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Integrated Weed Management in Wheat

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Wheat is a major food-security crop and an important component of the rice–wheat production system of north-western India. Despite substantial improvements in wheat productivity through improved varieties, irrigation, fertilization, mechanization and weed control, weeds continue to be a major constraint to sustainable wheat production. Globally, weeds are estimated to cause greater yield losses than animal pests and pathogens, while in India, wheat yield losses associated with weeds have been estimated at 16-40%. The magnitude of loss varies with weed species, infestation level, crop management and environmental conditions. Among the diverse weed flora of wheat, littleseed canarygrass (*Phalaris minor* Retz.) is one of the most important and competitive weeds in the north-western Indo-Gangetic Plains. Its close morphological similarity to wheat during early growth makes it difficult to distinguish and control selectively. Its ability to emerge in several flushes, tolerate anaerobic conditions during the rice phase and shed seeds before wheat harvest further favours its persistence in the rice–wheat system. Other important weeds include wild oat (*Avena ludoviciana*), *Rumex dentatus*, *Chenopodium album* and other broadleaf species. Therefore, sustainable weed management must address the entire weed spectrum rather than focusing exclusively on a single weed species.

Herbicide Resistance: A Major Challenge

Herbicides have played an important role in improving the efficiency and profitability of wheat production, particularly under conservation agriculture and large-scale mechanized farming. However, their repeated and intensive use has placed considerable selection pressure on weed populations. Multiple herbicide resistance in *P. minor* against PS-II, ACCase and ALS/AHAS inhibitors has become a serious concern in Indian wheat production. The development of resistance has been associated with several interacting factors, including continuous rice–wheat monocropping, repeated use of herbicides with similar modes of action, inappropriate application rates, delayed spraying, intensive tillage, rice residue burning and delayed wheat sowing. Consequently, increasing herbicide rates or repeatedly using the same herbicide is not a sustainable solution. Instead, herbicides with different modes of action should be used judiciously in rotation, sequence or mixture, depending on the resistance status and weed spectrum of the field. Alternative herbicides such as pyroxasulfone, aclonifen, pendimethalin, flufenacet, flumioxazin, and bixlozone available as potential options for managing multiple herbicide-resistant *P. minor* populations. However, these herbicides should be integrated with non-chemical practices rather than being considered stand-alone solutions.

Integrated Weed Management

Sustainable weed management requires an integrated weed management (IWM) approach that combines preventive, cultural, mechanical and chemical tactics. The fundamental objective should be to prevent weeds from establishing, reproducing and replenishing the soil seed bank while maintaining weed populations below economically damaging levels. Timely wheat sowing is one of the simplest and most effective cultural practices. Delayed sowing can favour *P. minor* and other winter-season weeds and reduce the competitive ability of wheat. Advance sowing enables the crop to establish rapidly and develop a competitive canopy before weeds become dominant. Similarly, a higher seed rate and narrow row spacing of approximately 18 cm can increase crop competitiveness and suppress weed growth by improving canopy development and reducing light penetration to the soil surface. The use of competitive wheat cultivars is another important component of IWM. Cultivars with rapid early growth and strong competitive ability can suppress weeds and reduce seed production. Selection of suitable cultivars should therefore be considered alongside herbicide choice, particularly in fields with a history of herbicide-resistant weeds.

Stale Seedbed and Conservation Agriculture

A stale seedbed can help reduce the initial population of weeds by encouraging weed seeds to germinate before wheat sowing, followed by destruction of emerged seedlings. This practice can be particularly useful when combined with timely sowing and other cultural measures. Conservation tillage and residue management also have an important role in sustainable wheat production. Proper management of rice residues can modify the soil microenvironment and suppress weed emergence while contributing to soil organic matter and resource conservation. In contrast, rice residue burning can contribute to selection pressure and environmental problems and should be avoided. Conservation agriculture, therefore, should be accompanied by a carefully designed weed management programme rather than being viewed as a weed-control method by itself.

Judicious and Strategic Herbicide Use

Herbicides will remain an essential component of wheat weed management, but their use must become more strategic. Pre-emergence herbicides can provide early-season suppression and reduce the weed population before severe crop–weed competition develops. Post-emergence herbicides can subsequently target weeds that escape early control. However, the choice of herbicide should be based on the weed spectrum, resistance status, application timing and crop growth stage. Rotation of herbicides with different modes of action is essential to reduce selection pressure. Effective herbicide mixtures or sequential programmes involving different modes of action can provide broader and more consistent weed control than repeated application of a single herbicide. The use of alternative herbicides such as pyroxasulfone can be particularly valuable for managing populations resistant to commonly used herbicide groups (Table 1). Correct application technology is equally important. Poor spray coverage, incorrect water volume, over- or under-dosing and delayed application can reduce weed control and increase selection pressure for resistance. Farmers should therefore follow recommended doses, spray at the appropriate weed growth stage and calibrate spraying equipment regularly (see Table 1).

Crop Rotation and Diversification

Crop rotation is an important but often underutilized tool for sustainable weed management. Continuous rice–wheat cultivation provides weeds such as *P. minor* with a relatively predictable production environment and allows repeated selection by similar herbicide programmes. Diversification of crop sequences can alter crop establishment methods, planting dates, tillage operations and herbicide use patterns, thereby disrupting weed life cycles. Rotations involving crops with different sowing windows and weed management requirements can reduce the dominance of problem weeds and provide opportunities to use alternative herbicide modes of action. Thus, crop diversification should be considered an important component of long-term herbicide-resistance management.

Monitoring and Prevention of Weed Seed Production

Regular field scouting is essential for identifying changes in weed populations and detecting suspected herbicide resistance at an early stage. Farmers should pay particular attention to patches where weeds survive an otherwise effective herbicide application. Such patches should be managed before weeds produce seed to prevent the spread and enrichment of resistant populations.

The use of weed-seed-free crop seed is another simple preventive measure recommended for sustainable management. Preventing the introduction of weed seeds into clean fields is considerably easier and less expensive than attempting to eradicate an established weed population.

Towards Sustainable Wheat Production

The future of weed management in wheat should move from a reactive approach-controlling weeds only after they have emerged-to a proactive system that prevents weed establishment and reduces the weed seed bank. Sustainable management will require the simultaneous use of competitive crop establishment, timely sowing, narrow row spacing, higher seed rate, stale seedbed, conservation tillage, residue management, crop rotation and diversified herbicide programmes.

The integration of these practices is particularly important for managing multiple herbicide-resistant *P. minor*. Herbicide rotation or mixtures alone may provide short-term control, but their long-term effectiveness will depend on reducing the selection pressure through complementary non-chemical practices. The studies emphasize that alternative herbicides should be used in rotation, sequence or mixture together with crop rotation, competitive cultivars, higher seed rate, narrow row spacing, stale seedbed, advance sowing, conservation tillage and weed-free seed.

Conclusion

Sustainable weed management in wheat requires a diversified and integrated strategy rather than dependence on herbicides alone. In the rice–wheat system of north-western India, the increasing prevalence of multiple herbicide-resistant *Phalaris minor* highlights the limitations of repeated herbicide use and the urgent need for integrated approaches. Timely sowing, competitive cultivars, higher seed rate, narrow row spacing, stale seedbed, conservation tillage, crop rotation, residue management and weed-free seed should be integrated with judicious herbicide rotation, mixtures and sequential applications. Such diversification can improve weed control, prolong the effectiveness of available herbicides, reduce weed seed-bank replenishment and enhance the resilience and sustainability of wheat-based production systems.

Table 1. Herbicides for weed management in wheat

Type of weed flora	Herbicide	Dose product (g or ml/ acre)	Time of application
Mixed flora	Sulfosulfuron 75% + Metsulfuron 5%	16	Post emergence
Phalaris minor and wild oat	Clodinafop 15 WP	160	Post emergence
	Sulfosulfuron 75 WG	13	Post emergence
Resistant *Phalaris minor*	Pyroxasulfone 85 WG	60	Pre-emergence
Resistant *Phalaris minor* + mixed flora	Pyroxasulfone 85 WG + Pendimethalin 30 EC	60+ 1300	Pre-emergence
	Metribuzin 42% + clodinafop propargyl 12% WG	200	Post emergence
Phalaris minor	Pinoxaden 5.1 EC	400	Post emergence
Broad leaf weeds	Metsulfuron methyl 20 WP	8	Post emergence
Broad leaf weeds including *Medicago*, *Vicia*, *Lathyrus*, *Physalis*	Carfentrazone ethyl 40 DF	20	Post emergence
Broad leaf weeds including Medicago, Vicia, Lathyrus, Physalis	Metsulfuron 10% + Carfentrazone 40%	20	Post emergence
Broad leaf weeds	2,4-D sodium (80 WP), ester (38 EC), and amine (58 SL) salts	400-600	Post emergence

* *Avoid succeeding crops like maize or sorghum*

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