AGRI MAGAZINE
(International E-Magazine for Agricultural Articles)
Volume: 02, Issue: 10 (October, 2025)
Available online at http://www.agrimagazine.in
©Agri Magazine, ISSN: 3048-8656

Herbicide-Resistant Crops

Anand Kumar Jain, *Shaheen Naz, Suman Kalyani, Ranvir Kumar,
Beerendra Singh, Prem Chand Kumar and Uday Kumar
Bihar Agricultural University, Sabour-813210, Bihar, India
*Corresponding Author's email: shaheennaz9@gmail.com

Herbicide-resistant (HR) crops are genetically engineered plants that can tolerate specific herbicides, allowing farmers to spray the herbicide to kill weeds without harming the crop. First developed in the 1980s and commercialized in the mid-1990s, common examples include glyphosate-resistant (Roundup Ready) soybeans, corn, and cotton. These crops offer benefits like improved weed control and reduced tillage but also contribute to a growing challenge of herbicide-resistant weeds due to over-reliance on a single herbicide. Transgenic herbicide-resistant crops, also known as genetically modified herbicide-resistant crops or biotech crops, are a significant advancement in agricultural biotechnology. These crops have been genetically engineered to resist specific herbicides, enabling farmers to effectively control weeds while minimizing the negative impact on crop growth and yield. The development of transgenic herbicide-resistant crops emerged as a solution to the challenges posed by weeds in agricultural systems. Weeds compete with crops for water, nutrients, and sunlight, reducing crop productivity.

Traditional weed control methods, such as mechanical cultivation and chemical herbicides, have limitations and may have adverse environmental consequences. Transgenic herbicide-resistant crops were first introduced commercially in the 1990s and have since gained widespread adoption in several major crops, including soybeans, corn, cotton, and canola. These crops have been genetically modified by inserting specific genes that resist broad-spectrum herbicides or herbicides with particular modes of action. The most well-known example is the Roundup Ready system, developed by Monsanto (now Bayer), which introduced glyphosate herbicide tolerance in crops. This system enabled farmers to apply glyphosate-based herbicides, such as Roundup, to control weeds without causing harm to the transgenic crop. Similarly, other herbicide-resistant traits, such as glufosinate, dicamba, and 2,4-D resistance, have been incorporated into various crops to address specific weed control challenges. Developing and adopting transgenic herbicide-resistant crops have offered several benefits to farmers and the agricultural industry. These benefits include enhanced weed control, increased crop yield potential, reduced reliance on multiple herbicide applications, decreased labour and production costs, and improved efficiency in weed management. Furthermore, using herbicide-resistant crops has facilitated the adoption of conservation tillage practices, which help reduce soil erosion and improve soil health. However, deploying transgenic herbicide-resistant crops also raises concerns about environmental impact, herbicide resistance evolution, gene flow to related plant species, and potential effects on non-target organisms. Herbicide-resistant (or tolerant) crops, such as glyphosate-resistant crops are transgenic crops that are resistant to the herbicide glyphosate. Glyphosate is a broad spectrum herbicide that controls a wide range of plants and breaks down relatively quickly in the environment; it was first marketed under the trade name: Round-up. Round-up Ready soybeans were released in the US in 1996, and since then, additional glyphosate-resistant crops (corn, cotton, canola, sugarbeet, and alfalfa) have been developed and widely adopted in the US and other countries.

While India has had a moratorium on the commercial release of genetically modified (GM) herbicide-resistant crops like soybean and cotton due to biosafety concerns, it has released non-GM herbicide-tolerant (HT) rice varieties for commercial cultivation. India's first non-GM HT rice varieties, including Pusa Basmati 1979 and Pusa Basmati 1985 (RobiNOweed), were released in May 2024, and another non-GM variety, CR Dhan 807, was released earlier for non-basmati rice.

Genetically Modified (GM) crops

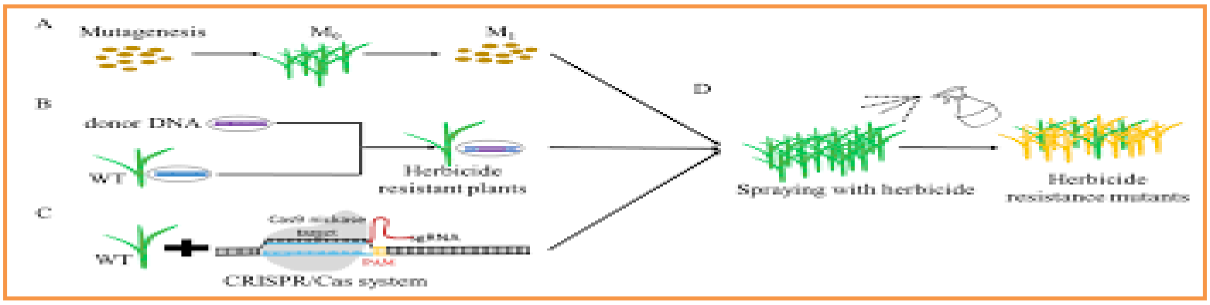
- India has not yet commercialized GM herbicide-resistant crops due to a 10-year moratorium on their release.
- This decision was made because data on biosafety issues is limited.
- Controlled trials for crops like herbicide-resistant soybean and cotton have been conducted.

Non-GM herbicide-tolerant (HT) crops

- **Pusa Basmati 1979 and Pusa Basmati 1985 (RobiNOweed):** These are non-GM, HT Basmati rice varieties developed by the Indian Agricultural Research Institute and released in May 2024.
- **CR Dhan 807:** This is a non-GM HT rice variety from the Sahbhagidhan genetic background, released for commercial cultivation in several states, including Jharkhand, Odisha, Chhattisgarh, Gujarat, Andhra Pradesh, and Tamil Nadu.
- These varieties are suitable for direct-seeded, rainfed, and zero-tillage rice cultivation methods, which can help with weed management and resource conservation.

Mechanism

Mechanisms of Herbicide Resistance in Weeds: Herbicide resistance occurs when weeds develop the ability to survive and reproduce, even when exposed to once- effective herbicides. The evolution of herbicide resistance in weeds is a complex process that involves various mechanisms, including: a. Target-site resistance: This occurs when the target site of the herbicide (such as an enzyme or protein) undergoes genetic changes, rendering it less sensitive or completely insensitive to the herbicide's action. b. Metabolic resistance: Weeds can develop enhanced metabolic pathways that detoxify or degrade the herbicide before it can have a detrimental effect. c. Reduced herbicide absorption: Weeds may develop thicker cuticles or altered cell wall structures that prevent the herbicide from entering and affecting the plant's vital tissues. d. Enhanced herbicide sequestration: Weeds can produce proteins or enzymes that bind to and sequester herbicides, reducing their availability and efficacy. e. Enhanced herbicide efflux: Weeds may develop transport proteins that actively pump herbicides out of their cells, reducing the herbicide concentration within the plant. These mechanisms can act individually or in combination, leading to varying levels of herbicide resistance in weed populations.



(Source: The Development of Herbicide Resistance Crop Plants Using CRISPR/Cas9-Mediated Gene Editing)

- **Gene Introduction:** Genes are introduced into the crop's DNA that produce a protein capable of detoxifying or breaking down the herbicide.

- **Targeted Application:** Farmers can then apply a broad-spectrum herbicide that would normally kill the crop, but because the crop contains the resistance gene, it remains unharmed while weeds that do not have the gene are killed.

Examples

- Glyphosate Resistance: Many common crops, such as soybeans, corn, and canola, have been genetically modified to resist glyphosate, a popular herbicide.
- Glufosinate Resistance: Other varieties are resistant to the herbicide glufosinate, and these are often found in corn and canola.

Benefits

- **Efficient Weed Control:** Provides farmers with an effective and flexible way to manage weeds.
- **Reduced Tillage:** Enables farmers to adopt no-till or direct seeding practices, which can improve soil health and reduce erosion.
- **Increased Adoption:** Widespread use and acceptance by farmers indicate the technology's effectiveness and commercial success.

Challenges

- **Herbicide-Resistant Weeds:** Over-intensive and prolonged use of the same herbicides, especially glyphosate, has led to the evolution of weeds that are resistant to these herbicides.
- **Need for New Solutions:** This necessitates the development of crops resistant to alternative herbicides or the integration of different weed management strategies to combat resistant weed populations.

Herbicide Resistance Management Strategies

Several strategies and best management practices have been developed to combat herbicide resistance. These strategies aim to prolong the effectiveness of herbicides and minimize the evolution and spread of resistant weed populations. Key approaches include: a. Diverse herbicide modes of action: Rotating or alternating different herbicides with distinct modes of action can reduce the selection pressure for resistance and prevent the dominance of resistant weed populations. b. Integrated weed management (IWM): Utilizing cultural, mechanical, biological, and chemical control methods can effectively manage weeds while reducing reliance on herbicides. c. Herbicide mixtures and tank mixes: Using herbicide mixtures or tank mixes that combine multiple active ingredients with different modes of action can improve weed control and reduce the likelihood of resistance development. d. Monitoring and early detection: Regular monitoring of weed populations for herbicide resistance and adopting early detection methods can help identify resistant populations before they become widespread. e. Education and awareness: Providing Education and training to farmers and agronomists on the importance of herbicide resistance management and promoting best management practices can contribute to more effective weed control and sustainable agriculture. By implementing these strategies, it is possible to slow down the development and spread of herbicide resistance and maintain the long-term efficacy of herbicides in weed management. Continuous research and monitoring are essential to adapt and refine these strategies in response to evolving resistance issues. Development of Transgenic Herbicide Resistance in Crops Herbicide-resistant crops (HRCs) are a major component of modern agricultural production systems. The first HRCs, bromoxynil-resistant cotton and glyphosate-resistant canola, were commercialized in 1995. Since then, HRCs have been developed for a wide range of crops, including soybeans, corn, cotton, alfalfa, sugarbeets, and wheat. HRCs have had a significant impact on weed management, crop yields, and environmental quality. The development of HRCs has been driven by the need for more effective and sustainable weed management practices. Herbicides are the most widely used pesticides in agriculture, and they are an essential component of integrated weed management systems. However, the use of herbicides can lead to the development of herbicide- resistant weeds. HRCs offer a way to manage herbicide-resistant weeds by providing crops with resistance to specific herbicides. HRCs have had a number of benefits for farmers. They have allowed farmers to use herbicides more effectively, which has led to increased crop yields and reduced weed pressure. HRCs have also reduced the need for tillage, which has improved soil quality and reduced greenhouse gas emissions. HRCs have also had a number of benefits for the environment. They have reduced the use of broad-spectrum herbicides, which can harm non-target organisms. HRCs have also reduced the need for tillage, which can improve water quality and reduce soil erosion. Transgenic herbicide-resistant crops are developed through genetic engineering techniques that introduce specific genes into crop plants to confer herbicide resistance. This allows farmers to effectively control weeds while minimizing the negative impact on crop growth and yield. The development process includes several key steps, as outlined below:

Genetic engineering techniques

a. Gene Isolation: The first step is to identify and isolate the gene responsible for herbicide resistance from a known resistant source, such as a naturally occurring herbicide resistant plant or a microorganism. b. Gene Cloning: Once the resistance gene is isolated, it is cloned using molecular biology techniques to obtain multiple copies of the gene for further manipulation. c. Gene Modification: Genetic modification techniques, such as site-directed mutagenesis or gene editing technologies (e.g., CRISPR-Cas9), can be employed to modify the gene to enhance its expression or optimize its function in the crop plant. d. Gene Expression Regulation: Promoters and regulatory elements are incorporated to ensure the herbicide resistance gene is expressed in the desired plant tissues and at the appropriate levels.

Strategies to Mitigate the Development and Spread of Herbicide Resistance

a. Diverse Herbicide Modes of Action: Using a diverse range of herbicides with different modes of action helps prevent or delay the emergence of herbicide-resistant weed populations. Rotating or alternating herbicides with different modes of action is essential. b. Herbicide Mixing and Sequencing: Mixing or sequencing multiple herbicides with different modes of action can provide effective control while reducing the selection pressure for resistance. c. Effective Herbicide Application: Following recommended herbicide rates, application timings, and proper spray coverage can maximize herbicide efficacy and minimize the survival and selection of resistant weed individuals. d. Integrated Weed Management (IWM): IWM combines multiple control methods, such as cultural practices (crop rotation, cover cropping), mechanical methods (tillage, hand-weeding), biological controls (biocontrol agents), and chemical controls (herbicides), to reduce reliance on herbicides and manage weed populations more sustainably. e. Monitoring and Early Detection: Regular monitoring of weed populations for herbicide resistance is crucial. Early detection of resistant individuals allows for timely intervention and the implementation of appropriate management strategies. f. Education and Awareness: Educating farmers, agronomists, and stakeholders about herbicide resistance management and promoting best practices is essential for effective resistance management.

The conclusion is that herbicide-resistant crops offer benefits like simpler weed control and reduced tillage, leading to some positive environmental effects, but they also risk the evolution of resistant weeds and the transfer of resistance genes to wild relatives. To be sustainable, these crops must be used as part of an integrated weed management (IWM) program, which includes rotating herbicides and using other methods to mitigate risks like resistance and gene flow. Herbicide-resistant crops (HRCs) in India are still in the early stages of development and evaluation, unlike their widespread use in other countries. These crops are genetically engineered to withstand herbicides, allowing farmers to spray the entire field to kill weeds without harming the crop, which can simplify weed management. While some non-transgenic (non-GM) herbicide-tolerant rice varieties have been released, major adoption of genetically modified (GM) HRCs has not occurred yet due to regulatory and evaluation stages. The adoption of GM herbicide-resistant crops faces challenges in India due to ongoing evaluation and regulatory processes. There are concerns about potential environmental impacts, and a need for integrated weed management strategies to address the evolution of herbicide-resistant weeds.