germination performance and plant establishment of maize genotypes under drought stress conditions.

| Variety | Mean Germination (%) | Established Plants/Plot |
|---|---|---|
| BHM-9 | 97.8 | 29.3 |
| BWMRI-1 | 96.7 | 29.0 |
| BHM-17 | 72.2 | 21.7 |
| BHM-14 | 62.2 | 18.7 |

Values represent mean performance across experimental replications and indicate the initial establishment capacity of each genotype.

**Variation in Morphological and Physiological Traits Under Drought Stress**

The mean performance of major morphological and physiological traits under 40% field capacity drought stress is summarized in Table 2. Significant variation was detected among genotypes for plant height, grain count per cob, relative water content (RWC), chlorophyll content, and cob height. BHM-9 exhibited the highest plant height (305.4 cm), grain count per cob (645.4 grains), and cob height (24.2 cm), demonstrating superior growth and reproductive performance under drought stress (Table 2). Conversely, BHM-14 showed reduced plant height and grain production, suggesting greater drought sensitivity. Physiological traits also showed genotype-dependent variation. BHM-9 maintained comparatively higher RWC (55.2%) and chlorophyll content (54.6 SPAD), indicating better water conservation and photosynthetic stability under drought conditions (Table 2).

**Table 2.** Mean ± standard deviation of key morphological and physiological traits of maize genotypes exposed to managed drought stress (40% field capacity).

| Trait | BHM-9 | BHM-14 | BHM-17 | BWMRI-1 |
|---|---|---|---|---|
| Plant Height (cm) | 305.4 ± 35.6 | 207.9 ± 25.1 | 255.3 ± 22.4 | 253.8 ± 30.2 |
| Grain Count / Cob | 645.4 ± 112 | 377.1 ± 112 | 497.2 ± 115 | 537.1 ± 150 |
| RWC (%) | 55.2 ± 5.1 | 53.8 ± 6.2 | 53.5 ± 5.9 | 54.5 ± 7.8 |
| Chlorophyll (SPAD) | 54.6 ± 5.4 | 53.8 ± 5.9 | 53.5 ± 4.3 | 54.5 ± 7.1 |
| Cob Height (cm) | 24.2 ± 4.3 | 15.4 ± 4.1 | 19.6 ± 3.9 | 19.1 ± 8.3 |

**Trait Association and Correlation Analysis**

The relationships among measured traits are presented in Table 3 and visualized through the Pearson correlation heatmap (Figure 6). Plant height showed strong positive relationships with grain count and cob height, suggesting that improved vegetative development contributed to enhanced reproductive performance. Similarly, positive associations between RWC, chlorophyll content, and yield-related traits indicate that physiological stability played an important role in maintaining productivity under drought stress.

**Principal Component and Cluster Analysis**

Principal component analysis demonstrated clear separation among maize genotypes based on combined morphological and physiological traits (Figure 7). The first two principal components explained 57.4% of the total phenotypic variation, indicating that these components effectively summarized major drought-response characteristics. BHM-9 was positioned separately on the positive side of PC1 due to its superior growth and physiological performance. In contrast, BHM-14 was positioned negatively, reflecting weaker adaptation under drought conditions. Hierarchical clustering further confirmed these differences (Figure 8). The analysis grouped genotypes into three distinct phenotypic clusters, with BHM-9 forming an independent cluster due to its unique drought-response characteristics.

**Table 3.** Pearson correlation coefficients among morphological and physiological traits associated with drought response in maize.

| Trait | Plant Height | RWC | Chlorophyll | Cob Height | Grain Count |
|---|---|---|---|---|---|
| Plant Height | 1.00 | 0.58 | 0.62 | 0.85 | 0.72 |
| RWC | - | 1.00 | 0.81 | 0.55 | 0.62 |
| Chlorophyll | - | - | 1.00 | 0.59 | 0.68 |
| Cob Height | - | - | - | 1.00 | 0.79 |

## Discussion

Drought stress is one of the most important abiotic constraints affecting maize productivity, particularly in regions where rainfall distribution is irregular and crop production is highly dependent on available soil moisture. In the present study, significant differences were observed among the evaluated maize genotypes for several drought-responsive traits, indicating considerable genetic variation that can be exploited for drought tolerance improvement. The superior performance of BHM-9 under water-limited conditions, reflected by improved growth, physiological stability, and yield-related traits, suggests that this genotype possesses adaptive characteristics enabling better performance under drought stress. Similar findings have been reported in maize, where drought-tolerant genotypes maintain higher water status, photosynthetic activity, and grain development compared with susceptible genotypes (Hoque et al., 2018; Rahman, 2022).

Maintenance of plant water balance is a critical mechanism for drought adaptation because it influences cellular metabolism, photosynthesis, and reproductive development. In this study, relative water content (RWC), chlorophyll concentration, and yield-associated traits showed positive relationships, suggesting that physiological stability contributed to improved drought performance. Higher RWC reflects better water conservation capacity, while sustained chlorophyll content indicates protection of the photosynthetic apparatus during drought exposure. Similar physiological responses have been identified as important indicators for selecting drought-resilient maize genotypes (Hossain, 2021). However, further investigation involving stomatal conductance, root architecture, and biochemical responses would provide deeper understanding of the mechanisms involved.

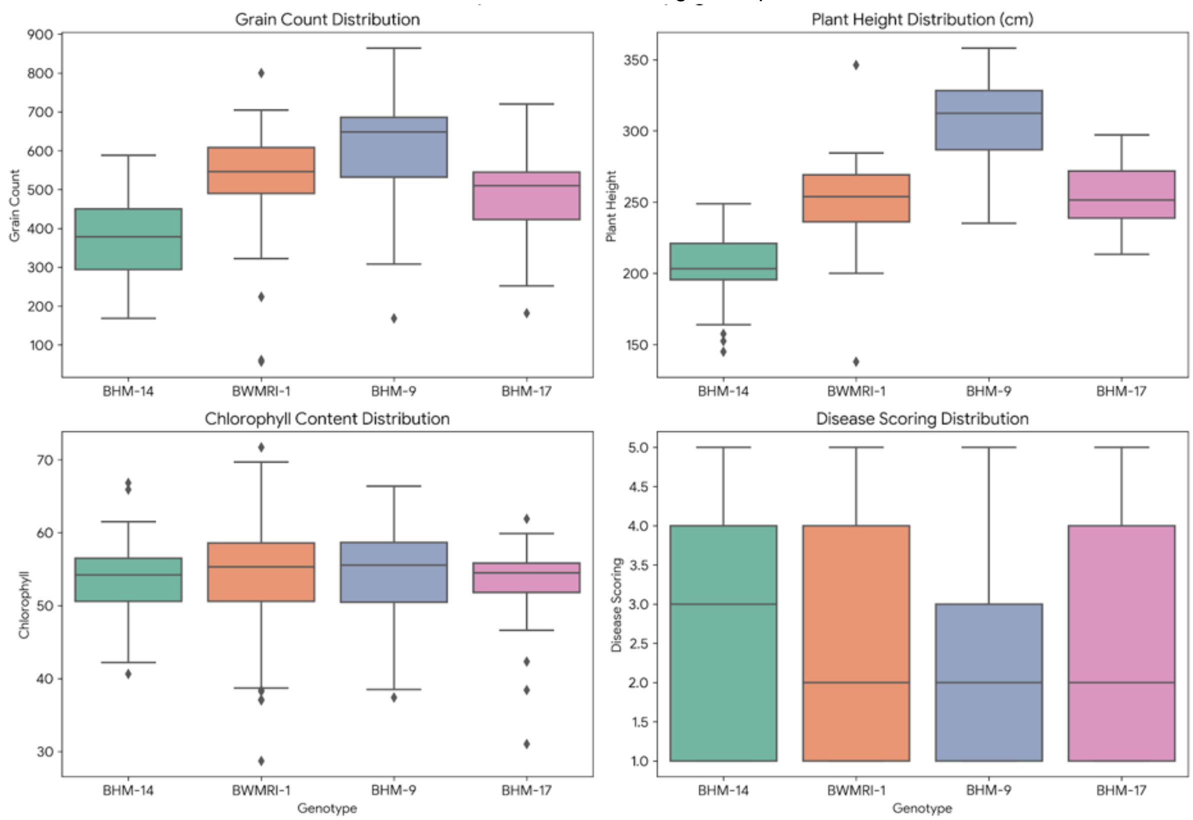


**Figure 5.** Distribution of major agronomic traits among maize genotypes under drought stress conditions. Boxplots represent variation in grain count, plant height, chlorophyll content, and disease scoring.

### AI Model Performance for Drought Trait Prediction

The performance of AI-based prediction models is shown in Figure 9. The Random Forest model successfully predicted relative water content using UAV-derived multispectral indices with high accuracy ($R^2$ = 0.89 and RMSE = 4.8%). The results demonstrate that UAV-assisted AI phenotyping can provide reliable estimation of physiological traits while reducing dependence on manual measurements. Similar approaches have been reported for maize and other crops where vegetation indices combined with machine learning models improved prediction accuracy for complex traits (Teodoro et al., 2024).

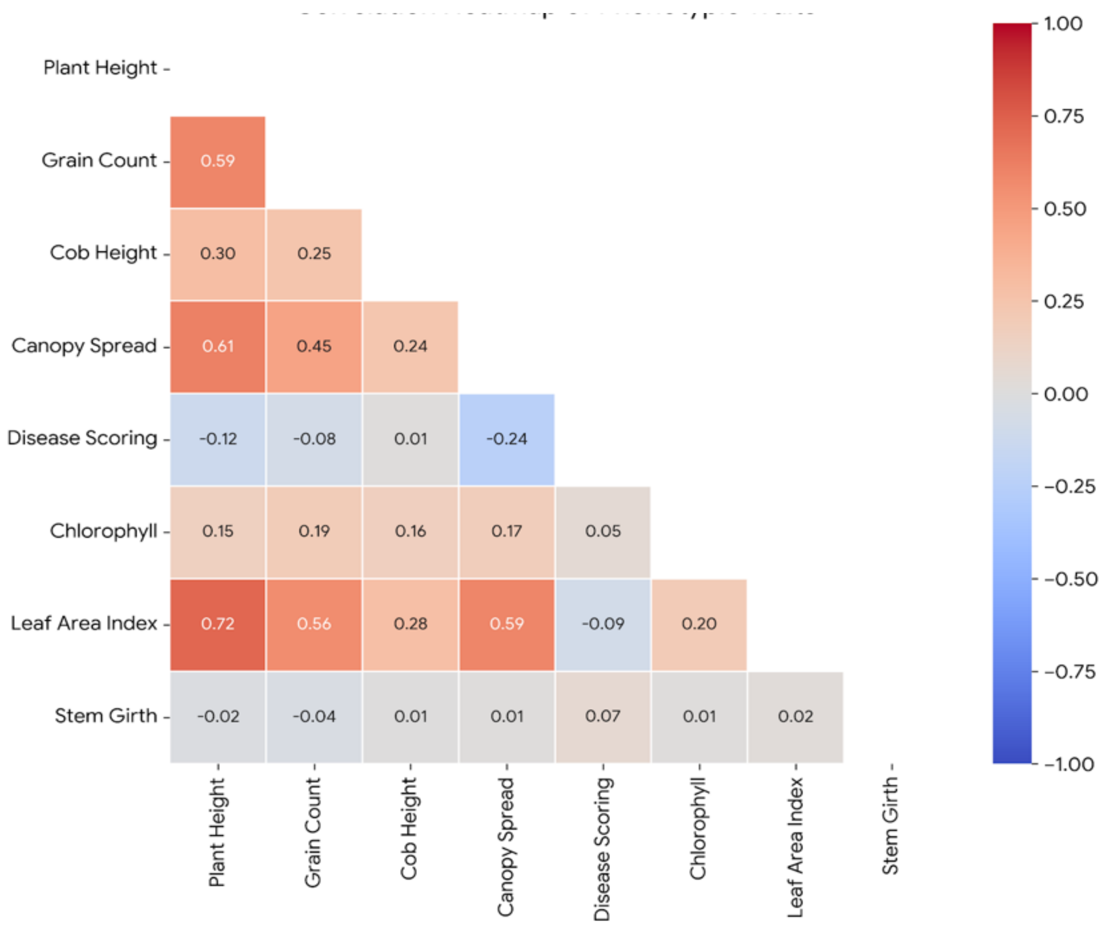


**Figure 6.** Correlation analysis among phenotypic traits showing relationships between growth, physiological response, and yield-related characteristics.

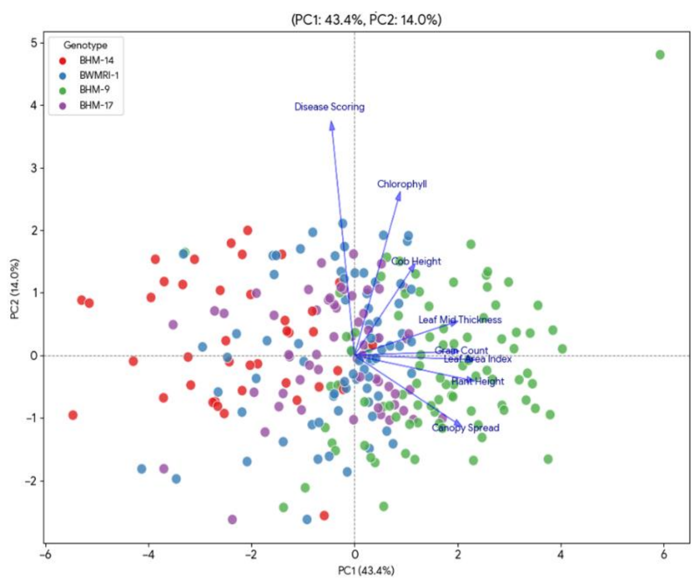


**Figure 7.** Principal component analysis showing genotype separation based on combined morphological and physiological drought response traits.

The integration of UAV-based multispectral phenotyping provided an efficient approach for monitoring drought responses throughout crop development. Conventional phenotyping methods are often limited by labor requirements and the inability to capture multiple traits at large scale. High-throughput phenotyping platforms overcome these limitations by enabling rapid, non-destructive measurement of crop characteristics using advanced imaging technologies (Song et al., 2021). UAV-based multispectral approaches have been successfully applied for estimating crop growth, biomass, yield-related traits, and drought responses in cereals (Zhang, 2022; Herrmann et al., 2019).

The application of artificial intelligence models further improved the potential of UAV-based phenotyping. In this study, the combination of ResNet-50 convolutional neural network and Random Forest regression showed strong capability for automated extraction and prediction of drought-related traits. Deep learning models are particularly useful because they can automatically identify complex image features, while machine learning algorithms such as Random Forest can efficiently model nonlinear relationships between spectral information and biological traits. Previous studies have demonstrated the effectiveness of deep learning and machine learning approaches for maize drought stress identification and trait prediction (An et al., 2019; Shao et al., 2022). The integration of AI with crop phenomics has been increasingly recognized as a promising strategy for accelerating breeding processes and improving selection accuracy (Farooq et al., 2024).

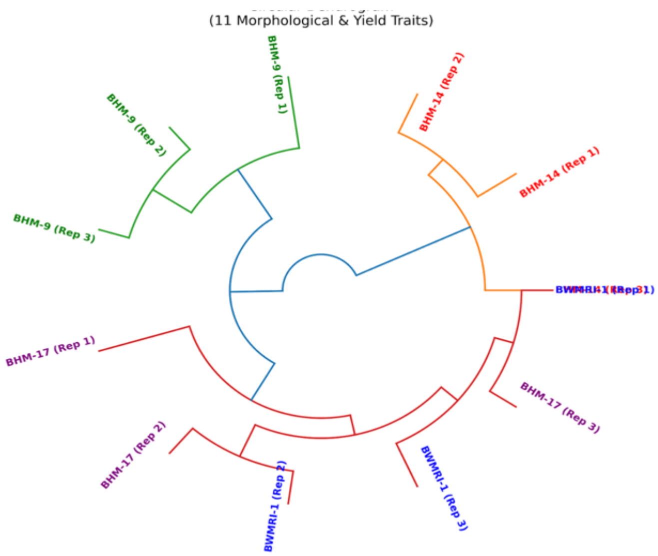


**Figure 8.** Hierarchical clustering of maize genotypes based on multiple phenotypic traits demonstrating drought-response grouping patterns.

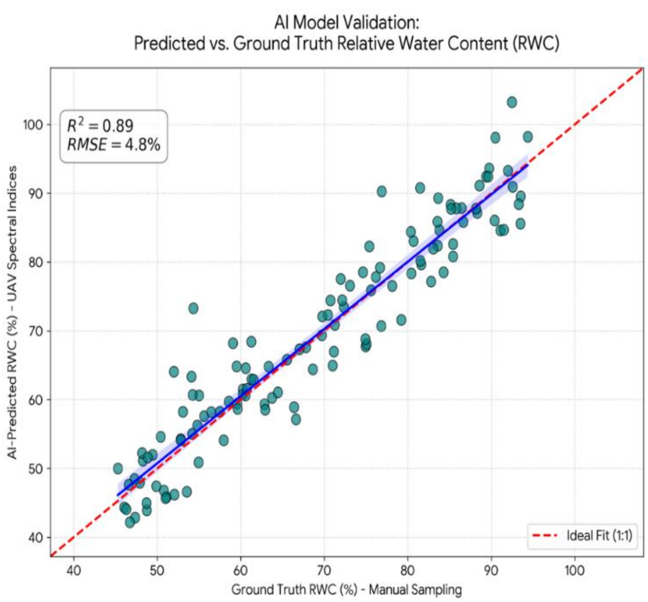


**Figure 9**. Validation performance of the AI prediction model for relative water content using UAV-derived multispectral indices.

The PCA and hierarchical clustering analyses confirmed that combined phenotypic information can effectively distinguish drought response patterns among genotypes. The clear separation of BHM-9 from other genotypes indicates that drought tolerance is a complex trait controlled by interactions among physiological, morphological, and yield-related characteristics. Multivariate approaches provide a more comprehensive evaluation of drought adaptation compared with analysis of individual traits alone.

Although the results demonstrate the potential of AI-driven phenotyping, several limitations should be considered. The present study evaluated a limited number of genotypes under a single experimental environment. Therefore, multi-location and multi-season validation will be necessary before wider application in breeding programs. In addition, AI model performance depends on dataset size, image quality, environmental variation, and independent validation procedures. Recent studies emphasize that although UAV and machine learning technologies provide powerful tools for crop improvement, model transferability and robustness remain important considerations (Adak et al., 2024; Shamsuddin et al., 2024).

Overall, this study demonstrates that integrating UAV-based multispectral imaging, physiological assessment, statistical analysis, and artificial intelligence provides an effective framework for drought tolerance evaluation in maize. The developed approach can support rapid screening of breeding materials and contribute to future climate-resilient maize improvement programs.


**Figure 10.** Multivariate phenotypic profile of maize genotypes illustrating overall trait performance under drought stress.

## Conclusions

This study successfully established an AI-driven high-throughput phenotyping framework for drought response assessment in maize. Among the evaluated genotypes, BHM-9 showed superior drought resilience, while BWMRI-1 demonstrated promising physiological characteristics. The integration of UAV-based imaging, statistical analysis, and AI models provides an effective approach for rapid drought screening and future maize breeding programs. Further multi-environment validation and genomic studies are recommended to enhance the application of this framework.

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## Conflict of Interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

## References


Adak, A., DeSalvio, A. J., Arik, M. A., & Murray, S. C. (2024). Field-based high-throughput phenotyping enhances phenomic and genomic predictions for grain yield and plant height across years in maize. G3: Genes, Genomes, Genetics, 14.

An, J., Li, W., Li, M., Cui, S., & Yue, H. (2019). Identification and Classification of Maize Drought Stress Using Deep Convolutional Neural Network. Symmetry, 11, 256.

Bongomin, O., et al. (2024). UAV image acquisition and processing for high-throughput phenotyping in agricultural research and breeding programs. *The Plant Phenome Journal*.

Farooq, M. A., Gao, S., Hassan, M. A., Huang, Z., Rasheed, A., Hearne, S., Prasanna, B., Li, X., & Li, H. (2024). Artificial intelligence in plant breeding. Trends in Genetics, 40, 891–908.

Gano, B., et al. (2024). Drone-based imaging sensors, techniques, and applications in plant phenotyping for crop breeding: A comprehensive review. *The Plant Phenome Journal*.

Herrmann, I., Bdolach, E., Montekyo, Y., Rachmilevitch, S., Townsend, P. A., & Karnieli, A. (2019). Assessment of maize yield and phenology by drone-mounted superspectral camera. Precision Agriculture, 21, 51–76.

Hoque, M. I. U., Uddin, M. N., Fakir, M. S. A., & Rasel, M. (2018). Drought and salinity affect leaf and root anatomical structures in three maize genotypes. Journal of the Bangladesh Agricultural University, 16, 47–55.

Hossain, M. (2021). Drought Stress in Maize: Impacts and Adaptation in Northwest Bangladesh. J. Agro. Environ., 15(2), 45–58.

Rahman, M. (2022). Drought Tolerance Mechanisms in Bangladesh Maize. Crop Sci., 62(4), 1892–1905.

Shamsuddin, D., et al. (2024). Multimodal Deep Learning Integration of Image, Weather, and Phenotypic Data Under Temporal Effects for Early Prediction of Maize Yield. Remote Sensing, 16, 4043.

Shao, G., et al. (2022). Estimation of transpiration coefficient and aboveground biomass in maize using time-series UAV multispectral imagery. The Crop Journal, 10, 1376–1385.

Sheikh, M., et al. (2024). Integrating artificial intelligence and high-throughput phenotyping for crop improvement. *Journal of Integrative Agriculture*, 23, 1787–1802.

Song, P., Wang, J., Guo, X., Yang, W., & Zhao, C. (2021). High-throughput phenotyping: Breaking through the bottleneck in future crop breeding. The Crop Journal, 9, 633–645.

Teodoro, P.E., et al. (2024). High-throughput phenotyping in maize and soybean genotypes using vegetation indices and computational intelligence. *Plant Methods*, 20, 164.

Zhang, X. (2022). UAV Phenotyping for Drought Response in Cereals. Plant Phenomics, 4, 987.


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