

## AGRICULTURE FORUM FOR TECHNICAL EDUCATION OF FARMING SOCIETY

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### Gene Pyramiding: Combining Multiple Resistance Genes for Durable Disease Resistance

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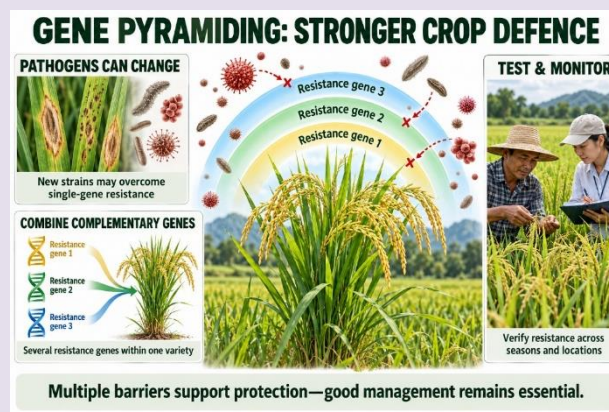
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## INTRODUCTION

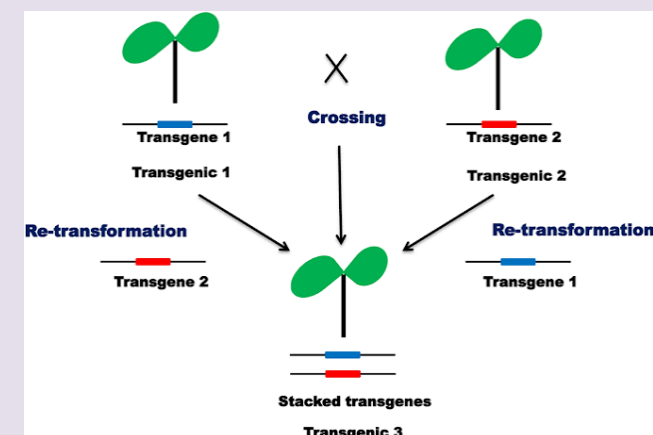
A healthy crop starts with its protection, but that protection is constantly under threat from disease-causing organisms. A good variety today might be compromised by the emergence of a new strain of the pathogen. Farmers end up with damaged crops, more sprays and an uncertain income. Gene pyramiding provides a practical breeding approach to enhance crop defence through the accumulation of several beneficial resistance genes within a single cultivar. As a house with multiple layers of security, the plant now has several barriers to infection. The aim is to have dependable protection that enables a productive farming system, recognising that resistance must be challenged, observed and managed over the life of a variety.



## 2. Understanding Gene Pyramiding

Gene pyramiding is defined as the intentional combining of two or more resistance genes, or any desirable genes, in a single plant. These genes could confer protection against different strains of the same pathogen or multiple diseases. They are usually

sourced by breeders from the cultivated or landrace or wild relatives. Crossing and selection combine the desired genes while keeping the positive attributes of the crop. A gene pyramid, therefore, is not like mixing the seeds of different varieties together: its protective elements are all within single plants. It is also not automatically a genetically modified crop, because many pyramids are produced through conventional crossing supported by modern DNA testing.



## 3. Why Single Genes Can Lose Protection

A number of resistance genes aid plants in recognising molecules related to invading pathogens. Recognition triggers defence responses that constrain infection or disease progression. But not all pathogens, some isolates can avoid recognition and/or suppress plant defences. When a single resistance gene is deployed over a large area, the ability to overcome that gene is strongly selected for. Their recrudescence can erode the protection that farmers once relied on. This is why a variety should never be considered to be disease proof in perpetuity. Combining carefully selected genes can make

successful infection more difficult, especially when the genes provide effective and complementary barriers against important pathogens.

#### 4. Building Complementary Layers of Defence

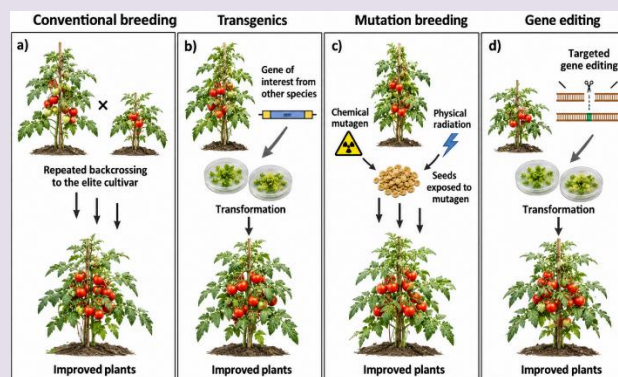
The value of a pyramid is a function of how well its components work together. One gene might detect a pathogen signal, another could limit pathogen proliferation, and other genes may inhibit the movement of the disease within plant tissue. A pathogen that can breach one barrier could still be stopped by another. But the presence of more genes did not necessarily translate into stronger resistance. Genes with the same vulnerabilities might have a very small effect on the resistance, and some combinations actually have a negative effect. Therefore, breeders take into account resistance mechanisms, pathogen complexity, and gene compatibility in selecting a combination. The target is a synergistic system of defence whose efficacy exceeds that of its parts in situ.

#### 5. Finding the Right Resistance Sources

Successful pyramiding is based on a good disease problem definition. Breeders recognize the key pathogens they face; evaluate the strains that occur locally and choose the resistance sources that best fit these threats. Beneficial genes might be found in forgotten landraces or wild relatives that have endured different environments. Donor plants are assessed for the intensity and spectrum of resistance. Another criteria of selection is that whether in non-infecting soil monoculture sequence crop host a gene is still effective. Genetic diversity must be maintained because the resources for future breeding rely on them. A narrow search for familiar genes can overlook valuable protection and repeatedly expose agriculture to the same biological weaknesses.

### 6. Combining Genes Through Breeding

Traditional pyramiding is based on crossing parents with different resistance genes. Their progeny is screened, and selected plants are crossed or selfed until the desired gene combination is stabilized. Backcrossing also may be used to recover the traits of a commercial cultivar, while acquiring resistance from the donor parents. During this, breeders still have to select for yield, maturity, quality and adaptation as well as disease protection. The problem is that resistance genes can dissociate in reproduction, and that similar disease reaction types may conceal different genetic combinations. Records and repeated selection are therefore necessary. A good plant only becomes useful if its progeny can consistently maintain the necessary resistance and agricultural performance.



### 7. DNA Markers Make Selection Easier

DNA markers act as signposts that help breeders follow resistance genes through successive generations. Marker assisted selection means that the beneficial seedlings can be selected prior to a disease epidemic. It is also useful when multiple genes are involved with similar phenotypic outputs or when a

dominant gene is masking the effect of another gene. The desired variety is recovered by background selection, and the undesired donor segments can be minimized by additional markers. However, a marker signifies a genetic linkage and does not confirm field resistance. Markers need to be validated in the appropriate breeding material and the selected plants must still be challenged with the disease, to see if the anticipated protection actually works.

### 8. Rice Demonstrates the Possibilities

Rice is a good case study for practical gene pyramiding. Bacterial blight breeding programmes, for instance, have stacked genes like xa5, xa13 and Xa21 for increased resistance in preferred varieties. More recently, a resistance to bacterial blight and blast were also incorporated in the same breeding line. In a work reported in 2025, the blast resistance genes Pi9 and Pb1 was pyramided with Xa4, xa13 and Xa21 with the background of BRRI dhan100. Some of the selected advanced lines exhibited enhanced resistance to the disease under the conditions of the reported test. Such results show the potential for breeding, but local adaptation, seed availability and sustained performance need to be achieved before generalized recommendations can be made.

### 9. Strengthening Wheat Against Rusts

Wheat breeding is increasingly using strong resistance genes in combination with genes that reduce disease severity in adult plants. This strategy is effective against rusts, as their changing populations can defeat specific resistance sources. A study in 2015 reported improved stripe rust resistance from a combination of Yr78 and Yr36 in common wheat. Other programmes are adding more rust resistance genes together, using molecular breeding or biotechnology. This illustrates a concept: the strength and durability of resistance is

a function of the characteristics of the combination, not the number of genes. Relevant rust populations and growing conditions must be incorporated into the tests, as the protection detected in one environment may not be directly transferable to others.

## 10. Combining Strong and Partial Resistance

Major resistance genes can give high levels of protection, occasionally leading to no visible symptoms on specific pathogen strains. Quantitative resistance is typically conferred by multiple genomic regions, each of which has a small effect, such as reducing lesion size or pathogen reproduction. The combination of such types of resistance may allow to achieve both strong protection and a second tier of partial resistance. Should a major gene lose its effectiveness, the other components may still at least contribute to damage reduction. Nonetheless, quantitative effects may be sensitive to environment and genetic background. Breeders thus quantify disease development and retain useful background resistance rather than simply breeding for dramatic responses associated with a single major gene.

## 11. New Tools Expand Breeding Opportunities

New tools are making it easier to plan and track resistance combinations. Genome sequencing can be used to identify candidate genes, and a collection of many varieties can reveal resistance genes that are not present in a single reference genome. Speed breeding can reduce generation length in controlled environments. Genomic prediction can be used to select for complex traits using information scattered throughout the genome. Gene editing can be used to target susceptibility genes or other genes involved in

defence, but a gene edit is not necessarily equal to a validated resistance pyramid. The new tools increase breeding options, but their utility is contingent on the underlying biology, the reliability of tests, the costs of tests and breeding, and the regulatory requirements associated with each development pathway.



## 12. Field Testing Remains Essential

Beyond the laboratory, a reliable pyramid must also prove itself in the field. Breeders inoculate plants with representative pathogen strains and measure disease severity, progression of infection and crop performance. Tests at different locations and seasons show if the resistance is still effective in the face of changing weather conditions and disease pressure. Seedling tests may only miss protection expressed later, while adult plant tests may miss early plant tests. Molecular tests can verify the target combination, and tests against appropriate parent lines can show added value. Yield, maturity and product quality must also be tested. Both genetic confirmation and evaluation provide stronger evidence than either DNA results or pretty plants do when considered separately.

## 13. Protecting Yield and Market Quality

Introducing resistance can sometimes bring undesirable traits from the donor parent. Linkage drag can be a concern for traits such as maturity, plant height, yield or quality. Resistance genes may also interact with one another or impose growth penalties in certain genetic backgrounds. Such effects are potential, not certain, and can be minimized with careful breeding. Farmers require varieties that not only provide crop protection but also fit into existing production and marketing systems. Appearance, taste, shelf life and harvest period are still particularly important for vegetables. A very resistant line with low market acceptability has little value, so the performance of the entire crop is always the focus when selecting.

## 14. Benefits Farmers Can Expect

For farmers, the main benefit is more dependable disease protection built into the seed. Effective resistance may reduce crop losses and decrease the need for some disease control treatments. This can lower labour requirements, reduce exposure during spraying and improve production stability. However, savings depend on the crop, disease pressure, seed price and existing management practices. A resistant variety does not yield more when disease is absent, and it cannot protect against every production constraint. Economic evaluation should therefore compare total costs, harvest quality and returns under realistic conditions rather than assume that every additional resistance gene guarantees greater profit.

## 15. Combine Resistance with Good Management

Gene pyramiding works best within integrated disease management. Farmers should combine suitable resistant varieties with healthy planting material, crop sanitation, balanced nutrition, appropriate irrigation and locally recommended crop rotations. Monitoring remains necessary because unexpected symptoms may indicate another disease, environmental stress or a change in pathogen populations. Where treatments are justified, they should follow validated local recommendations. Reducing disease pressure supports crop health and helps protect the value of genetic resistance. Resistance is therefore a foundation for management rather than permission to neglect the field. Strong genetics and sound agronomy reinforce each other throughout the growing season and across crops.

## 16. Towards Lasting Disease Protection

Pyramiding resistance genes seems a promising strategy for achieving improved crop protection, but success in this approach implicates more than just gathering a set of resistance genes. The correct genes need to be pyramided in adapted backgrounds, challenged with relevant pathogens, and delivered through functional seed systems. Recent advances reveal growing potential to protect crops against single diseases, as well as multiple diseases. Surveillance, genetic variation and integrated management are crucial to maintaining these gains. For the farmer, the breeder and the extension worker, the practical message is simply making a multiple line of defence, test the performance of these lines and continue to improve them. Long-lasting protection results from healthy genetics and prudent management.

## CONCLUSION

Gene pyramiding provides an effective means to enhance disease resistance by assembling synergistic resistance genes in one cultivar. We hypothesise that this will be successful if careful gene selection on the basis of genetic compatibility is followed by testing in relevant pathogen populations, in different locations and in different seasons. Breeding must also maintain yield, quality and the traits that farmers and consumers want. While several resistance genes can provide more reliable protection, they cannot assure lifelong protection. Genetic survival and integration with good crop management practices to remain important for the future life of the industry. When underpinned by strong seed systems, gene pyramiding can reduce disease losses and thereby enhance the resilience of and progress towards more sustainable agriculture.