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Recent Advances and Breeding Strategies in Pigeonpea (*Cajanus cajan* L.)

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Pigeonpea (*Cajanus cajan* L.) is a major pulse crop of the semi-arid tropics and plays a crucial role in ensuring food, nutritional and livelihood security, particularly in developing countries such as India. Despite its importance, the productivity of pigeonpea has remained relatively stagnant for several decades due to a combination of genetic, physiological and environmental constraints. The crop is exposed to a wide range of biotic stresses including insect pests and diseases, as well as abiotic stresses such as drought, salinity and waterlogging. Conventional breeding approaches have contributed significantly to varietal improvement; however, their progress has been slow due to the narrow genetic base and long generation time of the crop. In recent years, advances in molecular biology, genomics, and hybrid breeding technologies have opened new avenues for enhancing yield potential and stability in pigeonpea. This article reviews the origin and genetic diversity of pigeonpea, major production constraints, traditional and modern breeding strategies, recent advances in molecular breeding and hybrid technology, and future prospects for sustainable yield improvement.

Keywords: Pigeonpea; Cajanus cajan; breeding strategies; genetic diversity; hybrid technology; molecular breeding; biotic and abiotic stress resistance; yield improvement

Introduction

Pigeonpea (*Cajanus cajan* L.), commonly known as red gram or arhar, is one of the most important grain legumes cultivated in tropical and subtropical regions of the world. India accounts for the largest share of global area and production of pigeonpea, where it serves as a primary source of dietary protein for a large vegetarian population. The crop is valued not only for its nutritional richness but also for its ecological benefits, including atmospheric nitrogen fixation, improvement of soil fertility, and efficient utilization of residual soil moisture. Despite these advantages, pigeonpea yields have remained low compared to their genetic potential. The national average productivity is considerably lower than that achieved under experimental conditions. Factors such as susceptibility to insect pests and diseases, photoperiod sensitivity, drought stress, and limited adoption of improved cultivars contribute to this yield gap. Therefore, there is a pressing need to enhance pigeonpea productivity through efficient breeding strategies supported by recent scientific advances.

Origin and Genetic Diversity of Pigeonpea

Pigeonpea is believed to have originated in Peninsular India, which is recognized as the primary center of origin, while Africa is considered the secondary center of diversity. The wild progenitor of cultivated pigeonpea is *Cajanus cajanifolius*, and domestication is thought to have involved natural hybridization with closely related wild species such as Cajanus scarabaeoides. Cultivated pigeonpea is a diploid species with a chromosome number of 2n = 22. Although pigeonpea exhibits considerable morphological diversity in terms of growth habit, maturity duration, and seed characteristics, molecular studies have revealed a relatively narrow genetic base within cultivated germplasm. This limited diversity is mainly due to repeated use of a few landraces and elite lines in breeding programs. The availability and effective utilization of wild relatives and landraces are therefore essential for broadening the genetic base and enhancing genetic gains.

Constraints in Pigeonpea Production

Pigeonpea productivity is constrained by several physiological, genetic and environmental factors. One of the major physiological constraints is photoperiod sensitivity, as pigeonpea is a quantitative short-day plant. Variations in day length can delay flowering and maturity, leading to poor yield stability across environments. In addition, limited understanding of crop physiology under stress conditions hampers effective selection for yield-related traits. Biotic stresses cause substantial yield losses every year. Insect pests such as Helicoverpa armigera and Maruca vitrata are the most destructive, while diseases like Fusarium wilt and sterility mosaic disease are widespread and economically important. Abiotic stresses including drought, salinity and waterlogging further aggravate yield instability, particularly in rainfed ecosystems. Genetic contamination due to natural outcrossing and linkage drag during introgression from wild species also pose challenges in breeding programs.

Conventional Breeding Strategies

Traditional breeding approaches have played a pivotal role in pigeonpea improvement. Pure line selection from landraces has resulted in the development of several region-specific varieties with stable performance. Pedigree breeding has been widely used to combine desirable traits such as high yield and disease resistance. Mass selection has been practiced under farmer field conditions, especially for intercropping systems where adaptability is crucial. Mutation breeding has also contributed to the creation of novel variability for traits such as plant architecture and maturity duration. Chemical mutagens like ethyl methane sulfonate have been successfully used to develop improved pigeonpea varieties. Although these conventional approaches have yielded significant achievements, their progress has been relatively slow due to the long generation cycle and complex inheritance of yield traits.

Breeding for Biotic Stress Resistance

Breeding for resistance to insect pests and diseases is a major objective in pigeonpea improvement programs. Host plant resistance to pod borers has been explored using both cultivated germplasm and wild relatives. Resistant donor lines identified through systematic screening have been utilized in breeding programs to develop improved cultivars. For disease resistance, screening under sick plot conditions has enabled identification of stable resistance sources to Fusarium wilt and sterility mosaic disease. Varieties such as Maruti and Asha have shown durable resistance and wide adaptability. However, continuous evolution of pathogens necessitates ongoing efforts to identify new resistance genes and diversify resistance sources.

Breeding for Abiotic Stress Tolerance

Abiotic stresses are major contributors to yield fluctuations in pigeonpea, particularly in rainfed environments. Drought tolerance breeding focuses on improving root traits, water use efficiency, and matching crop duration with available soil moisture. Early and extra-early maturing varieties have been developed to escape terminal drought stress. Salinity and waterlogging tolerance have been identified in certain wild relatives and cultivated genotypes. Genetic studies have shown that tolerance to these stresses is often controlled by simple dominant genes, facilitating their transfer into elite cultivars. Development of stress-tolerant varieties is essential for ensuring yield stability under adverse climatic conditions.

Recent Advances in Molecular Breeding

Recent advances in molecular biology and genomics have significantly enhanced the efficiency of pigeonpea breeding. The development of molecular markers, genetic linkage maps and availability of draft genome sequences have enabled precise identification of genes and quantitative trait loci associated with important agronomic traits. Genotyping-by-sequencing and marker-assisted selection have been successfully employed to improve resistance to Fusarium wilt and sterility mosaic disease. These approaches allow early and accurate selection, thereby reducing breeding cycle duration and increasing genetic gains.

Hybrid Pigeonpea Technology

Hybrid breeding represents a major breakthrough in pigeonpea improvement. The discovery of genetic male sterility and subsequent development of cytoplasmic nuclear male sterility systems enabled commercial hybrid production. CMS-based hybrids have demonstrated yield advantages ranging from 30 to 50 percent over conventional varieties. Several hybrids have been released in India with superior yield potential and disease resistance. Although challenges related to hybrid seed production and fertility restoration were initially encountered, continuous refinement of CMS systems has improved hybrid stability and farmer adoption.

Conclusion

Breeding strategies in pigeonpea have evolved from conventional selection methods to advanced molecular and hybrid approaches. While challenges such as yield stagnation, pest pressure and climate variability persist, recent scientific advances provide promising opportunities to overcome these constraints. An integrated breeding approach that combines genetic diversity, modern genomics, hybrid technology and efficient seed systems is essential for enhancing pigeonpea productivity. Sustained research and policy support will play a crucial role in ensuring food and nutritional security through improved pigeonpea production.

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