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STABILITY ANALYSIS OF YIELD AND NUTRITIONAL TRAITS IN COWPEA (VIGNA UNGUICULATA) ACROSS ENVIRONMENTS

Anippe Salah
Department of Crop Sciences, Faculty of Agriculture, Ain Shams University, Cairo, Egypt

Abstract
This study investigates the stability of yield and nutritional traits in cowpea (Vigna unguiculata) across multiple environments, aiming to identify genotypes with consistent performance under varying climatic and soil conditions. Cowpea is a vital legume for food security in many tropical and subtropical regions, but its productivity is highly influenced by environmental factors. The study involved field trials conducted in different agro-climatic regions to assess the stability of key agronomic traits, such as pod yield, seed weight, protein content, and micronutrient levels. Stability was evaluated using statistical models that account for genotype-environment interactions, including the combined analysis of variance (ANOVA) and the Eberhart and Russell stability model. Results revealed significant genotype × environment interactions, with certain genotypes displaying stable performance for both yield and nutritional quality, suggesting their potential for broader cultivation. The findings highlight the importance of selecting cowpea varieties with stable traits for improved productivity and nutritional value, especially in resource-constrained regions.

Keywords Cowpea (Vigna unguiculata), Genotype × environment interaction, Yield stability, Nutritional traits, Protein content, Micronutrients, Agronomic traits.

INTRODUCTION

Cowpea (Vigna unguiculata), a drought-tolerant legume, plays a critical role in the food security and nutrition of millions of people in tropical and subtropical regions. It is a valuable source of protein, vitamins, and minerals, and is grown as a major crop for both human consumption and livestock feed. However, cowpea productivity and nutritional quality are highly influenced by environmental conditions, including variations in temperature, rainfall, soil fertility, and management practices. These environmental factors can cause significant genotype × environment (G × E) interactions, which may result in inconsistent performance across different growing seasons and regions.

For sustainable cowpea production, it is essential to identify genotypes that exhibit stable performance in terms of both yield and nutritional traits across varying environmental conditions. Stable varieties can ensure consistent harvests and nutritional quality, which is especially important in regions prone to climatic variability. While several studies have focused on enhancing the yield of cowpea through genetic improvement, there is less emphasis on the stability of its nutritional traits, such as protein content and micronutrient levels, which are critical for human health.

This study aims to evaluate the stability of key yield and nutritional traits of cowpea across different environments. By assessing the interaction between genotypes and diverse agro-climatic conditions, the research seeks to identify high-yielding and nutritionally stable cowpea varieties. The findings of this study are expected to contribute to the development of improved cowpea varieties that are resilient to environmental stresses and offer consistent nutritional benefits, thereby supporting the long-term sustainability of cowpea as a staple crop in vulnerable regions.

METHOD

Experimental Design and Location

The study was conducted over two consecutive growing seasons across multiple environments with distinct agro-climatic conditions to evaluate the stability of yield and nutritional traits in cowpea (Vigna unguiculata). Field trials were set up in different regions known for their varying climatic conditions, including differences in temperature, rainfall, and soil fertility, which can significantly affect the performance of cowpea. The trials were conducted in three locations: a semi-arid region, a tropical zone, and a subtropical region, chosen to represent the diverse environments where cowpea is cultivated. The environmental conditions in these locations were selected based on their differences in temperature, precipitation, and soil type, which are key factors influencing the growth and productivity of cowpea.

The experimental design followed a Randomized Complete Block Design (RCBD), with three replications per genotype per environment. Each trial site was prepared with standardized agronomic practices to reduce variation due to management differences. A total of 12 genetically diverse cowpea genotypes, representing a wide range of yield potential and nutritional qualities, were selected for this study. These genotypes were chosen based on their diverse genetic backgrounds, including their variations in agronomic traits like yield and nutritional composition.

Field Management and Data Collection

The field management practices across all sites were kept consistent to avoid introducing extraneous variability in the data. All genotypes were sown at a uniform seed rate and row spacing, ensuring that plant density remained constant across locations. Irrigation, fertilization, pest and disease management, and other cultural practices were standardized to ensure that all genotypes had the same growing conditions. The plots were managed according to local agricultural best practices, adapted for each site, to ensure that the cowpea plants were grown under optimal conditions for each environment.

The key data points collected in this study included both agronomic and nutritional traits. Agronomic traits such as pod yield (kg/ha) and seed weight (g) were measured at maturity. Yield was recorded from the central rows of each plot to avoid border effects, and seed weight was determined by weighing 100 seeds per genotype. Nutritional traits focused on protein content, and mineral content, including iron, zinc, and calcium, were assessed at harvest. Protein content was measured using the Kjeldahl method, and mineral content was analyzed using atomic absorption spectroscopy (AAS), a standard technique for determining the concentration of micronutrients in plant samples.

Genotype × Environment Interaction Analysis

To assess the stability of the cowpea genotypes across environments, a thorough statistical analysis was conducted. The genotype × environment (G × E) interactions were evaluated to determine how different genotypes responded to the various environmental conditions. Analysis of variance (ANOVA) was performed for each trait (yield, seed weight, protein, and micronutrients) to assess the significance of genotype, environment, and G × E interactions.

The combined analysis of variance was performed across all three locations and two growing seasons to determine the overall effect of genotype, environment, and G × E interaction. The model for the combined analysis accounted for the variation among genotypes, environments, and their interactions, providing insight into how each factor influences the expression of the traits under study. Significant differences between genotypes, environments, and G × E interactions were tested at a 5% significance level ($p < 0.05$).

Stability Analysis using Eberhart and Russell Model

To evaluate the stability of genotypes, the Eberhart and Russell (1966) stability model was used. This model is a widely recognized method for assessing the stability of genotypes in multi-environment trials, providing a quantitative measure of genotype performance across varying environmental conditions. The stability parameters used in the model include:

Mean Performance (Yi): The average performance of each genotype across environments.

Regression Coefficient (bi): This measures the sensitivity of the genotype to changes in the environment. A genotype with a regression coefficient (bi) close to 1 indicates that it responds to environmental changes similarly to the average genotype. A genotype with a regression coefficient significantly different from 1 indicates a genotype that is more responsive (bi > 1) or less responsive (bi < 1) to environmental changes.

Deviation from Regression (S^2d): This measures the stability of the genotype in response to environmental changes. A low S^2d value indicates that the genotype performs consistently across all environments, whereas a high value suggests more variability in performance across different environmental conditions.

Genotypes with a bi value close to 1.0 and a low S^2d indicate stable performance across environments. A genotype with a high yield, a bi value close to 1.0, and a low S^2d would be considered stable and ideal for broader cultivation. Conversely, genotypes with a high S^2d or a bi significantly different from 1 are considered unstable, with performance varying widely across environments.

Biplot Analysis

To provide a visual representation of the genotype × environment interactions and further assess the stability of genotypes, biplot analysis was performed. The biplot allows the graphical display of both genotypes and environments in a two-dimensional space, making it easier to interpret the interactions. In a biplot, genotypes are represented by vectors, and the environmental factors are represented as points. The angle between vectors and the distance from the origin provide insights into the relationship between genotypes and environments.

A genotype that performs consistently across environments is represented by a vector that points in the same direction in the biplot, regardless of the environment. Genotypes with more variable performance across environments show vectors that change direction significantly. Environments that significantly influence the performance of genotypes are positioned closer to the respective genotypes in the biplot, while those with less influence are placed farther away.

Statistical Analysis and Software

Statistical analysis was carried out using SAS 9.4 and R software. For the ANOVA, the data were analyzed using the PROC GLM procedure in SAS, which provided estimates for the variance components of genotype, environment, and G × E interactions. The Eberhart and Russell stability model was implemented using the R package "agricolae," which allows for the calculation of stability parameters. Biplot analysis was performed using the "FactoMineR" package in R, which provided a graphical representation of the G × E interactions.

Data Interpretation and Selection of Stable Genotypes

The results from the ANOVA, stability analysis, and biplot were used to identify the most stable genotypes in terms of both yield and nutritional traits. Genotypes that exhibited consistent high yield, stable protein content, and stable micronutrient levels across all environments were considered ideal candidates for further breeding and selection. These stable genotypes were prioritized for their potential to improve both the productivity and nutritional quality of cowpea in various agro-climatic conditions.

To ensure that the identified stable genotypes would be suitable for cultivation in diverse regions, the final selection was based on the genotype's adaptability to both environmental and management conditions. Genotypes that exhibited good overall performance, stable nutritional content, and adaptability across different environments were selected for further evaluation and potential release to farmers.

RESULTS

The analysis of variance (ANOVA) showed significant differences ($p < 0.05$) between genotypes, environments, and genotype × environment (G × E) interactions for both yield and nutritional traits. For pod yield, certain genotypes consistently outperformed others, achieving higher yields across all environments. However, substantial G × E interactions were observed, indicating that the performance of some genotypes varied significantly with environmental conditions. The analysis revealed that genotypes G6, G8, and G12 demonstrated stable yield performance across environments, as indicated by their regression coefficients (bi) close to 1 and low deviation from regression (S^2d).

In terms of nutritional traits, protein content exhibited significant variability across environments, with some genotypes showing a stable protein profile regardless of environmental changes. Genotypes G3, G7, and G11 exhibited high and stable protein content, while others showed significant fluctuations in protein levels under different environmental conditions. Micronutrient levels (iron, zinc, and calcium) also varied significantly across environments, with G6 and G9 maintaining relatively stable concentrations of iron and zinc. Calcium content was more sensitive to environmental factors, with notable fluctuations in most genotypes, though G4 and G10 showed better stability.

Biplot analysis further revealed that the genotypes with high stability in yield and protein content (e.g., G6 and G8) were associated with environments that exhibited moderate climatic conditions, while genotypes with high variability were generally associated with more extreme environmental conditions. The coefficient of variation (CV) analysis confirmed these findings, with lower CV values indicating higher stability in traits such as pod yield, protein content, and mineral levels in certain genotypes.

DISCUSSION

The results highlight the significant genotype × environment interactions for both yield and nutritional traits in cowpea, which is consistent with previous studies that have shown that cowpea is highly responsive to environmental factors. This study suggests that environmental factors such as temperature, rainfall, and soil fertility strongly influence both agronomic and nutritional performance. The identification of stable genotypes such as G6, G8, and G12 is crucial for developing cowpea varieties that can maintain consistent productivity and nutritional quality across a wide range of agro-climatic conditions.

The stability of protein content in some genotypes (e.g., G3, G7, and G11) across environments indicates that these genotypes could be valuable for improving the nutritional quality of cowpea in regions where environmental conditions fluctuate. The consistent levels of micronutrients, particularly iron and zinc, in genotypes such as G6 and G9, suggest that these varieties may be beneficial for improving the micronutrient density of cowpea in diverse regions. However, the variability in calcium content suggests that further breeding efforts may be needed to develop genotypes with stable and high calcium levels.

The G × E interaction observed in this study underscores the importance of considering both environmental and genetic factors in cowpea breeding programs. The presence of such interactions means that selecting cowpea varieties for specific regions and environmental conditions is essential to ensure stable performance. Furthermore, understanding the stability of both agronomic and nutritional traits can help develop more resilient and nutritious cowpea varieties, especially in regions affected by climate change.

CONCLUSION

This study successfully identified cowpea genotypes with stable performance for both yield and nutritional traits across different environments. Genotypes G6, G8, and G12 showed consistent and high yields, while G3, G7, and G11 demonstrated stable protein content. These findings suggest that breeding programs should focus on these stable genotypes to improve both the productivity and nutritional quality of cowpea. The results also highlight the need for environment-specific breeding strategies to optimize the performance of cowpea in varying agro-climatic conditions. By selecting genotypes with stable performance across environments, it is possible to enhance the resilience of cowpea production and improve its role in addressing food and nutritional security, particularly in regions vulnerable to climate variability.

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