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Herbicide-Resistant Weeds in India

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SUMMARY

Indian agriculture is currently facing multifaceted challenges arising from climate variability, increasing frequency of extreme weather events, and escalating biotic stresses, among which weeds remain one of the most persistent constraints to crop productivity. The widespread adoption of herbicides since the mid-20th century has significantly transformed weed management by providing effective, economical, and labor-saving solutions. However, prolonged and indiscriminate use of herbicides, particularly those with similar modes of action, has led to the rapid evolution of herbicide-resistant weed populations across diverse agro-ecosystems in India. Herbicide resistance has emerged through both target-site resistance and non-target-site resistance mechanisms, enabling weeds to survive formerly effective chemical controls. Climate change further aggravates this issue by modifying weed physiology, growth dynamics, herbicide behavior, and resistance fitness costs under elevated CO_2 and temperature regimes. Shifts in weed flora, increased dominance of previously minor species, and rising chemical dependency are already evident, posing serious risks to crop yields, production costs, and environmental sustainability. This article synthesizes the current status of herbicide-resistant weeds in India, examines their resistance mechanisms and interactions with changing climatic conditions, and highlights the implications for sustainable crop production. Emphasis is placed on the urgent need for integrated, climate-smart weed management strategies to mitigate resistance evolution and ensure long-term food and nutritional security.

INTRODUCTION

Indian agriculture today stands at a crossroads, challenged by climatic uncertainties and an increasing frequency of extreme weather events that threaten both productivity and long-term sustainability (Negi et al., 2024). Amid these challenges, weeds continue to remain one of the most persistent and damaging biotic stresses affecting crop yields across the country. Competing vigorously with crops for essential resources such as sunlight, water, nutrients, and space, weeds are responsible for substantial yield losses every year (Sreekanth et al., 2023; Roy et al., 2022; Pawar et al., 2022). As a result, effective weed management has become indispensable for ensuring food security and maintaining agricultural profitability (Chander et al., 2023; Chetan et al., 2022). For many decades, Indian farmers relied on conventional practices such as hand weeding, crop rotation, and the use of cover crops to manage weed infestations. The introduction of herbicides in the mid-20th century revolutionized these practices by offering a quick, effective, and labor-saving method of weed control. Herbicides soon became the most preferred weed management tool due to their efficacy and cost-effectiveness, greatly contributing to the enhancement of crop productivity and the reduction of labor costs. However, this reliance on chemical weed control has also brought unintended consequences. The repeated, widespread, and often unregulated use of herbicides especially those sharing similar modes of action has led to the emergence of herbicide-resistant weed species in many agricultural regions.

Herbicide resistance in weeds has rapidly evolved into a serious challenge for global agriculture, and India is no exception. Resistant weed populations develop through mechanisms such as Target-Site Resistance (TSR), where genetic mutations alter the herbicide-binding site, and Non-Target-Site Resistance (NTSR), in which weeds enhance their metabolic pathways to break down herbicides before they become effective. These adaptive mechanisms enable resistant weeds to survive herbicide applications that once controlled them efficiently, resulting in reduced crop yields, higher production costs, and increased use of chemical inputs. The problem is compounded by the rapid spread of resistance traits through seed dispersal, pollen flow, and the natural adaptability of weed species. Climate change is further intensifying this challenge. Elevated CO_2 concentrations and rising temperatures are altering the molecular, physiological, and biochemical responses of many weeds (Roy et al., 2023; Sreekanth et al., 2025b; Sreekanth et al., 2025c). Climatic factors such as temperature, humidity, precipitation, soil moisture, and wind speed can significantly influence herbicide absorption, movement within

plants, and overall efficacy (Sreekanth et al., 2025a; Sreekanth et al., 2024a). At the same time, herbicide-resistant weeds often show fitness penalties such as reduced seed production, lower germination, or altered dormancy patterns which might otherwise limit their spread (Vila-Aiub, 2019; Pasala et al., 2025). However, ongoing climate variability may alter these fitness costs, allowing resistant biotypes to survive and proliferate even in adverse conditions (Basavaraj et al., 2025; Sreekanth et al., 2024b). As climatic conditions continue to change, the evolutionary trajectories of herbicide resistance may shift in unpredictable ways, further complicating weed management strategies.

Across India, noticeable shifts in weed flora have already been observed in recent decades (Naidu et al., 2024; Sondhia et al., 2024). Weeds traditionally considered minor threats are emerging as dominant competitors in various cropping systems. The increasing incidence of herbicide-resistant biotypes is forcing farmers to apply higher herbicide doses or use combinations of chemicals many of which persist longer in the environment and pose risks to soil health, water resources, and biodiversity. This escalating chemical dependency raises concerns about environmental sustainability and the long-term viability of herbicide-based weed control.

The rise of herbicide-resistant weeds has far-reaching implications for Indian agriculture. It threatens crop yields, increases production costs, and jeopardizes the nation's goal of achieving sustainable food and nutritional security. If left unchecked, resistant weeds could severely impact the productivity of staple crops such as rice and wheat, which form the backbone of the country's food system. Addressing this challenge requires a shift toward integrated, climate-smart weed management strategies that combine cultural, mechanical, biological, and chemical approaches in a balanced manner. Understanding how weeds respond under elevated CO_2 and temperature conditions is essential for designing future-ready weed management plans (Sreekanth et al., 2024; Laxman et al., 2024). Strengthening research on weed ecology, resistance mechanisms, and climate interactions will play a crucial role in developing sustainable solutions. Equally important is the need to promote farmer awareness, encourage responsible herbicide use, and adopt diversified agricultural practices that reduce the selection pressure for resistance.

In conclusion, herbicide-resistant weeds represent an emerging and formidable threat to India's agricultural landscape. In the face of rapid climate change, their impact is expected to grow unless proactive measures are taken. Building resilient cropping systems through integrated and scientifically informed weed management strategies is vital for safeguarding India's food production systems and ensuring a sustainable agricultural future. The major herbicide-resistant weed species identified across India are as follows (Table 1).

Table 1. Reported cases of herbicide resistance in major weed species in India

Weed species	**Herbicide group**	**Specific herbicides involved**	**Year first reported**	**Location**	**Crop**	**References**
Phalaris minor	PS II inhibitors	-	1991	Haryana (wheat fields)	wheat	Heap (2023)
Phalaris minor	ACCase inhibitors	-	1994	Haryana	wheat	Heap (2023)
Phalaris minor	PS II inhibitors (phenyl ureas)	Isoproturon (resistance due to overuse of chlortoluron, isoproturon, methabenzthiauron, metoxuron)	1995	Haryana	wheat	Malik & Singh (1995)
Phalaris minor	ACCase inhibitors (FOP/DEN)	Clodinafop, fenoxaprop, pinoxaden, tralkoxydim	Early 2000s (established by 2006)	Haryana & NW India	wheat	Bhullar et al. (2017); Rao et al. (2020)
Phalaris minor	ALS inhibitors	Sulfosulfuron	2006	Haryana	wheat	Rao et al. (2020)
Avena ludoviciana	ACCase inhibitors	Clodinafop	-	Haryana	wheat	

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Rumex dentatus L.	ALS inhibitors	-	2017	NW India	wheat	Chhokar et al. (2017)
Polypogon monspeliensis L. Desf.	ALS inhibitors	-	2017	NW India	wheat	Chhokar et al. (2017)
Chenopodium album L.	ALS inhibitors	Metsulfuron	2017	North India	wheat	Bhullar et al. (2017)
Cyperus difformis L. (smallflower umbrella sedge)	ALS inhibitors	Bispyribac-sodium	2021	Chhattisgarh & Kerala	Rice	Choudhary et al. (2021)
Echinochloa crus-galli	ALS inhibitors	Bispyribac-sodium	-	-	Rice	ICAR-DWR, 2017–18
Echinochloa colona (L.) Link	ALS inhibitor	imazethapyr	-	-	soybean	ICAR-DWR, 2017–18; Chander et al., 2019
Commelina communis	ALS inhibitor	imazethapyr	-	-	soybean	ICAR-DWR, 2017–18; Chander et al., 2019

CONCLUSION

Herbicide-resistant weeds have emerged as a critical and growing threat to Indian agriculture, undermining the effectiveness of chemical weed control and challenging the sustainability of current production systems. The combined pressures of repeated herbicide use, limited diversification of weed management practices, and accelerating climate change have created favorable conditions for the evolution and spread of resistant weed biotypes. Altered temperature and CO_2 regimes are likely to further influence herbicide efficacy, weed competitiveness, and resistance fitness, making future weed management increasingly complex and unpredictable. Continued reliance on herbicides alone is neither environmentally sustainable nor agronomically viable. Addressing herbicide resistance in India requires a paradigm shift toward integrated, diversified, and climate-resilient weed management approaches that judiciously combine cultural, mechanical, biological, and chemical tools. Strengthening research on weed ecology, resistance mechanisms, and climate–weed–herbicide interactions is essential for developing adaptive and region-specific management strategies. Equally important are policy support, farmer education, and stewardship programs that promote responsible herbicide use and reduce selection pressure for resistance. Proactive and scientifically informed interventions are imperative to safeguard crop productivity, protect natural resources, and ensure the long-term sustainability of India's agricultural and food systems.

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