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HERBICIDE-RESISTANT CROPS

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Introduction

Herbicide-resistant crops (HRCs) mark a major breakthrough in agricultural biotechnology, as they are genetically engineered to survive applications of specific herbicides. This modification allows farmers to manage weeds more efficiently, lower labor requirements, and boost crop productivity. By incorporating genes that provide resistance to certain herbicides, these crops offer a streamlined and more sustainable solution for weed control. Glyphosate-resistant crops, for instance, are among the most widely adopted HRCs, enabling plants to withstand glyphosate—a commonly used, broad-spectrum herbicide.

This advancement has simplified weed management for many growers, though it has also sparked concerns about the emergence of herbicide-resistant weed species. Since the introduction of HRCs in the mid-1990s, weed management strategies have evolved considerably. By 2010, approximately 148 million hectares worldwide were cultivated with genetically modified crops possessing traits for herbicide, insect, drought, or salinity resistance, as well as enhanced nutritional value. Of this area, about 61% was dedicated to herbicide-resistant varieties such as soybean, maize, cotton, canola, sugar beet, and alfalfa, while 22% featured crops with combined herbicide and insect resistance traits.

History

The development of herbicide-resistant crops represents a significant milestone in the field of agricultural biotechnology, motivated by the need for more effective weed control and higher crop yields. In the late 20th century, conventional weed management techniques—such as hand weeding and the use of non-selective herbicides were often laborious and not always successful in eliminating stubborn weeds. These limitations encouraged scientists to turn to genetic engineering as a way to improve weed control by modifying crops themselves.

A major advancement occurred in the 1990s when Monsanto, a pioneer in agricultural biotechnology, launched glyphosate-resistant soybeans in 1996, marketed as Roundup Ready. Glyphosate is a widely used herbicide that targets the shikimic acid pathway, a crucial process for plant survival. Before the advent of glyphosate-resistant crops, using glyphosate on fields would harm both weeds and crops. Monsanto overcame this challenge by introducing a gene from the bacterium Agrobacterium tumefaciens into soybeans, granting them resistance to glyphosate. This innovation allowed farmers to apply glyphosate for weed control without damaging their soybean crops, revolutionizing weed management and reducing the need for manual labor in agriculture.

After the introduction of glyphosate-resistant soybeans, the technology was quickly applied to other major crops, including corn and cotton. This expansion allowed farmers growing these crops to benefit from more effective weed control and easier farm management. As a result, herbicide-resistant crops were rapidly adopted throughout the United States and other key agricultural regions, largely because of their success in improving weed management.

The early achievements with glyphosate-resistant crops fueled further developments in this area of biotechnology. By the early 2000s, new varieties resistant to different herbicides were introduced. For example, LibertyLink crops were engineered to tolerate glufosinate, providing an alternative to glyphosate and helping to reduce dependence on a single herbicide. In the years that followed, crops resistant to additional herbicides, such as dicamba and 2,4-D, became available. These innovations gave farmers more weed control options and proved especially useful in tackling weed species that had developed resistance to glyphosate.

However, the widespread use of herbicide-resistant crops also brought new challenges. Over time, the heavy reliance on glyphosate led to the rise of weed species, like Palmer amaranth and waterhemp, that could survive glyphosate applications. This forced farmers to increase herbicide use and adopt more integrated approaches to weed management.

The growth of herbicide-resistant crop cultivation has also raised environmental and regulatory concerns. Researchers and policymakers continue to examine the impacts of ongoing herbicide use on biodiversity, soil health, and broader ecosystem stability. Additionally, public opinion and regulatory policies regarding genetically modified organisms (GMOs) remain important factors influencing the future development and acceptance of herbicide-resistant crops.

Transgenic Herbicide Resistant Crops

Transgenic herbicide-resistant crops represent a major advancement in agricultural biotechnology, developed to tackle the persistent challenge of weed control. These crops are genetically modified to survive applications of certain herbicides, enabling farmers to treat entire fields with these chemicals without damaging their crops. The foundation for this technology was laid in the 1980s, but it reached a significant milestone in 1996 when Monsanto introduced glyphosate-resistant soybeans under the Roundup Ready® brand. Glyphosate, a widely used herbicide, works by blocking a crucial enzyme pathway in plants, making it highly effective against a broad range of weeds. By incorporating a gene from the bacterium Agrobacterium tumefaciens, which imparts resistance to glyphosate, scientists were able to develop crops that could withstand glyphosate treatments, greatly simplifying weed management and enhancing yields.

Following the success of glyphosate-resistant soybeans, similar genetic modifications were applied to other staple crops like corn and cotton, allowing them to tolerate glyphosate as well. This wave of innovation continued with the development of crops resistant to other herbicides, such as LibertyLink® varieties that can survive glufosinate applications, as well as crops engineered to tolerate herbicides like dicamba and 2,4-D. These new options expanded the choices available to farmers and helped address the growing problem of weeds that had evolved resistance to glyphosate. For example, the emergence of glyphosate-resistant weeds such as Palmer amaranth and waterhemp prompted the adoption of additional herbicides and integrated weed management practices.

Transgenic herbicide-resistant crops provide substantial advantages in modern agriculture. They allow for more effective weed management, reducing the dependence on manual labor and heavy machinery, which in turn lowers operational costs. These crops also support the use of conservation tillage methods, which help maintain soil structure and reduce erosion by minimizing the need to disturb the soil. The ability to safely apply herbicides over entire fields has contributed to higher yields and improved overall farm productivity.

Despite these benefits, the widespread adoption of herbicide-resistant crops has raised several concerns. One major issue is the emergence of weeds that have adapted to survive herbicide treatments, challenging the long-term effectiveness of this technology. Additionally, there are ongoing debates about the environmental consequences of extensive herbicide use, particularly regarding its potential effects on biodiversity and soil health.

Examples of non-transgenic herbicide-resistant crops, developed by traditional breeding/selection techniques

Selection method	Herbicide family	Crop	Year of disclosure
Whole plant	Triazine	Canola	1984
Microspore selection	Imidazolinone	Canola*	1989
Seed mutagenesis	Sulfonylurea	Soybean*	1987
	Imidazolinone	Wheat*	1991
	Imidazolinone	Rice*	1998
	Triazine	Wheat	2006
Pollen mutagenesis	Imidazolinone	Corn/Maize*	1992
Tissue culture	ACCase inhibitor	Corn/Maize	1992
	Imidazolinone	Corn/Maize*	1991
	Triazine	Soybean	1996
	Sulfonylurea	Canola	2002
Cell selection	Imidazolinone	Sugarbeet	1998
Transfer from weedy relative	ALS inhibitor	Sunflower*	2000
	ALS Inhibitor	Sorghum	2008
	ACCase inhibitor	Sorghum	2008

Current transgenic herbicide-resistant crops and associate trait genes

Crop	Resistance trait	Trait gene	First Sales
Alfalfa	Glyphosate	*cp4 epsps*	2005
Canola	Glyphosate	*cp4 epsps* and *goxv 247*	1996
	Glufosinate	*pat*	1995
	Bromoxynil	*bxn*	2000
Cotton	Bromoxynil	*bxn*	1995
Corn/Maize	Glyphosate	*cp4 epsps*	1996
		Two *cp4 epsps*	2006
		zm-2mepsps	2009
	Glufosinate	*bar*	2004
	Glyphosate	Three modified *cp4 epsps*	1998
		Two *cp4 epsps*	2001
	Glufosinate	*pat*	1997
	Glyphosate + glufosinate	Double stack	Not clear
Soybean	Glyphosate	*cp4 epsps*	1996
		cp4 epsps	2009
	Glufosinate	*pat*	2009
Sugarbeet	Glyphosate	*cp4 epsps*	2007

Future Herbicide-resistant Crop Technologies

Herbicide-resistant crops (HRCs) and other genetically modified crops have become a permanent fixture in modern agriculture. While these crops offer many advantages, their widespread use also brings about certain challenges some immediately noticeable, others less so. One of the most pressing concerns following the commercialization of HRCs is the development of herbicide resistance within weed populations. In response, agrochemical and seed companies have focused substantial resources on creating the next generation of HRCs, aiming to broaden crop options for farmers and address weed resistance by enabling the use of herbicides with multiple modes of action.

Many of these new HRC technologies are designed to be stacked with glyphosate resistance, and several were expected to reach the market in the early 2010s. However, the introduction of these innovations is often delayed or halted due to stringent regulatory requirements and other undisclosed factors. For instance, a novel glyphosate resistance mechanism, which was combined with another herbicide resistance trait, was withdrawn from commercialization not long after its development. Additionally, new formulations have been created specifically for crops resistant to herbicides like dicamba and 2,4-D, to be used in conjunction with these stacked traits. Another notable advancement is the use of air induction nozzles, which help minimize spray drift by producing larger droplets, particularly when applying 2,4-D and dicamba to resistant crops.