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REVIEW ARTICLE

Current Trends in Weed Management for Sustainable Wheat Cultivation-A Review

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ABSTRACT
Wheat is a staple crop worldwide, having its production in India continuous growth from 11 million to 112.7 million tons from 1960 to 2022-23 respectively. This increase can largely be attributed to the adoption of high-yielding varieties, fertilizers, and herbicides. However, the high nutrient and water demands of these varieties, coupled with their limited competitive ability, have resulted in increased weed infestations. Weeds are a significant threat to wheat productivity, accounting for up to one-third of all pest-related crop losses, and can reduce yields substantially if not managed effectively. The adoption of various weed control methods, including manual, cultural, biological, and chemical approaches, has been explored. While manual weeding remains effective, its high labour costs and inefficiency on large-scale farms make it less feasible. Chemical herbicides have become widely used due to their efficiency, but the prolonged use of herbicides has led to herbicide-resistant weed populations. Biological control offers a sustainable alternative by using natural predators or pathogens to suppress weeds, although it requires time and careful management to avoid unintended consequences. Integrated Weed Management (IWM) presents a promising solution, combining chemical, biological, mechanical, and cultural practices to manage weeds sustainably and mitigate the risk of herbicide resistance. This review highlights the current trends and challenges in weed management for wheat cultivation, emphasizing the importance of IWM in ensuring sustainable wheat production. The paper underscores the need for continuous research into innovative weed management strategies to safeguard wheat yields and environmental health.
Keywords: *Wheat, Weed Management, Integrated Weed Management (IWM), Herbicides, Biological Control, Sustainability.*

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INTRODUCTION

Wheat is a crucial crop both globally and in India, with production increasing significantly from 11 million tons in 1960-61 to 112.7 million tons in 2022-23. This dramatic growth, over eight times higher, is largely due to the introduction of short-stature, high-yielding varieties, as well as greater use of fertilizers, irrigation, and herbicides. However, these high-yielding varieties have higher nutrient and water requirements and are less competitive, leading to favourable conditions for weed growth.

Weeds are a significant obstacle to crop production, responsible for nearly one-third of the total losses caused by all types of pests [24]. They compete with crops for critical resources like nutrients, sunlight, and water, with this competition beginning early in the crop's growth stages. The level of weed density is a key factor in reducing crop yields [31]. In wheat, prolonged competition with high weed densities greatly lowers yields [33]. Among various biotic factors, including nematodes, insects, and other pests, weeds are one of the most economically impactful contributors to yield losses [34]. Their effect on wheat yields is even more severe than the damage caused by pests and diseases [32].

There were several methods for controlling weeds that have been explored, with manual eradication consistently proving superior for the management of weed population. This method has not become widely popular among wheat farmers because it is time-consuming, labour-intensive, and expensive.

Moreover, the lack of available labour during peak demand periods often makes it impractical [26]; [37]; [28]. Since timely weeding is essential to reduce yield losses, chemical weed control has emerged as the most effective alternative in such situations [4]. In modern farming, the use of chemical herbicides has grown significantly due to their proven ability to eliminate weeds efficiently [22].
Chemical weed management has proven to be as effective as manual eradication in various crops, offering additional advantages by reducing labour costs associated with manual weeding. In wheat cultivation, several pre- and post-emergence herbicides have become integral to crop management practices. However, the prolonged and continuous use of certain herbicides poses the risk of herbicide resistance developing in weeds over time [17]. Therefore, it is essential to evaluate herbicide-based weed management strategies to ensure sustainable and effective weed control in wheat.

WEED FLORA DENSITY AND DIVERSITY

The types of weeds found in crops can vary greatly between regions and fields due to factors such as climate, irrigation methods, fertilizer use, soil characteristics, weed management practices, and crop rotation patterns [35]. The main weed species commonly associated with wheat crops are listed in Table 1.

Table no. 1: Weed flora associated with the wheat crop.

Type of Weed	Scientific Name	Classification
Bind weed	*Convolvulus arvensis* L.	Broadleaf
Black grass	*Alopecurus myosuroides*Huds.	Grassy
Spiny amaranth	*Amaranthus spinosus* L.	Broadleaf
Ryegrass	*Lolium multiflorum* L.	Grassy
Sleeping beauty	*Oxalis corniculata* L.	Broadleaf
Black nightshade	*Solanum nigrum* L.	Broadleaf
Southern crab grass	*Digitaria ciliaris* L.	Grassy
Frog fruit	*Phyla nodiflora* L.	Broadleaf
Wild mustard	*Sinapis arvensis* L.	Broadleaf
Lawn grass	*Cynodondactylon* L.	Grassy
False daisy	*Emilia sonchifolia* L.	Broadleaf
Common vetch	*Vicia sativa* L.	Broadleaf
Canada thistle	*Cirsium arvense* (L.) Scop.	Broadleaf
Knot weed	*Polygonum plebeium* L.	Broadleaf
Canary grass	*Phalaris brachystachys* Link.	Grassy
Wild oat	*Avena sterilis* L.	Grassy
Meal weed	*Melilotus alba* L.	Broadleaf
Shortawn foxtail	*Alopecurus aequalis* L.	Grassy
Yellow pea	*Lathyrus aphaca* L.	Broadleaf
Cannabis	*Cannabis sativa* L.	Broadleaf
Fineleaf fumitory	*Fumaria parviflora* L.	Broadleaf
Dwarf copperleaf	*Alternanthera sessilis* L.	Broadleaf
Catchweed bedstraw	*Galiumtricornutum* L.	Broadleaf
Sweet clover	*Chenopodium album* L.	Broadleaf
Bluegrass	*Poa annua* L.	Grassy
White clover	*Trifolium repens* L.	Broadleaf

Source: [15], [30].

Common weeds in wheat fields. Bacterial Practices in Agriculture. pp. 311-332.

The longer the period of competition with weeds, the greater the decrease in crop yield, meaning that extended competition leads to a significant reduction in yield. In the early stages of crop growth, weed competition can harm yield [5]. Annual wheat yield losses due to weed infestations have been reported in the billions. Therefore, effective weed management is essential for achieving better economic returns [21]. Severe weed infestation is a key factor in the decline of wheat yields. Studies have shown that weeds cause yield losses of 5% in commercial agriculture, 10% in semi-commercial agriculture, 20% in subsistence agriculture (Choudhury and Singh, 2015), and 37-79% in dryland agriculture [38].The critical period for weed competition occurs between 30 and 60 days after sowing, and beyond this period, it becomes economically unfeasible to remove weeds from the field [2];[20]. Various weed control methods, such as biological, cultural, mechanical, and chemical approaches, can be used. To maximize crop yield, it is crucial to select an effective and environmentally safe weed management method [3]. While hand weeding is a traditional practice, it faces challenges due to strong weed competition, which results in lower wheat productivity. For this reason, chemical weed control is considered more efficient, cost-effective, and practical in managing diverse weed species in wheat crops [10].

LOSSES CAUSED BY WEEDS

Weed infestations in wheat crops can cause significant yield losses, ranging from 20% to 100% [25]; [27]. [40] found that a season-long infestation of *Melilotus* spp. reduced wheat yields by 29.1% compared to weed-free plots. The greatest yield losses were attributed to complex weed infestations (48%), followed by grassy weeds (30%) and broad-leaved weeds (24%) in wheat [19]. [12] and [36] reported that allowing weeds to remain in the field for the entire season resulted in reductions of 38.0% and 58.3% in wheat yields, respectively. Across various regions in India, average yield losses due to weeds ranged from 20% to 32% [27]. The northern hills, northeastern plains, and northwestern plains zones experience higher yield losses from weed infestations compared to the central and peninsular zones. According to [11], weeds cause the second-highest economic losses in wheat, after rice, and they estimated that actual and potential yield losses due to weeds were 18.6% and 30.3%, respectively.

WEED MANAGEMENT STRATEGIES IN WHEAT CROP

A. Manual Weed Control

Manual weed control (Table no. 2), often referred to as mechanical weed control, involves the physical removal of weeds from fields using either hand techniques or simple tools. This approach includes practices such as hand-pulling, hoeing, ploughing, and mowing [42]. As one of the oldest methods of weed control, dating back to the dawn of agriculture, manual control offers several advantages. It is straightforward, requires no specialized knowledge, is cost-effective for small farms, and poses no risks to the environment or human health. Additionally, it can be particularly effective for perennial weeds by disrupting their underground structures [6]. However, this method has significant drawbacks. It is labour-intensive, time-consuming, and often impractical for large-scale operations. Furthermore, manual weed control may disturb the soil, leading to erosion and the exposure of additional weed seeds from the soil seed bank [16].

Table no. 2: Effects of manual weed management on wheat crops

Manual Weed Management Practice	Effect on Wheat Crop
Hand Weeding	Provides effective control of weeds, especially in small-scale operations, but is labour-intensive and costly.
Hoeing	Controls surface weeds and loosens soil, improving aeration, but may damage wheat roots if not done carefully.
Pulling Weeds (by hand or tool)	Reduces weed competition directly around wheat plants; however, it is time-consuming and physically demanding.
Mulching (Manual)	Suppresses weed germination by blocking sunlight, maintains soil moisture, and improves soil health.
Mowing	Controls taller weeds that may compete with wheat, reduces weed seed production, but may not address root systems.
Soil Solarization (Manual Preparation)	Reduces weed seed bank by heating the soil, leading to fewer weed problems, but requires pre-season planning.
Spot Treatment with Herbicides	Directly targets weeds in specific areas, reducing the impact on the entire field, though still relies on chemicals.

Cultural Weed Control

Cultural weed control involves altering the farming system to suppress weed growth and reduce their competitive ability. This approach encompasses practices such as crop rotation, intercropping, cover cropping, mulching, and adjusting planting times and densities [8] (Table no. 3). A key advantage of cultural control is its integration within the farming system, which minimizes reliance on external inputs. Additionally, it can enhance farm productivity and resilience by improving soil health and diversifying income sources [24]. However, the effectiveness of cultural control varies depending on the farming system, weed species, and local conditions. Some practices may demand additional labour or adjustments in farm management, which can pose challenges for certain farmers [19].

Table no. 3: The effects of cultural weed management on wheat crops:

Cultural Weed Management Practice	Effect on Wheat Crop
Crop Rotation	Disrupts weed life cycles, reduces weed seed bank, and promotes soil health, leading to improved wheat yield.
Row Spacing Adjustment	Reduces weed competition by allowing better crop growth, improves light interception, and helps wheat grow stronger.
Adjusting Planting Dates	Ensures wheat is planted at a time when weeds are less competitive, reducing early-season weed pressure.
Use of Mulches	Suppresses weed germination, conserves moisture, and enhances soil health, supporting wheat growth.
Tillage (Conventional or Reduced)	Breaks up weed seeds and roots, reduces weed establishment, but excessive tillage may increase soil erosion risks.
Cover Cropping	Provides weed suppression through competition, reduces soil erosion, and improves soil fertility for wheat growth.
Intercropping	Increases competition with weeds, reducing weed establishment while diversifying crop yields and improving soil structure.
Smother Crops	Inhibits weed growth by providing dense ground cover, reducing weed establishment and supporting wheat growth.

Biological Weed Control

A notable example of successful weed control in Australia is the management of cactus (*Opuntia tomentosa* Salm-Dyck) using *Cactoblastis cactorum* (Berg.). Biological weed control involves the use of living organisms—such as insects, mites, or pathogens—to suppress weed populations (Table no. 4). These agents are typically host-specific, targeting particular weed species [9]. Other successful cases of biological control include the application of the cinnabar moth (*Tyria jacobaeae*) to manage ragwort (*Senecio jacobaea*) in North America and the rust fungus (*Puccinia chondrillina*) to control skeleton weed (*Chondrilla juncea*) in Australia.

The primary advantage of biological control is its potential to provide long-term, sustainable weed suppression with minimal environmental impact. Once established, biological control agents can self-perpetuate, continuing to suppress weed populations over time [14]. However, biological control is not without its challenges. It often requires significant time to show results and may not always be entirely effective. Furthermore, there are risks of non-target effects and the potential for the control agent to become invasive itself [41].

Table no. 4: The effects of Biological Weed Control on weed management in wheat crops:

Biological Weed Control Method	Effect on Wheat Crop
Use of Natural Predators (e.g., insects, grazing animals)	Reduces weed populations by targeting specific weed species, promoting natural weed suppression without harming wheat.
Introduction of Weed-Specific Pathogens (e.g., fungi, bacteria)	Suppresses weed growth by infecting and killing weeds, reducing weed competition with wheat.
Use of Allelopathic Plants	Allelopathic plants release chemicals that inhibit weed seed germination and growth, reducing weed pressure on wheat.
Grazing by Livestock (e.g., goats, sheep)	Livestock consume weeds, particularly broadleaf species, and prevent their establishment, which improves wheat yield.
Encouraging Beneficial Insects (e.g., aphid predators)	Reduces herbivorous insect pressure on weeds and wheat, indirectly helping in weed control.
Use of Biocontrol Agents (e.g., nematodes)	Targets specific weed species, reducing their growth without affecting wheat, enhancing overall crop health.

Chemical Weed Control

Chemical weed control refers to the use of herbicides to eliminate or suppress weeds. Herbicides can be categorized based on their mode of action, timing of application, or selectivity [1]. The primary advantage of chemical weed control lies in its effectiveness and efficiency. Herbicides are capable of managing a wide variety of weed species and are relatively easy to apply, making them particularly suitable for large-scale agricultural operations (Table no. 5). However, the extensive reliance on chemical weed control has resulted in significant challenges, such as the emergence of herbicide-resistant weed populations [43]. Additionally, chemical weed control poses environmental and health risks, including water resource contamination, adverse effects on non-target organisms, and potential harm to human health due to herbicide residues.

Table no. 5: Major herbicides used for controlling weeds in wheat crops, along with the classification of weeds they target (broadleaf or grassy weeds).

Herbicide	Type of Herbicide	Weed Classification	Mode of Action	Common Weeds Controlled
2,4-D	Post-emergence	Broadleaf weeds	Synthetic auxin (growth regulator)	*Amaranthus spp.*, *Chenopodium spp.*, *Polygonum spp.*
Pendimethalin	Pre-emergence	Grassy and broadleaf weeds	Microtubule inhibitor	*Setaria spp.*, *Lolium spp.*, *Convolvulus spp.*
Fluroxypyr	Post-emergence	Broadleaf weeds	Growth regulator (auxin mimics)	*Sorghum halepense*, *Cirsium arvense* (Canada thistle)
Imazamox	Post-emergence	Broadleaf and grassy weeds	ALS inhibitor	*Amaranthus spp.*, *Echinochloa spp.* (barnyardgrass)
Clodinafop-propargyl	Post-emergence	Grassy weeds	Acetyl-CoA carboxylase inhibitor	*Avena fatua* (wild oats), *Lolium spp.* (ryegrass)
Mesosulfuron-methyl	Post-emergence	Grassy weeds	ALS inhibitor	*Avena fatua* (wild oats), *Bromus spp.* (cheatgrass)
Pinoxaden	Post-emergence	Grassy weeds	Acetyl-CoA carboxylase inhibitor	*Avena fatua* (wild oats), *Lolium spp.* (ryegrass)

Source: [1] and [43].

Integrated Weed Management (IWM)

Integrated Weed Management (IWM) is a sustainable approach to controlling weeds in wheat production, combining chemical, biological, mechanical, and cultural practices to minimize the impact of weeds on crop yield and quality. IWM strategies focus on reducing reliance on herbicides, addressing the problem of herbicide resistance, and promoting ecological balance. This approach includes crop rotation, the use of resistant wheat varieties, intercropping, mechanical tillage, and the careful application of herbicides. The combination of multiple weed control methods is more effective in managing weed populations and reducing environmental risks associated with herbicide use [1]. For example, rotating wheat with non-cereal crops can disrupt weed life cycles, while the use of cover crops can suppress weed germination [43]. Research has also shown that combining herbicide use with cultural practices, such as adjusting planting dates and row spacing, can provide effective long-term weed control [39]. Furthermore, biological control methods, including the use of natural predators and pathogens, are being explored as supplementary tools for weed management in wheat fields [29].

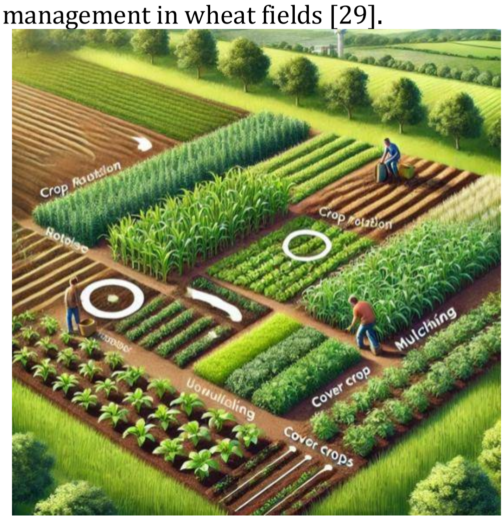

Fig: Integrated weed management practice

CONCLUSION

Effective weed management in wheat crops requires a multifaceted approach that combines cultural, mechanical, and chemical methods. However, challenges such as herbicide resistance, environmental impact, and increasing weed biodiversity continue to complicate efforts. Integrated Weed Management (IWM) systems, which combine various strategies and focus on sustainability, are essential in addressing these challenges. Additionally, continuous research into new technologies, herbicides, and alternative management techniques is crucial for improving weed control in wheat farming.

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