International Journal of Agriculture and Food Science 2025; 7(8): 119-122

ISSN Print: 2664-844X
ISSN Online: 2664-8458
NAAS Rating (2025): 4.97
IJAFS 2025; 7(8): 119-122
www.agriculturaljournals.com
Received: 12-05-2025
Accepted: 16-06-2025

Dr. Atul Sharma
Associate Professor, Faculty of Agriculture, Jagannath University, Jaipur, Rajasthan, India

Ravi Kumar
Assistant Professor, School of Agriculture, RNB Global University, Bikaner, Rajasthan, India

Appy
Research Scholar, Department of Genetics and Plant Breeding, Tantia University, Sriganganagar, Rajasthan, India

Corresponding Author:
Dr. Atul Sharma
Associate Professor, Faculty of Agriculture, Jagannath University, Jaipur, Rajasthan, India

Role of recent improved breeding methods in crop improvement in India

Atul Sharma, Ravi Kumar and Appy

DOI: https://www.doi.org/10.33545/2664844X.2025.v7.i8b.601

Abstract
India, with its vast population and diverse agro-climatic zones, faces the challenge of ensuring food security amidst climate change, shrinking arable land, and increasing biotic and abiotic stresses. Recent advances in plant breeding methods, including genomic-assisted breeding, speed breeding, CRISPR/Cas9 genome editing, and marker-assisted selection, have revolutionized crop improvement. These techniques have accelerated the development of high-yielding, stress-tolerant, and nutritionally enhanced crop varieties. This paper reviews the role of these improved breeding methods in enhancing crop productivity in India, with a focus on recent examples such as heat-tolerant pigeonpea, drought-resistant wheat, and biofortified rice. The integration of these technologies with conventional breeding, their impact on Indian agriculture, and the challenges of adoption are discussed, along with future prospects for sustainable crop improvement.

Keywords: Crop improvement, genomic-assisted breeding, speed breeding, CRISPR/Cas9, marker-assisted selection, India, food security

1. Introduction
Agriculture is the backbone of India's economy, supporting over 50% of its population and contributing significantly to GDP. With a projected population of 1.7 billion by 2050, India must double its agricultural productivity to meet food demands while addressing challenges like climate change, water scarcity, and soil degradation (Godfray *et al*., 2010) [4]. Traditional breeding methods, while effective during the Green Revolution, are time-consuming and limited by genetic diversity constraints. Recent advancements in breeding technologies, such as genomic-assisted breeding (GAB), speed breeding (SB), and genome editing, have transformed crop improvement by enabling precise, rapid, and efficient trait selection (Varshney *et al*., 2021) [16]. These methods have been instrumental in developing climate-resilient, high-yielding, and nutritionally superior crop varieties in India. This paper explores the role of these improved breeding methods, highlights recent examples, and evaluates their impact on Indian agriculture.

2. Recent Improved Breeding Methods
2.1 Genomic-Assisted Breeding (GAB)
GAB integrates genomic tools like molecular markers, quantitative trait loci (QTL) mapping, and genome-wide association studies (GWAS) to enhance breeding efficiency. It shifts from phenotype-based to genotype-based selection, reducing breeding cycles and improving precision (Mangal *et al*., 2024) [7] In India, GAB has been widely adopted for crops like rice, wheat, and pulses. For instance, marker-assisted selection (MAS) has been used to introgress drought tolerance genes into rice varieties like IR64 and Swarna (Swamy *et al*., 2021 and Kumar *et al.*, 2024) [15, 5]. Similarly, GWAS identified QTLs for blast resistance in rice, enabling the development of resistant varieties (Kumar *et al*., 2024) [5].

2.2 Speed Breeding (SB)
SB accelerates crop generation cycles by optimizing environmental conditions like light, temperature, and photoperiod, allowing multiple generations per year (Potts *et al*., 2023) [10]. In India, SB has been pivotal in developing climate-resilient varieties. For example, the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) used SB to

develop the world's first extreme heat-tolerant pigeonpea, enhancing resilience in semi-arid regions. SB is often integrated with GAB and gene editing to further expedite breeding programs.

2.3 CRISPR/Cas9 Genome Editing

CRISPR/Cas9 enables precise modifications in crop genomes, targeting traits like yield, stress tolerance, and nutritional quality (Nerkar *et al*., 2022) [9]. Unlike transgenic methods, CRISPR-edited crops are often free of foreign DNA, easing regulatory hurdles. In India, CRISPR has been used to enhance rice nutritional content by editing genes for carotenoid accumulation, resulting in biofortified golden rice (Dong *et al*., 2020) [2]. Additionally, CRISPR-edited wheat varieties with improved disease resistance are under development (Nerkar *et al*., 2022) [9].

2.4 Marker-Assisted Selection (MAS)

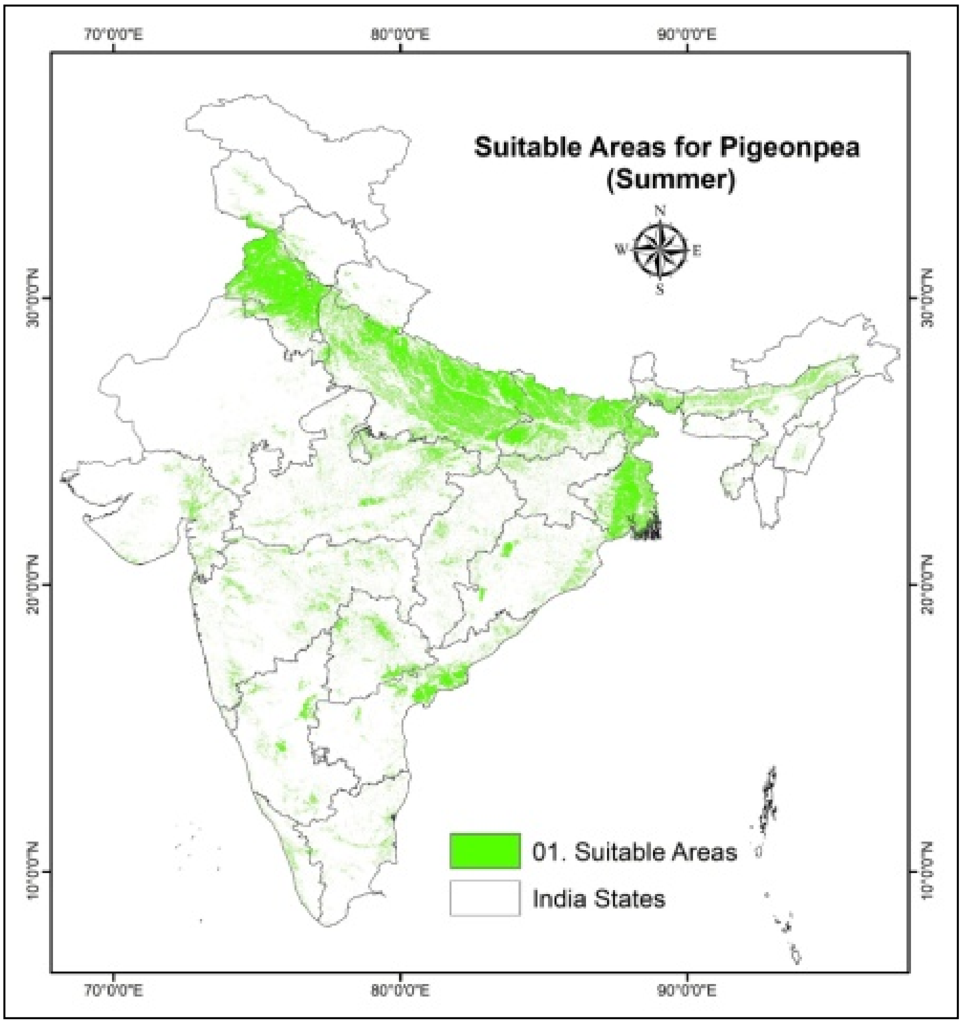
MAS improves breeding accuracy for complex traits like disease and drought tolerance by using molecular markers to select desired features (Kumar *et al.*, 2024) [5]. According to Neeraja *et al.* (2007) [8], MAS has played a crucial role in the development of flood-tolerant rice varieties in India, such as Swarna-Sub1, which carries the SUB1 gene for submergence resistance. MAS is commonly used in public sector breeding programs and is reasonably priced (Yadav and Das, 2024) [17].

2.5 Mutation Breeding: Using chemical or physical mutagens, mutation breeding creates genetic variety to improve qualities like stress tolerance and yield. The Bhabha Atomic Research Centre (BARC) in India has created more than 50 mutant varieties, such as the highly productive Trombay Groundnut and Trombay Mung mungbean, which are more resistant to disease (Raina *et al*., 2016) [11].

3. Recent Examples of Crop Improvement in India

3.1 Heat-Tolerant Pigeonpea

ICRISAT's speed breeding program developed an extreme heat-tolerant pigeonpea variety, addressing yield losses in India's semi-arid tropics. By accelerating generation cycles under controlled conditions, this variety was released in record time, boosting farmer resilience against rising temperatures. The world's first heat-tolerant pigeonpea cultivar, ICPV 25444, was created by ICRISAT and can endure summer temperatures of 45 °C while ripening in 125 days. It has been tested in Telangana, Odisha, and Karnataka and produces 2 tons per hectare, allowing for year-round agriculture. Researchers grew four generations a year by cutting the variety development time from 15 to 5 years using a ground-breaking speed-breeding methodology. This innovation reduces imports by USD 800 million and solves India's 1.5 million-ton pigeonpea imbalance. ICPV 25444 promotes both horizontal and vertical growth, increasing profitability by USD 234/ha, especially in summer fields and rice fallows, and transforming Indian agriculture (Anonymous, 2025) [1].



3.2 Drought-Resistant Wheat

Using MAS and GAB, the Indian Agricultural Research Institute (IARI) developed drought-tolerant wheat varieties like HD 2967 and HD 3086. These varieties carry QTLs for root architecture and water-use efficiency, ensuring stable yields under water-limited conditions (Sundaram *et al*., 2019) [14].

3.3 Biofortified Rice

CRISPR/Cas9 was used to enhance the nutritional quality of rice by increasing carotenoid content, addressing vitamin A deficiency in India. The resulting golden rice variety is under regulatory evaluation and promises to improve public health (Dong *et al*., 2020) [1].

3.4 Flood-Tolerant Rice

The Swarna-Sub1 rice variety, developed through MAS, has transformed rice farming in flood-prone eastern India. The SUB1 gene confers submergence tolerance for up to 14 days, increasing yields by 1–3 t/ha in affected areas (Neeraja *et al*., 2007) [8].

3.5 Disease-Resistant Groundnut

Mutation breeding at BARC produced the Trombay Groundnut variety with resistance to leaf spot and rust diseases. This variety has improved yields by 15–20% in Gujarat and Maharashtra (Raina *et al*., 2016) [11].

4. Impact on Indian Agriculture

4.1 Enhanced Productivity

Improved breeding methods have significantly increased crop yields. For instance, Swarna-Sub1 rice has boosted productivity in flood-prone regions, while drought-tolerant wheat varieties have stabilized yields in rainfed areas (Sundaram *et al*., 2019) [14]. These gains are critical for meeting India's food security goals.

4.2 Climate Resilience

Climate-resilient varieties like heat-tolerant pigeonpea and drought-resistant wheat have reduced yield losses due to abiotic stresses. These varieties are vital for adapting to India's diverse agro-climatic zones, where extreme weather events are increasingly common (Fels *et al*., 2019) [3].

4.3 Nutritional Security

Biofortified crops like golden rice address micronutrient deficiencies, improving public health outcomes. Such interventions align with India's National Nutrition Mission, targeting malnutrition in vulnerable populations (Dong *et al*., 2020) [2].

4.4 Economic Benefits

High-yielding and stress-tolerant varieties have increased farmer incomes by reducing input costs and stabilizing yields. For example, Trombay Groundnut has lowered fungicide use, enhancing profitability for smallholder farmers (Raina *et al*., 2016) [11].

5. Challenges in Adoption

5.1 Regulatory Hurdles

Genome-edited crops face stringent regulations in India, delaying commercialization. While SDN-1 and SDN-2 edited plants are exempt from biosafety regulations, public acceptance remains a challenge (Nerkar *et al*., 2022) [9]. Clear policies are needed to streamline approvals.

5.2 Infrastructure Limitations

SB and GAB require advanced facilities like controlled environment chambers and high-throughput genotyping platforms, which are limited in India's public sector institutions (Potts *et al*., 2023) [10]. Investments in infrastructure are essential for scaling these technologies.

5.3 Capacity Building

The adoption of advanced breeding methods demands skilled personnel. Training programs for breeders and extension workers are critical to bridge the knowledge gap (Potts *et al*., 2023) [10].

5.4 Socio-Economic Barriers

Smallholder farmers, who dominate Indian agriculture, face financial constraints in accessing improved varieties and technologies. Subsidies and public-private partnerships can enhance affordability and dissemination.

6. Future Prospects

The integration of SB, GAB, and CRISPR/Cas9 with artificial intelligence (AI) and high-throughput phenotyping offers immense potential for crop improvement. AI can predict breeding outcomes, while phenotyping platforms can accelerate trait identification (Sun *et al*., 2024) [13]. India should prioritize investments in research, infrastructure, and policy frameworks to harness these technologies. Public-private collaborations and participatory breeding approaches can enhance farmer adoption and ensure equitable benefits. Additionally, leveraging India's rich genetic diversity through gene banks can fuel future breeding programs.

7. Conclusion

Recent improved breeding methods have revolutionized crop improvement in India, addressing challenges of food security, climate change, and nutritional deficiencies. Techniques like GAB, SB, CRISPR/Cas9, MAS, and mutation breeding have delivered high-yielding, stress-tolerant, and biofortified varieties, with notable examples including heat-tolerant pigeonpea, drought-resistant wheat, and golden rice. Despite their transformative impact, challenges like regulatory hurdles, infrastructure limitations, and socio-economic barriers must be addressed to scale adoption. With strategic investments and policy support, these technologies can drive sustainable agricultural growth, ensuring India's resilience in a rapidly changing world.

8. References

1. Anonymous. Breakthrough at ICRISAT: World's first extreme heat-tolerant pigeonpea developed via speed breeding [Internet]. ICRISAT; 2025 [cited 2025 Aug 5]. Available from: https://pressroom.icrisat.org/breakthrough-at-icrisat-worlds-first-extreme-heat-tolerant-pigeonpea-developed-via-speed-breeding
2. Dong OX, Yu S, Jain R, Zhang N, Duong PQ, Butler C. Marker-free carotenoid-enriched rice generated through targeted gene insertion using CRISPR-Cas9. Nat Commun. 2020;11:1178. https://doi.org/10.1038/s41467-020-14981-y

3. Fels KPV, Stahl A, Hickey LT. Modern crop breeding for future food security. BMC Biol. 2019;17(18):2–7.
4. Godfray HCJ, Beddington JR, Crute IR, Haddad L, Lawrence D, Muir JF. Food security: The challenge of feeding 9 billion people. Science. 2010;327(5967):812–818. https://doi.org/10.1126/science.1185383
5. Kumar R, Bhandari S, Sarita, Gayathri PM. Effect of heat stress on wheat production in semi-arid region of Rajasthan. AGBIR. 2024;40(4):1210–1213.
6. Kumar R, Das SP, Choudhury BU, Kumar A, Prakash NR, Verma R, *et al*. Advances in genomic tools for plant breeding. Biol Res. 2024;57:1–23.
7. Mangal V, Verma LK, Singh SK, Saxena N, Roy A, Karn A, *et al*. Triumphs of genomic-assisted breeding in crop improvement. Heliyon. 2024;10:1–16.
8. Neeraja CN, Maghirang-Rodriguez R, Pamplona A, Heuer S, Collard BCY, Septiningsih EM. A marker-assisted backcross approach for developing submergence-tolerant rice cultivars. Theor Appl Genet. 2007;115(6):767–776. https://doi.org/10.1007/s00122-007-0607-0
9. Nerkar G, Devarumath S, Purankar M, Kumar A, Valarmathi R, Devarumath R, Appunu C. Advances in crop breeding through precision genome editing. Front Genet. 2022;13:1–14.
10. Potts J, Jangra S, Michael VN, Wu X. Speed breeding for crop improvement and food security. Crops. 2023;3(4):276–291.
11. Raina A, Laskar RA, Khursheed S, Amin R, Tantray YR, Parveen K, Khan S. Role of mutation breeding in crop improvement: Past, present and future. Asian Res J Agric. 2016;2(2):1–13. https://doi.org/10.9734/ARJA/2016/29334
12. Serres JB, Parker JE, Ainsworth EA, Oldroyd GED, Schroeder JI. Genetic strategies for improving crop yields. Nature. 2019;575(7781):109–118.
13. Sun L, Lai M, Ghouri F, Nawaz MA, Ali F, Baloch FS, *et al*. Modern plant breeding techniques in crop improvement and genetic diversity. Plants. 2024;13:1–32.
14. Sundaram RM, Vishnupriya MR, Laha GS, Balachandran SM, Reddy GA, Viraktamath BC. Marker-assisted breeding for development of improved rice varieties in India. Plant Breed Rev. 2019;42:189–226.
15. Swamy BPM, Rahman MA, Inabangan-Asilo MA, Amparado A, Manito C, Chadha-Mohanty P. Advances in breeding for drought tolerance in rice. Plant Breed Rev. 2021;45:279–328. https://doi.org/10.1002/9781119828228.ch8
16. Varshney RK, Bohra A, Yu J, Graner A, Zhang Q, Sorrells ME. Designing future crops: Genomics-assisted breeding comes of age. Trends Plant Sci. 2021;26(6):631–649. https://doi.org/10.1016/j.tplants.2021.03.010
17. Yadav MK, Das J. Breeding strategies for vegetable improvement: An extensive analysis. J Biodivers Environ Sci. 2024;24(3):27–36.