



Gene Pyramiding: Boosting Crop Resilience and Productivity through Genetic Innovation

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Abstract

Gene pyramiding is a valuable strategy to incorporate multiple genes from diverse sources into a single plant. This approach provides a more robust and durable resistance against various biotic and abiotic stresses. By stacking multiple resistance genes, gene pyramiding enhances the plant's ability to withstand a broader range of challenges, increasing the longevity and effectiveness of resistance in crops and heightened adaptability to changing environmental conditions. This technique has become a critical aspect of modern agriculture as it contributes to increased crop resilience and productivity, ultimately helping to ensure food security and sustainable agriculture practices. Various conventional as well as modern techniques can be used to achieve gene pyramiding in a crop for better yielding varieties under different range of environment.

Keywords: Conventional, Gene pyramiding, Resistance, Sustainable

Introduction

Agriculture has come a long way in recent decades, with scientific advances and technological innovations driving significant improvements in crop yield and quality. Plant breeding plays a vital role in ensuring global food security, as it aims to develop improved crop varieties with enhanced traits, including high yield, disease resistance and stress tolerance. Gene pyramiding is a powerful technique used in plant breeding that involves combining multiple desirable genes into a single plant variety, resulting in superior performance and increased resistance to various stresses. This article explores the concept of gene pyramiding, its significance in modern agriculture and its potential for addressing global challenges.

What is Gene Pyramiding?

Watson and Singh (1952) first introduced the concept called gene pyramiding. Gene pyramiding is a breeding strategy that involves stacking multiple genes for different traits into a single plant variety. These genes can be derived from different sources, including wild relatives, closely related species, or even unrelated organisms. By combining these genes, plant breeders can create varieties that possess a

combination of desirable traits that are difficult to achieve through conventional breeding methods. This method has the potential to boost crop resilience, disease resistance and overall productivity while reducing the need for chemical inputs. By combining multiple beneficial genes within a single plant, gene pyramiding aims to create crops that are robust, high-yielding and better adapted to the challenges of modern agriculture.

Significance in Modern Agriculture

Enhanced Yield

Gene pyramiding allows breeders to incorporate multiple yield-enhancing traits into a single variety. This approach can lead to significant improvements in crop productivity and meet the growing demand for food globally.

Increased Nutritional Value

Researchers have used gene pyramiding to develop crops with improved nutritional content, such as higher vitamin or mineral levels, which can have positive health effects on consumers.

Enhanced Resistance to Diseases and Pests

Incorporating multiple genes for disease resistance in a crop

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variety can provide broad-spectrum protection against a range of pathogens. This approach reduces the reliance on chemical pesticides and helps in sustainable agriculture.

Improved Tolerance to Environmental Stress

Gene pyramiding offers a way to develop crop varieties that can withstand multiple stresses such as drought, salinity and extreme temperatures. This is particularly crucial in the face of climate change, as it enables the cultivation of crops in regions previously unsuitable for agriculture.

Reduced Environmental Impact

By reducing the reliance on chemical pesticides and fertilizers, gene-pyramided crops contribute to more sustainable and environmentally friendly agricultural practices.

Process of Gene Pyramiding

Gene pyramiding is a multi-step process that begins with the identification of target genes and traits of interest. Plant breeders search for specific genes that confer the desired characteristics, such as resistance to a particular disease or increased drought tolerance. These genes can be sourced from wild relatives of the crop or other plant species and in some cases, they may even be artificially synthesized. Once the target genes are identified, the process of introducing them into the crop plant begins. This step is known as pedigree step. This is often achieved through genetic engineering techniques such as transgenesis or through traditional breeding methods like hybridization and backcrossing. The key is to successfully incorporate the desired genes into the crop's genetic makeup without disrupting the overall genetic balance or introducing unwanted traits.

After the genes have been integrated into the crop's genome, the plant goes through multiple generations of selection and breeding to ensure stability and genetic uniformity. This step is known as fixation step and this process helps to eliminate undesirable traits and confirm that the newly created crop variety retains the desired characteristics.

Gene Pyramiding Techniques

Gene pyramiding can be applied in conventional and advanced molecular breeding programs to introduce novel lines. The conventional pyramiding technique involves backcross breeding, pedigree breeding or recurrent selection. Marker-based gene pyramiding and genetic engineering are the advanced and fastidious methods for the developing desired combinations of various genes in a single genotype.

Conventional Breeding

Traditional breeding methods involve crossing plants with desirable traits and selecting the progeny with the desired combination of genes. This process is time-consuming and labor-intensive.

Marker-Assisted Selection (MAS)

MAS utilize molecular markers linked to specific genes of interest to identify plants with the desired traits more efficiently. This technique enables breeders to track and select plants carrying multiple genes simultaneously. The

prime aim of marker-assisted backcross breeding is to transfer the targeted genes into the background of elite cultivars and recover the recurrent parent genome as quickly as possible with a limited number of backcrosses (Ramalingam et al., 2020). Marker-assisted recurrent selection is also an improved system that enables genotype selection and inter-crossing in one cropping season.

Genetic Engineering

Genetic engineering techniques such as transgenesis and genome editing can be employed to introduce specific genes into crops. This approach allows breeders to precisely stack multiple genes, overcoming the limitations of traditional breeding.

Challenges and Concerns

While gene pyramiding offers tremendous potential for improving crop productivity and sustainability, it is not without its challenges and concerns. Some of the key issues include:

Regulatory and Safety Concerns

The use of genetic engineering techniques can raise regulatory and safety concerns. Stricter regulations, testing and public acceptance are necessary to ensure the safety of gene-pyramided crops.

Genetic Diversity

The process of gene pyramiding can reduce genetic diversity in crop varieties, potentially making them more susceptible to new diseases and environmental changes. Careful monitoring and breeding strategies are needed to address this issue.

Ethical Concerns

Some individuals and organizations have ethical concerns about genetic modification, which can create resistance to adopting gene-pyramided crops.

Future Perspectives

Crop improvement has been done in many crops through gene pyramiding such as resurrection of wheat cultivar PBW-343 for rust resistance (Sharma et al., 2021), enhanced resistance achieved against bacterial blight, blast and sheath blight disease in rice (Ramalingam et al., 2020), pyramiding of soybean mosaic virus resistant genes in soybean (Wang et al., 2017) and various other crops. Looking ahead, advancements in genomic technologies, such as next-generation sequencing and gene editing techniques, will significantly enhance the efficiency and precision of gene pyramiding. Furthermore, international collaborations, public-private partnerships and supportive policies can facilitate the deployment of gene pyramiding in diverse crop systems worldwide.

Conclusion

Gene pyramiding is a powerful tool in the hands of modern plant breeders, offering the potential to create crop varieties that are more resilient, productive and sustainable. As the global population continues to grow and climate change poses challenges to agriculture, innovative techniques like gene pyramiding can play a crucial role in ensuring food

security and reducing the environmental impact of farming. However, it is important to address regulatory, ethical and genetic diversity concerns while maximizing the benefits of this promising technology. With responsible and informed use, gene pyramiding can help revolutionize the way we grow and consume food in the 21st century.

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