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Herbicide tolerant crops

for weed management

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Weeds are a major constraint in Indian farming, often causing greater yield losses than insects or diseases. Manual weeding is becoming less viable due to labour shortages and rising costs. Herbicide-tolerant (HT) crops provide effective, broad-spectrum weed control, reduce labour, and support resource-conserving practices like direct-seeded rice and zero-tillage. Globally, HT crop varieties in soybean, maize, cotton, and canola have delivered productivity gains but raised concerns about herbicide resistance and environmental impact. In India, non-GM imidazolinone-tolerant rice varieties (Pusa Basmati 1979, Pusa Basmati 1985, CR Dhan 807) and hybrids (SAVA 127, SAVA 134 Fullpage) are released, while HT mustard and others are under development. HT crops can cut weeding costs, boost yields, and reduce drudgery especially for women but sustainability depends on careful management. Over-reliance on one herbicide may accelerate resistance. Integrating HT crops within an integrated weed management framework and strengthening policies and extension can enhance food security and profitability.

Keywords: Challenges, Herbicide-tolerant crops, Innovation, Integrated weed management

WEEDS are among the most destructive yet underestimated threats in Indian agriculture. Unlike insects or diseases, they grow unnoticed alongside crops, competing for water, nutrients, sunlight, and space, while harbouring pests, clogging irrigation systems, and contaminating harvests with seeds. If not managed early (within the first 30–40 days after sowing) weed damage can cause permanent yield losses of 20–40% in crops like rice, wheat, maize, soybean, and cotton, and may even result in total crop failure. Traditionally, farmers relied on manual weeding, spending long hours hand-pulling weeds or using hoes and animal-drawn weeders. Selective herbicide use became common only in the late twentieth century. Today, labour shortages, rising wages, fragmented landholdings, and shifting weed populations make older methods less practical. Herbicide-tolerant (HT) crops provide a modern solution, enabling farmers to apply broad-spectrum herbicides safely to control diverse weeds efficiently, protect yields, and secure livelihoods.

Weed problems in major crops

Rice: The gradual shift towards Direct-Seeded Rice (DSR) from traditional puddled transplanted rice, aimed at saving water and labour, has triggered a weed explosion. *Echinochloa crusgalli, Echinochloa colona,* sedges like *Cyperus iria,* and broadleaf weeds such as *Eclipta alba* are important weeds in rice. Weedy rice is the most serious challenge in DSR systems. It closely resembles cultivated rice but competes aggressively, contaminating harvests and reducing grain quality.

Wheat: The notorious weed in wheat is *Phalaris minor*, a grassy weed that looks almost identical to wheat at early growth stages. Due to the repeated use of the same herbicides, it has developed resistance. Weeds like *Chenopodium album* and *Melilotus alba* are also widely reported.

Maize: In maize, weeds germinate quickly after sowing and are particularly competitive during the first 30 days. Common weeds include *Amaranthus viridis, Trianthema portulacastrum,* and grassy weeds such as *Echinochloa colona.*

Soybean: Soybean is highly sensitive to weed pressure in the early growth stages. *Parthenium hysterophorus, Euphorbia hirta,* and grassy weeds dominate fields.

Cotton: Cotton is particularly vulnerable to weeds during the first 6–8 weeks after sowing. Weeds like *Cyperus rotundus, Trianthema portulacastrum*, and several grasses compete aggressively.

Emerging challenges in weed management

Climate change is shifting weed populations,

Pusa Basmati 1985

SAVA 134 FP

favouring heat- and drought-tolerant species like *Parthenium hysterophorus.* Overuse of a few herbicides has triggered resistance, as seen in *Phalaris minor* in wheat, forcing costlier, complex mixes. Weed mimicry, such as weedy rice in DSR and *Phalaris minor* in wheat, complicates identification. Labour shortages and rising wages make manual weeding unaffordable, with weeding costs reaching 25% of total cultivation expenses. Indiscriminate herbicide use harms soil microflora, contaminates water, and threatens non-target species. Addressing these challenges requires precision herbicide use, diversified strategies, and integration with non-chemical methods for sustainable weed management.

Herbicide-tolerant crops: Science and development

Herbicide-tolerant crops are defined as genetically modified plants engineered either to reduce the sensitivity of certain enzymes to herbicides or to include pathways that detoxify herbicides, enabling them to survive specific herbicide applications without damage. HT crops provide farmers with an essential tool to combat weeds and are compatible with no-till methods, which help preserve topsoil. They give farmers the flexibility to apply herbicides only when necessary, control the total input of herbicides, and select herbicides with desirable environmental characteristics. Non-selective herbicides like glyphosate and glufosinate help broaden the range of weeds controlled, which is especially important in no-till systems and farmers sow an HT crop, when weeds emerge, they spray a broad-spectrum herbicide, and weeds die, but the crop survives unharmed. This makes weed control easier, faster and more reliable, especially during the critical early stages of crop growth.

Mechanisms of herbicide tolerance

- ***Target-site modification:*** Mutations in herbicide target enzymes prevent binding (e.g. ALS/AHAS mutation in HT rice for imidazolinone tolerance).
- ***Metabolic detoxification:*** Added genes produce enzymes that deactivate herbicides (e.g. bar/pat gene detoxifies glufosinate).
- ***Overexpression of target enzyme:*** Crops produce excess target enzymes, reducing herbicide sensitivity (e.g. CP4-EPSPS gene in glyphosate-tolerant crops).
- ***Physiological/structural traits:*** Traits like thicker cuticles, reduced absorption, or faster herbicide breakdown limit damage.

Herbicide-tolerant crop development

Conventional/Mutation breeding: Induce mutations to find tolerant plants, then cross with high-yielding varieties (e.g. Clearfield® rice). In India, CR Dhan 807, Pusa Basmati 1979, and Pusa Basmati 1985 are non-GM rice tolerant varieties to imazethapyr.

Transgenic approaches: Introduce foreign genes for tolerance (e.g. CP4-EPSPS for glyphosate, bar/pat for glufosinate, DMO for dicamba). Widely adopted in the USA, Brazil, and Canada.

Genome editing (CRISPR-Cas9): Precisely edits

MTU 1010 Imazethapyr sprayed

CRR Dhan 807

Sava 127 FP hybrid rice


Pusa Basmati 1979

DNA without adding foreign genes (e.g. ALS gene editing for imidazolinone-tolerant rice or wheat). Faster, precise, and less controversial than transgenics.

Global adoption of HT crops

HT crops are widely adopted worldwide. Over 90% of U.S. soybean and maize, nearly all Brazilian soybean and cotton, and most Canadian canola are HT. In Asia, countries like Vietnam, the Philippines, and India grow HT rice. Their global success shows HT crops significantly cut weeding costs and labour while boosting productivity.

Table 1. Major herbicide-tolerant crop systems

Crop	Herbicide	Mode of action	Benefit	Concern
Soybean, maize, cotton, canola	Glyphosate	Inhibits EPSPS enzyme	Effective, broad-spectrum and relatively safe herbicide	Overuse has led to glyphosate-resistant weeds (e.g. *Amaranthus palmeri)*
Canola, maize, soybean, cotton	Glufosinate	Inhibit glutamine synthase enzyme in plant	Effective against glyphosate-resistant weeds	Slightly more expensive; requires precise application
Rice, maize, wheat, sunflower	Imidazolinone	InhibitALS/ AHAS enzyme	Non-GM, accepted in many countries	Rapid development of resistant weeds if misused
Soybean, cotton	Dicamba and 2,4-D	Synthetic auxin	Effective on broadleaf weeds resistant to glyphosate	Risk of herbicide drift damaging sensitive crops

Advantages of non-GM HT crops for India

India remains cautious about GM crops. Non-GM HT varieties like Pusa Basmati 1979, Pusa Basmati 1985, and CR Dhan 807 rice offer a safer entry as they avoid regulatory and export hurdles, can be bred conventionally or via mutation, and are more acceptable to farmers and consumers.

Why HT crops must be used with stewardship?

HT crops are valuable but not fool proof. Over-reliance on one herbicide can cause resistance, as seen with weedy rice in Clearfield® systems, a real risk for India's direct-seeded rice and wheat. Stewardship is vital, it rotate herbicides with different modes of action, avoid continuous use, integrate cultural methods like stale seedbeds, crop rotation, mulching, and mechanical weeding, and educate farmers through Krishi Vigyan Kendras and Farmer Producer Organizations.

Global experience

Herbicide-tolerant crops' three-decade history offers India both promise and caution.

- ***USA:*** >90% of soybean, maize, and cotton are HT, boosting yields and no-till farming. Overuse of glyphosate bred resistant weeds (*Amaranthus palmeri*), prompting costly mixtures and tillage, showing the need for herbicide rotation and IWM.
- ***Brazil:*** Nearly all soybean is HT, lowering costs but causing resistant weeds *(Conyza, Digitaria)*.
- ***Canada:*** 95% HT canola success stems from multiple HT systems and strong stewardship.
- ***Asia:*** Clearfield® rice controls weedy rice but bred resistant strains, thus rotation is vital.
- ***U.S. Dicamba drift:*** Off-target damage caused disputes, spray management matters.
- ***Australia:*** Integrated strategies slowed resistance development.

HT crops bring major gains (weed control, yield and labour) but need multiple systems, farmer education, regulation, drift control, and IWM for long-term sustainability.

Current status of herbicide-tolerant crops in India

India, a major agrarian economy, remains cautious with HT-crops, unlike the U.S. or Brazil where HT crops dominate. Labour shortages, water stress, and rising weed resistance are driving renewed interest.

- ***Officially released HT crops:*** Non-GM HT rice is the only approved HT crop, like Pusa Basmati 1979, Pusa Basmati 1985, and CR Dhan 807 tolerate imazethapyr, reflecting India's preference for non-GM options.
- ***HT mustard (DMH-11):*** A GM mustard hybrid tolerant to glufosinate, approved by GEAC in 2022, faces legal challenges. A 2024 Supreme Court split verdict directed creation of a national GM policy, leaving its future uncertain.
- ***HT cotton:*** Unapproved HT *Bt* cotton is grown illegally in several states. Farmers adopt it for easy weeding despite quality and legal risks,

underscoring demand for HT solutions and regulatory delays pushing grey-market adoption.

- ***Policy and regulatory framework:*** India's regulation of HT crops is cautious. Non-GM varieties like CR Dhan 807 and Pusa Basmati 1979/1985 face fewer hurdles, while GM HT crops encounter opposition over biosafety, biodiversity, and trade. In 2022, glyphosate use was restricted to licensed Pest Control Operators, limiting farmer access. This reflects a precautionary approach balancing HT crop potential with environmental and social concerns.
- ***Role of research institutions:*** ICAR, SAUs, and the seed industry are progressing with HT crop research. ICAR-CRRI released CR Dhan 807 for direct-seeded rice; ICAR-IARI released Pusa Basmati 1979 and 1985; Delhi University developed GM mustard hybrid DMH-11; SAUs are developing HT maize and soybean and are currently under trials. The Seed Industry (SAVANNAH Seeds) released SAVA 127 and SAVA 134 with Fullpage technology; others are working on developing HT varieties.This reflects India's dual approach: Non-GM HT crops for faster adoption and GM/genome-edited crops for long-term innovation.
- ***Farmer demand for HT crops:*** Farmer behaviour clearly shows strong demand for HT technology, as labour shortages and high weeding costs make HT crops attractive. Farmers growing cotton, rice, and soybean are especially keen on HT options, and many have even self-adopted illegal HT Bt cotton despite regulatory risks, proving that practicality often outweighs policy restrictions.
- ***Opportunities and risks for India:*** HT rice can boost DSR by saving water and labour; HT mustard may cut edible oil imports through higher yields; HT cotton and soybean can reduce labour needs and costs are some opportunities. While overuse of single herbicides may cause resistant weeds, environmental issues like drift and soil residue, public resistance to GM crops, and legal risks for unapproved HT crop cultivation are possible risks.
- ***Integrated weed management with HT Crops:*** India must avoid past global mistakes of rapid herbicide resistance. HT crops should be integrated into IWM, using crop and herbicide rotation, stale seedbeds, mechanical and cultural controls, and farmer training via KVKs and FPOs to ensure sustainable weed management.

Benefits of herbicide-tolerant crops for farmers

- ***Labour savings:*** 10–15 days/ha, reducing dependence on scarce workers.
- ***Cost reduction:*** Weeding costs drop from ₹ 4,000–6,000/ha to ₹ 800–1,200/ha.
- ***Timely, broad-spectrum control:*** Protects crops during the critical 30–40 days after sowing.
- ***Reduced crop injury and higher yields:*** CR Dhan 807 showed 15–20% yield gains under DSR.
- ***Supports conservation agriculture:*** Enables zero-tillage and residue retention.
- ***Smallholder flexibility:*** Backpack sprayers suffice.
- ***Low soil residue:*** Glyphosate and glufosinate minimize carry-over.
- ***Gender benefits:*** Lessens women's weeding drudgery.
- ***Higher incomes:*** Adds ₹ 5,000–8,000/ha for cotton and rice farmers.

Risks, concerns, and stewardship needs

- ***Herbicide resistance:*** Possible in HT rice if imazethapyr is overused.
- ***Gene flow:*** Tolerance genes may spread to wild relatives or conventional crops.
- ***Environmental impacts:*** Soil health, biodiversity, and water contamination concerns.
- ***Spray drift:*** A concern for fragmented farms.
- ***Increased herbicide use:*** Resistance may require higher doses or multiple herbicides.
- ***Legal risks:*** Only Pusa Basmati 1979, 1985, CR Dhan 807, SAVA 127, and SAVA 134 FP are approved (as of July 2025).
- ***Awareness gaps:*** Misuse of doses, timing, and safety gear.
- ***Socio-economic issues:*** Dependence on seed firms and unequal benefits.
- ***Shared responsibility:*** Requires stewardship by all stakeholders.

Future prospects and recommendations

- ***Expand HT rice:*** Develop region-specific and basmati lines.
- ***Strengthen mustard research:*** Use transparent communication to build trust.
- ***Explore HT soybean and maize:*** Suitable for central India and mechanized farming.
- ***Ensure legal seed systems:*** Prevent illegal, poor-quality seeds.
- ***Promote IWM:*** Rotate crops/herbicides, use mixtures, manage volunteers, and integrate mechanical methods.
- ***Farmer training:*** Use KVKs, FPOs, and digital platforms.
- ***Policy clarity:*** Adopt science-based, transparent regulations balancing innovation and safety.

SUMMARY

Weeds silently threaten Indian agriculture, while HT crops provide modern solutions to reduce labour, cut costs, and boost yields. However, misuse can lead to resistant weeds, environmental problems, and social conflicts. The success of HT crops in India depends on responsible stewardship, integration into weed control strategies, effective regulation, and farmer awareness. When combined with water-saving practices like DSR and conservation agriculture, HT crops can lessen drudgery, increase profitability, and enhance long-term food and nutritional security especially under supportive policies and comprehensive extension services.

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