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Advancements and Challenges of Modern Breeding over Conventional Breeding

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Abstract

Plant breeding dates back thousands of years, when people first deliberately bred plants based on visually pleasing characteristics. The domestication of wild plants aided this process, resulting in the evolution of numerous breeding strategies over time. Conventional breeding, which is distinguished by selective breeding based on superior performance, used procedures such as pure-line selections, mass selection, backcross breeding, recurrent selection, and hybridization. While effective, classical breeding procedures were time-consuming and overly reliant on phenotypic expression, which can be altered by external variables, resulting in selection mistakes. To address these restrictions, breeders began incorporating diverse fields of biology into plant breeding, resulting in the creation of contemporary breeding techniques. With the introduction of Mendelian theory and the discovery of DNA and RNA, plant breeding entered the molecular era. Breeders started focusing on less environmentally susceptible parameters such as genotypes, visual and genetic markers, image analysis, and loci mapping. Common modern breeding practices include genomic selection, marker-assisted breeding. However, the advancements in plant breeding have also raised concerns about gene erosion due to the loss of local landraces and wild-type plants. Preserving genetic diversity is crucial for the long-term sustainability of plant breeding efforts and agricultural systems. Despite these challenges, plant breeding continues to evolve, driven by the need to meet the increasing demand for food production while addressing environmental and societal concerns.

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INTRODUCTION

The initiation of modern human civilization traces back to 10,000 BC, marked by a transition from hunting and gathering to agriculture. Over millennia, humans gradually domesticated plants and animals, leading to the emergence of modern agriculture. This process began with gathering wild plants, followed by cultivation and finally domestication. The Neolithic Age saw the first domestication of staple crops such as wheat, maize, and potatoes, paving the way for the development of modern plant breeding (Zohary et al., 2021; Borlaug, 1983).

Plant breeding, the deliberate manipulation of plant genetics to enhance desirable traits, has been a cornerstone of agricultural progress. From primitive selection practices to Mendel's laws of inheritance and the modern techniques of hybridization and genetic engineering, plant breeding has continually evolved. Notable milestones include Norman E. Borlaug's "Green Revolution," which introduced high-yielding and disease-resistant wheat varieties, revolutionizing global food production (Gepts et al., 2012, (Jiang, 2013; Meyer and Purugganan, 2013).

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With the world's population projected to reach 10 billion by 2040, the demand for food is expected to rise significantly. Plant breeding offers a solution by increasing crop yields through the creation of genetic variation and the development of shorter life cycles in crops. This chapter aims to explore various breeding methodologies, distinguishing between conventional and modern approaches. It serves as a comprehensive resource for scientists and researchers in the field of plant breeding, offering insights into the past, present, and future of agricultural innovation.

CONVENTIONAL BREEDING

Conventional Breeding, a foundational methodology in plant breeding, relies on selective breeding techniques without the use of advanced molecular technologies. It adheres to natural laws of inheritance and utilizes hybridization to introduce desirable traits from closely related individuals into new cultivars. Variability is generated through hybridization, with selection based on phenotype to identify superior genotypes. However, conventional breeding is a lengthy process, often taking more than a decade to release new cultivars, and is susceptible to errors due to its reliance on phenotypic expressions influenced by genotype-environment interactions (Acquaah 2009; Allard, 1961; Lema 2018).

While conventional breeding has led to significant agricultural advancements, its subjective nature and dependency on breeder experience can result in inconsistent outcomes. In contrast, modern breeding practices leverage scientific advancements and are less reliant on subjective analysis, resulting in more effective and efficient cultivar development. This paper aims to explore the differences between conventional and modern breeding methodologies, highlighting the strengths and limitations of each approach to inform future research and breeding strategies.

MODERN BREEDING

Over the past two decades, modern technologies have been integrated with conventional breeding practices, expanding the scope of breeding objectives beyond merely improving crop yield. Unique traits such as weed resistance, enhanced nutrition, and responsiveness to soil and microbial communities are now robustly studied. To address these novel goals, conventional breeding is combined with genomics and other scientific disciplines to thoroughly investigate plant genetics. Emerging technologies like Genomic Selection, Enviromics, and High Throughput Phenotyping (HTP) are employed to enhance the genetic gain of cultivars, forming the foundation of modern breeding practices. Genomics, Enviromics, and Phenomics constitute the modern plant breeding triangle, enabling breeders to target specific traits efficiently (Fu, 2015; Crossa et al., 2017; Ewing et al., 2019).

Modern breeding techniques have accelerated crop improvement efforts, particularly in staple crops like rice, wheat, sorghum, and maize. Various complementary approaches are utilized to boost global food production, focusing on traits that promote superior performance across diverse environments. Modern breeding strategies prioritize parents with consistent phenotypes, minimizing the impact of genotype-environment interactions. This chapter explores the integration of modern technologies into conventional breeding practices, highlighting their contributions to advancing crop improvement and addressing global food security challenges.

ADVANTAGE OF MODERN PLANT BREEDING OVER CONVENTIONAL

From the Neolithic Age to the present, the evolution of plant breeding has seen a shift from traditional methods to modern techniques, resulting in more reliable and effective crop improvement strategies. Modern plant breeding offers several advantages over traditional breeding approaches:

1. Marker Assisted Breeding and Quantitative Trait Loci Mapping enable the selection of superior plants at the seedling stage, facilitating the removal of unwanted genes using specific markers.
2. Modern breeding allows for the selection of recessive alleles, which is challenging in conventional breeding due to reliance on phenotypic expression and the lengthy process of test crosses and selfing.

3. New breeding technologies like gene editing and genomic selection simplify the selection of quantitative traits governed by multiple alleles, overcoming the masking effects observed in traditional breeding.
4. Modern breeding programs are based on stable genotypes less affected by genotype by environment interactions, resulting in more effective and efficient genetic gains compared to conventional breeding.
5. Modern breeding is grounded in scientific research and findings, making it more objective and trustworthy compared to the subjective analysis and skill-dependent nature of conventional breeding practices (Anderson, 2013).

CHALLENGES OF MODERN BREEDING

Despite the advantages of modern plant breeding, several challenges hinder its widespread adoption and execution. These challenges include the need for skilled manpower with expertise in multiple biological disciplines, economic, institutional, and technical barriers, as well as specific challenges inherent to modern breeding programs:

1. Changing global weather patterns and climate uncertainties pose challenges for developing varieties resistant to multiple abiotic and biotic stresses. Negative correlations between stress-resistance genes and quantitative traits can reduce crop productivity, making it difficult for modern breeding programs to develop resilient varieties.
2. Genetic erosion, accelerated by intensive breeding efforts, has led to a rapid decline in genetic diversity in some regions. Low variability increases experimental errors and challenges the establishment of desired variation in offspring, complicating modern breeding efforts.
3. Modern breeding requires a high level of technical expertise in biotechnology, plant breeding, and agricultural statistics, surpassing the skills traditionally needed for breeding. Skilled manpower is essential for the successful operation of modern breeding programs.
4. The utilization of modern high-tech machinery and methodologies in plant breeding incurs significant costs, making it challenging for local farmers and developing nations to conduct such programs. Cost estimates for conducting breeding programs can be substantial, further limiting accessibility to modern breeding technologies (Morris and Bello, 2004).

Traditional Plant Breeding:

Plant breeding has evolved significantly over millennia, from traditional methods reliant on selective crossing to modern techniques leveraging genetic discoveries and biotechnological advancements (Moose and Mumm, 2008). Key milestones in the history of plant breeding include:

Genetic Discoveries

Gregor Mendel's work on inheritance principles and the discovery of DNA structure by Watson and Crick in the 20th century laid the foundation for modern plant breeding practices (Dempewolf, 2008).

Hybridization and Hybrid Vigor

The concept of hybridization revolutionized plant breeding, leading to the development of hybrid varieties with superior traits through the phenomenon of hybrid vigor or heterosis (Muthamilarasan and Prasad, 2015).

Biotechnology and Genetic Engineering

The advent of biotechnology and genetic engineering enabled scientists to manipulate genes directly, resulting in the development of genetically modified organisms (GMOs) with traits like pest resistance and increased nutritional content (Matin, 2020; Maarten and Stam, 2020).

Marker-Assisted Selection (MAS)

MAS emerged as a crucial technique allowing breeders to select plants with desired traits more efficiently by employing genetic markers linked to target traits (Zamir, 2021).

Genome Editing Techniques

Genome editing technologies like CRISPR-Cas9 have transformed plant breeding by enabling precise modifications of specific genes without introducing foreign DNA, offering vast potential for creating crops with enhanced traits (Rajeev, 2021).

Data-Driven Breeding and AI

The integration of data-driven approaches and artificial intelligence (AI) has revolutionized plant breeding, with sophisticated algorithms analyzing vast datasets to predict promising crosses and shorten the breeding cycle (Morrell, 2012).

CONCLUSION

In conclusion, plant breeding has undergone significant advancements with improvements in science and technology. From traditional methods of visual selection to modern breeding techniques incorporating molecular biology and biotechnology, breeding programs have become more efficient and effective. However, challenges persist in making modern breeding practices accessible, particularly in developing countries where infrastructure and resources may be lacking.

While modern breeding methodologies offer advantages such as shorter breeding cycles and reduced environmental impact, they also pose risks, including the loss of local landraces and wild-type plants. The extinction of these varieties diminishes genetic diversity and poses challenges for future crop improvement efforts. Genetic erosion can be managed through in situ and ex situ conservation strategies, as well as by identifying and harnessing sources of genetic diversity such as beneficial mutations and recombination events.

It is crucial to strike a balance between the adoption of modern breeding techniques for enhanced productivity and the preservation of genetic diversity for long-term sustainability. By addressing these challenges and implementing conservation measures, we can ensure the continued success of plant breeding programs and the resilience of agricultural systems in the face of evolving environmental and societal pressures.

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