: Genomic selection; Marker-assisted selection; High-throughput phenotyping; Genotype-phenotype associations; Crop improvement; Sustainable agriculture

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In the realm of agricultural innovation [1], integrated genomic approaches have emerged as transformative tools for accelerating genetic enhancement in crop breeding. is introduction sets the stage for examining how these advanced genomic technologies are reshaping traditional breeding practices to address global challenges such as food security, climate change resilience, and sustainable agriculture. Historically, crop breeding has relied on phenotypic selection and classical breeding methods to improve agronomic traits [2]. However, the advent of genomics has revolutionized this eld by providing insights into the genetic basis of traits and enabling more precise and e cient selection of desirable genotypes. Genomic selection (GS) stands out as a cornerstone of these advancements, leveraging genome-wide markers to predict the breeding value of plants early in the breeding cycle [3]. By harnessing genomic information, breeders can identify individuals with superior genetic potential for traits like yield, disease resistance, and stress tolerance, thereby accelerating the breeding process and increasing genetic gains.

Marker-assisted selection (MAS) complements GS by identifying and utilizing molecular markers linked to speci c traits of interest. is approach enhances breeding e ciency by enabling targeted selection of genotypes carrying favorable alleles, particularly for complex traits in uenced by multiple genes [4]. High-throughput phenotyping technologies have further revolutionized crop breeding by enabling rapid and detailed characterization of plant phenotypes under varying environmental conditions. ese technologies provide essential data to validate genomic predictions and establish robust genotype-phenotype associations critical for e ective breeding decisions [5]. e integration of these genomic approaches marks a paradigm shi

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the principles and applications of GS in predicting breeding values based on genome-wide markers. is included techniques such as genomic prediction models and genomic-enabled selection strategies. Investigations into the identi cation and utilization of molecular markers linked to target traits, facilitating e cient selection of desired genotypes in crop breeding programs.

Evaluation of technologies and methodologies for rapid and accurate phenotypic characterization of crops under varying environmental conditions. is encompassed remote sensing, imaging technologies, and automated phenotyping platforms [8-10]. Exploration of genomic tools and statistical approaches used to establish robust associations between genetic markers and phenotypic traits, providing insights into the genetic basis of trait variation. Additionally, the review considered studies addressing challenges and advancements in data management, bioinformatics tools, and ethical considerations associated with genomic technologies in crop breeding. Synthesizing these methodologies provided a comprehensive understanding of how integrated genomic approaches are transforming crop breeding practices, enhancing breeding e ciency, and contributing to sustainable agricultural development.

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e integration of integrated genomic approaches has revolutionized crop breeding, o ering powerful tools to accelerate genetic enhancement and address global agricultural challenges. roughout this review, we have explored the transformative impact of genomic selection (GS), marker-assisted selection (MAS), high-throughput phenotyping, and genotype-phenotype associations in advancing crop improvement strategies. Genomic selection has signi cantly expedited breeding cycles by enabling breeders to predict the breeding value of plants early in the selection process with unprecedented accuracy. By leveraging genome-wide markers, GS has facilitated the identi cation and deployment of superior genetic traits related to yield, disease resistance, and stress tolerance, thereby enhancing crop productivity and resilience in diverse environments. Marker-assisted selection continues to play a crucial role in targeting speci c genes or genomic regions associated with desired traits, complementing GS to achieve more e cient selection of genotypes with favorable alleles. is approach has proven e ective in improving complex traits that are challenging to address through conventional breeding methods alone. High-throughput phenotyping technologies have revolutionized the characterization of crop phenotypes, enabling rapid and precise assessment of traits under various environmental conditions. ese advancements have provided valuable data to validate genomic predictions and establish robust genotype-phenotype associations, enhancing breeding precision and e ectiveness.

e synergistic application of these integrated genomic approaches has not only accelerated genetic gains but also contributed to sustainable agricultural practices by reducing resource inputs and environmental impacts. However, challenges such as data management, bioinformatics infrastructure, and ethical considerations surrounding genetic manipulation remain critical areas for ongoing research and development. Looking forward, continued innovation and collaboration among researchers, breeders, policymakers, and stakeholders will be essential to harnessing the full potential of integrated genomic approaches in crop breeding. By addressing these challenges and maximizing the adoption of genomic technologies, we can meet the increasing global demand for food security, climate resilience, and sustainable agriculture. In conclusion, integrated genomic approaches represent a paradigm shi in crop breeding, o ering unprecedented opportunities to enhance agricultural productivity, resilience, and sustainability. By leveraging genomic insights and advanced technologies, we can shape a future where crops are more productive, resilient to environmental stresses, and contribute to global food security.

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None

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