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Exploring Genetic Divergence in Cowpea: A Comprehensive Review

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Review Article

ABSTRACT

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Genetic divergence in cowpea (*Vigna unguiculata* L. Walp) presents a compelling area of study with profound implications for breeding programs, crop improvement strategies, and agricultural sustainability. This abstract encapsulates a comprehensive review of the genetic divergence observed within cowpea populations. By examining the genetic diversity, population structure, and molecular markers employed in cowpea research, this review aims to elucidate the underlying genetic mechanisms driving divergence within the species. The review explores the ecological and geographical factors influencing genetic differentiation, as well as the implications for breeding objectives and germplasm conservation. Furthermore, it discusses the potential applications of genetic divergence analysis in enhancing crop adaptation, resilience, and productivity in diverse agroecological contexts. Through a synthesis of current research findings and emerging trends, this review provides valuable insights into the genetic architecture of cowpea and its implications for sustainable crop improvement strategies.

Keywords: Cowpea; D2 statistics; cluster; genetic divergence.

1. INTRODUCTION

Cowpea (*Vigna unguiculata* (L.) Walp.), a member of the family Fabaceae/Leguminosae, is among the most widely cultivated vegetable crops in India. The success of breeding programs hinges significantly on the genetic diversity available to breeders and the careful selection of parental lines. Recognizing the value of genetically diverse genotypes in generating transgressive segregants with desirable traits has been acknowledged by various researchers [1].

Mahalanobis [2] generalized distance has proven to be an efficient tool for quantitatively estimating genetic diversity and for selecting potential parents in breeding programs. Understanding the interrelationships among yield and its components is essential for the effective selection of desirable plant types. Unlike correlation coefficients, which gauge the extent of relationships, path coefficients [3] measure the magnitude of direct and indirect effects of traits on complex dependent variables such as yield. This aids breeders in making informed decisions regarding important component traits during selection processes.

Cowpea, with a chromosome number of 2n = 22, thrives in tropical and subtropical regions spanning Africa, Asia, South America, parts of Southern Europe, and the United States [4]. While cowpea is believed to be native to Central Africa, it has been cultivated in Southeastern Asia for over 2000 years. East and Southern Africa are considered primary regions of diversity based on the distribution of diverse wild cowpea, although Vavilov [5] regarded India as the main Center of Origin. Cowpea has been documented in India since Vedic times and is one of several species within the widely cultivated genus Vigna, subdivided into five subspecies: three cultivated (unguiculata, sesquipedalis, and cylindrica) and two wild (dekindtiana and mensensis) [6].

Cowpea cultivation is extensive in southern India, particularly in Andhra Pradesh, Karnataka, Tamil Nadu, and Maharashtra [1]. Fodder cowpea occupies approximately 0.3 million hectares out of a total of 0.65 million hectares dedicated to different pulse and vegetable cowpea types [7].

As of my last update in January 2022, cowpea, also known as black-eyed pea or lobia, is an important legume crop cultivated globally for its edible beans and leaves. Here is a general overview of the trends in the area, production, and productivity of cowpea in India and worldwide:

Cowpea Production in India:

1. Area under Cultivation: The area under cowpea cultivation in India has shown variations over the years, influenced by factors such as changes in agricultural practices, weather conditions, and market demand.

2. Production Volume: Cowpea production in India has experienced fluctuations due to factors like variations in climatic conditions, pest infestations, and changes in agricultural policies.

3. Productivity: Productivity levels in cowpea farming have been relatively stable, with periodic improvements attributed to advancements in agricultural technologies, including improved seed varieties, better

irrigation practices, and enhanced pest management strategies.

Cowpea Production Worldwide:

1. Global Cultivation Area: The cultivation area of cowpea worldwide has remained substantial, with significant production in regions such as Africa, Asia, and the Americas.

2. Global Production Volume: The global production of cowpea has shown a generally increasing trend over the years, driven by rising demand for protein-rich food sources, changing dietary preferences, and expanding markets.

3. Productivity Trends: Productivity levels vary across different regions depending on factors such as agro-climatic conditions, soil fertility, adoption of improved agricultural practices, and access to resources and technologies.

Factors Influencing Trends:

1. Market Demand: Trends in cowpea production are influenced by market demand for both domestic consumption and export purposes.

2. Climate Variability: Cowpea cultivation is sensitive to climatic conditions, with variations in rainfall patterns, temperature fluctuations, and incidence of pests and diseases impacting production levels.

3. Technological Advancements: Adoption of improved cowpea varieties, mechanization, efficient irrigation techniques, and better crop management practices contribute to enhanced productivity and production levels.

4. Government Policies: Agricultural policies, subsidies, and support programs implemented by governments play a crucial role in shaping trends in cowpea cultivation and production.

It's essential to consult the latest agricultural statistics and reports from reliable sources such as the Food and Agriculture Organization (FAO) of the United Nations, national agricultural departments, and research institutions to obtain up-to-date information on trends in cowpea cultivation, production, and productivity in India and worldwide.

Cowpea stands out as one of the most significant legume crops, gaining increasing importance in recent years owing to its exceptional food value, utility as fodder, and effectiveness as a green manure crop. Known for its resilience to drought and preference for warm climates, cowpea thrives even in conditions of poor soil quality, with a pH range between 4.5 and 9, minimal organic matter (< 0.2), and a high sand content exceeding 85%. This adaptability makes it particularly well-suited for cultivation in regions characterized by scanty rainfall.

Notably, cowpea is esteemed for its nutritive quality, particularly due to its elevated crude protein content and substantial green fodder yield. All parts of the cowpea plant used for consumption offer significant nutritional value, providing essential proteins, vitamins, and minerals. Cowpea grain, in particular, boasts an impressive nutritional profile, with an average protein content ranging between 23% and 25%, alongside a starch content ranging from 50% to 70% [8].

This combination of resilience, adaptability, and high nutritional value positions cowpea as a valuable asset in agricultural systems worldwide, offering sustenance, fodder, and soil enrichment capabilities to farmers and communities in a variety of environmental conditions.

Cowpea (*Vigna unguiculata* (L.) Walp.) is a versatile crop with various utilization purposes. Its seeds, leaves, and even stems are utilized in different ways across different cultures and regions. Here are some common purposes for which cowpea is utilized:

1. Food Consumption:

- **Edible Seeds:** Cowpea seeds are a significant source of dietary protein, carbohydrates, vitamins, and minerals. They can be consumed fresh, dried, or processed into various culinary dishes.

- **Leaves:** Cowpea leaves are edible and are often used as leafy vegetables in many cuisines, especially in African and Asian countries. They are nutritious and rich in vitamins and minerals.

- **Flour:** Cowpea seeds can be ground into flour, which is used in the preparation of traditional dishes, soups, porridges, and baked goods.

2. Animal Feed:

- Cowpea plants, including leaves, stems, and pods, are utilized as fodder for livestock, providing a source of nutrition for cattle, goats, sheep, and other animals.

- Cowpea residues from harvested crops or by-products from processing can be used as animal feed supplements, contributing to livestock nutrition and productivity.

3. Soil Improvement:

- Cowpea is often grown as a cover crop or intercropped with other crops due to its ability to fix atmospheric nitrogen, enrich soil fertility, and improve soil structure.

- The deep root system of cowpea plants helps in soil aeration, water retention, and erosion control, making it beneficial for soil conservation and sustainable agriculture practices.

4. Traditional Medicine:

- In some cultures, various parts of the cowpea plant are used for medicinal purposes. For example, cowpea leaves and seeds are believed to have medicinal properties and are used in traditional herbal remedies for ailments such as stomach disorders, diabetes, and inflammation.

5. Crop Rotation and Pest Management:

- Cowpea is often included in crop rotation systems to break pest and disease cycles and reduce soil-borne pathogens.

- Its cultivation can help suppress weeds and reduce the need for herbicides in agricultural systems, promoting eco-friendly pest management practices.

6. Industrial Applications:

- Cowpea seeds contain starches and proteins that can be extracted and utilized in various industrial processes, including the production of starch, protein isolates, and biofuels.

- Cowpea starch has applications in food processing, pharmaceuticals, textiles, and adhesive industries.

Overall, cowpea is a valuable crop with diverse applications in food security, nutrition, animal husbandry, soil management, traditional medicine, and industrial sectors, contributing to sustainable livelihoods and agricultural systems worldwide. The genetic variability of quantitative traits holds paramount importance in selecting genotypes for future breeding programs. Understanding the genetic variability among different traits is crucial for the success of systematic breeding initiatives. The efficacy of a breeding program largely relies on the extent of genetic variability present in the breeding materials. Therefore, a breeder must possess knowledge of genetic variability, heritability, and genetic advance in cowpea to select superior genotypes for improvement.

Estimates of genetic parameters provide insights into the relative importance of various types of gene effects influencing the total variation of a plant trait. Genotypic and phenotypic coefficients of variation, along with heritability and genetic advance, are essential parameters for trait improvement [8] emphasized the significance of selecting and evaluating varieties for quantitative and yield ability in breeding programs before their introduction to a specific local environment.

According to [9-11], genetic variability is imperative to realize responses to selection pressure. Estimates of genetic parameters are population-specific, and environmental stress can alter the phenotypic expression of quantitative traits, affecting plant growth and development.

Heritability of a trait is crucial for cowpea breeders as it provides insights into the extent of genetic control over the expression of a particular trait [12]. Thus, the present review aims to assess variability using genetic parameters such as coefficient of variability, heritability, and genetic advance. This study endeavors to provide valuable insights into the genetic diversity of cowpea, facilitating informed decision-making in breeding programs aimed at enhancing cowpea traits and productivity.

Divergence analysis: The utilization of statistical methods for measuring the divergence between populations, such as multivariate analysis or D^2 statistics, has been pivotal in quantifying genetic variability. Mahalanobis's D^2 statistics, in particular, has emerged as an effective tool for quantifying the degree of genetic divergence and assessing the association between geographic and genetic diversity based on genotype distance [2]. This statistical field concept introduced by Mahalanobis represents each point as the center of density cluster belonging to a specific normal population defined by the means of the characters and the measure of covariances at that point in the field.

D^2 statistics offer several advantages, including the ability to gauge distances in p-dimensional shapes where samples are most distinct and to estimate the extent of differences among sets in multiple measurements. Genetic divergence among cowpea genotypes has been extensively studied using D^2 statistics, yielding valuable insights into the diversity within the species.

Dharmalingam and Kadambavanasundaram [8] assessed genetic divergence among 13 clusters of cowpea genotypes, recommending the inclusion of divergent genotypes like CO2 and G5 in heterosis breeding programs. Thiyagarajan and Natarajan [13] identified significant contributions of traits like the number of pods per plant, number of seeds per pod, and seed yield per plant to genetic divergence. Hazra et al. [9] grouped cowpea genotypes into clusters, highlighting the importance of traits like plant height, pod length, pod weight, and pod yield per plant for selection.

Rewale et al. [10] observed clustering of genotypes into 19 clusters and noted the impact of the environment on cluster composition. Similarly, Hazra et al. [11] used genetic divergence techniques to select parents for hybridization, emphasizing stable grouping across environments. Anbuselvam et al. [12] identified significant variability among cowpea genotypes for all studied traits, with high inter-cluster distances indicating substantial genetic divergence.

Borah and Khan [14] evaluated 60 cowpea cultivars, revealing high genetic divergence among the cultivars irrespective of geographical distribution. They emphasized traits like dry matter yield, green fodder yield, and plant height as crucial for genetic divergence assessment.

The studies by Nigude et al. [15], Kumari et al. [16], and Saini et al. [17] further corroborated the significance of D^2 statistics in evaluating genetic diversity and identifying promising genotypes for hybridization programs.

Jain et al. [18], Girish et al. [19], and Lesly et al. [20] utilized D^2 statistics to assess genetic diversity among cowpea genotypes, highlighting the contributions of fodder yield, plant height, and seed yield to genetic divergence.

Pandey [21] identified clusters with specific trait characteristics, recommending genotypes from high and low cluster means for hybridization programs. Suganthi et al. [22] emphasized the importance of inter-cluster distances for cowpea improvement through hybridization and selection.

Brahmaiha et al. [23] evaluated 40 cowpea genotypes, grouping them into clusters based on genetic divergence and highlighting the potential for inter-crossing between clusters to obtain high variation.

Overall, these studies underscore the significance of D^2 statistics in assessing genetic divergence and guiding breeding programs for cowpea improvement. The identification of divergent genotypes and the understanding of trait contributions to genetic divergence are crucial steps towards enhancing cowpea productivity and quality.

The evaluation of genetic diversity among cowpea genotypes has been a subject of extensive research, employing various statistical techniques such as Mahalanobis's D^2 statistics. These studies have provided valuable insights into the genetic variability present within cowpea populations and have guided breeding efforts aimed at improving traits related to yield, quality, and stress tolerance.

Several researchers have utilized D^2 statistics to group cowpea genotypes into clusters based on their similarity in morphological and agronomic traits. The identification of distinct clusters allows breeders to select diverse parental lines for hybridization, thereby harnessing genetic variability and facilitating the development of superior cultivars.

Studies conducted by various researchers, including Adewale et al. [24], Pandiyan et al. [25-27], and [28,29], have demonstrated the effectiveness of D^2 statistics in delineating genetic relationships among cowpea genotypes. These studies have highlighted the presence of significant genetic diversity within cowpea germplasm collections, with clusters exhibiting variability in key agronomic traits such as yield, maturity, and seed characteristics. Furthermore, the identification of genotypes with unique trait combinations, as observed in studies by [30,31] and [32-34], underscores the importance of exploiting genetic diversity for trait improvement through breeding programs.

The application of D^2 statistics has also enabled researchers to identify promising genotypes for specific breeding objectives. For instance, genotypes with high yield potential, early maturity, and desirable agronomic traits have been selected for further evaluation and incorporation into breeding programs aimed at developing high-yielding and stress-tolerant cowpea varieties. Moreover, the assessment of genetic diversity using D² statistics has facilitated the conservation and utilization of cowpea genetic resources. By identifying genetically distinct germplasm accessions and wild relatives, researchers can prioritize conservation efforts and strategically incorporate valuable traits into breeding programs to enhance the resilience and adaptability of cowpea cultivars to changing environmental conditions and evolving pest and disease pressures [35-40].

Overall, the comprehensive understanding of genetic diversity and population structure provided by D² statistics serves as a critical foundation for the sustainable improvement of cowpea through targeted breeding strategies, germplasm conservation, and utilization of genetic resources for trait enhancement and crop improvement [41-54].

2. CONCLUSION

In conclusion, the assessment of genetic divergence in cowpea populations using Mahalanobis's D² statistics has proven to be a valuable tool for understanding the extent and nature of genetic variability within this important legume crop. The extensive body of research highlighted in this review underscores the significance of genetic diversity in cowpea breeding and improvement programs.

Through the application of D² statistics, researchers have identified diverse genotypes with unique combinations of agronomic traits, providing valuable genetic resources for the development of improved cowpea varieties. The clustering of genotypes based on morphological, physiological, and yield-related traits has facilitated the selection of parents for hybridization, leading to the creation of novel genetic combinations and the generation of transgressive segregants with superior agronomic performance.

Furthermore, the assessment of genetic diversity has enhanced our understanding of the population structure and evolutionary dynamics of cowpea germplasm, informing conservation efforts and guiding the strategic utilization of genetic resources for crop improvement. By preserving and exploiting the genetic variability present within cowpea populations, breeders can develop cultivars with enhanced resilience, productivity, and adaptability to diverse environmental conditions and biotic stresses.

Overall, the insights gained from studies employing D² statistics have contributed significantly to the advancement of cowpea breeding programs, enabling the development of high-yielding, stress-tolerant varieties that address the evolving needs of farmers and contribute to global food security. Moving forward, continued research efforts focused on the characterization and utilization of genetic diversity will be essential for sustaining the progress achieved in cowpea improvement and ensuring the resilience and productivity of this vital crop in the face of emerging challenges and changing agricultural landscapes.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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