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Weed Management in Wheat: A Review

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ABSTRACT

Wheat is the major staple food crop of India as well as of world. There is a need to enhance the production to feed the growing population in near future. There are many factors responsible for reduction in yield and weed infestation is one of the principle reasons among them. Weeds compete with the crops for various essential resources and do not allow the main crop plant to grow properly and have good yield. Its eradication from the field is very important for the farmers to achieve a higher produce. Different weed management techniques are used to control weeds such as mechanical methods, cultural methods and chemical methods. Chemical method of weed control is becoming very popular as well as effective against weed control due to low input cost. Different herbicides are used to control mixed flora of weeds in wheat crop according to their time of application or the type of target weed. Therefore, selection of effective measure to control the weed is essential for the better yield of crops.

Key words: Biological control, Chemical control, Integrated weed management, Weeds, Wheat.

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Wheat is an important crop worldwide and in India, its production increased from a mere 11.0 million tons during 1960-61 to 112.7 million tons during 2022-23. This more than eight-fold increase in wheat production was mainly due to the adoption of short stature high yielding varieties, increased fertilizers use, irrigation and herbicides (Banjara *et al*., 2022). The high nutrient and water requirements along with less competitive nature of these high yielding dwarf varieties have provided the conducive environment for increased weed infestation. Weeds are regarded as most limiting factor to crop production and account for about one third of total losses caused by all the pests (Liliane and Charles, 2020). Weeds impose competition for nutrients, solar radiation, water and it sets in at the early crop growth stages and their relative density plays significant role in reducing yield of crops (Qasem and Foy, 2001). High weed density and their competition with wheat crop for long term is responsible for serious yield reduction (Reddy, 2004). Weeds are one of the well-known and most economically important factors among all other factors including nematodes, insects, pests etc. which results in reduction of yield of wheat (Savary *et al*., 1997; Gupta, 2004). The reduction of yield in wheat by weeds is much greater than the reduction due to pests and diseases (Rao, 2000).

As regards the various weed control measures, manual eradication has proved its superiority over all the measures in managing weeds, however the adoption of this technique has not gained popularity amongst the wheat growers as it is time consuming, labour intensive, expensive and many a times becomes impractical because of scarcity of labour during peak labour need periods (Mohammadi, 2013; Shrestha *et al*., 2019; Monteiro and Santos, 2022). Timely weeding is most important to minimize the yield losses and therefore under such circumstances the only effective tool left is to control weeds through the use of chemicals (Beiermann *et al*., 2022). In modern day agriculture, use of chemical fertilizers is increasing because it has proved its worth in terms of efficiency in eradication of weeds (Kumar and Singh, 2010).

Management of weeds through the use of chemicals has also been found as effective as realized under manual eradication in various crops including over and above benefits in saving extra costs involved in use of labour on manual eradication of weeds. For controlling weeds in wheat, number of pre- and post-emergence herbicides has already found their place in cultivation package of wheat. However, continuous use of some of the herbicides may result in development of herbicidal resistance in weeds over the time (Kaur *et al*., 2018). Hence, keeping the above facts in view, there is dire need to assess the performance of herbicidal weed management options for providing effective control in wheat.

Status of weeds in wheat crop

Weed flora of crop differs from area to area and field to field depending on environmental conditions, irrigation, fertilizer use, soil type, weed control practices and cropping sequences (Shah *et al*., 2003). The predominant weeds associated with wheat crop in different wheat growing zones in India as mentioned in Table 1.

The time of competition with crop is inversely proportional to the amount of reduction in its yield which means that as the competition period increases it significantly decreases the amount of the yield produced by that crop. In the early stages of the crop development the competition affects the yield (Bekele, 2022). The losses which occur every year to the yield of wheat due to the weed infestation are reported to be in billions. Hence, it becomes very important to control the weeds efficiently for higher economic returns (Kumar *et al*., 2017). Excessive infestation of weed is one of the major causes for declining yield in wheat crop. Weeds were reported to cause yield loss of 5% in commercial agriculture, 10% in semi commercial agriculture, 20% in subsistence agriculture (Choudhury and Singh, 2015) and 37-79% in dry land agriculture (Singh *et al*., 2015). The critical period for weed competition is 30 to 60 days after sowing and after that it will not be economical to eradicate the weeds from the field (Ahmad and Shaikh, 2003; Korav *et al*., 2018). There are various ways to control weeds including biological, cultural, mechanical and chemical. For the enhancement of the crop yield, an efficient and ecologically safe weed control measure acts as one of the key factor (Atta and Khaliq, 2002). Hand weeding is although traditional method of weed management but crop faced the severe competition which resulted in declining wheat productivity. Hence, chemical weed management is effective, cheaper and effective against mixed flora of weeds in wheat crop (Fu *et al*., 2022).

Strategies of weed management

Different cultivars of crop have different growing habitat which can help in affecting the balance of crop and weed. The cultivars which grow fast and have the potential to form canopy earlier than the weeds don't get as much weed competition than other crop cultivars (Lee *et al*., 2017). There is a negative association among the competition ability in wheat and yield potential under weed free environment. The loss in yield due to weeds is high in case of high yielding dwarf varieties as compared to tall varieties (Zimdahl, 2018). It has been reported that the genotypes of wheat which are tall *i.e*., 115 cm when compared to shorter genotypes can supress the effect of *Phalaris minor* more effectively (Mennan and Isik, 2004). Tillage also helps in reducing the weed infestation as it influences the soil properties like bulk density, roughness of surface and penetration resistance. The distribution of seeds of weeds can be disturbed by tillage practices (Wang *et al*., 2022) and the difference in their distribution helps in changing the dynamics of population of weeds (Buhler, 1991). Tillage practices also help to bury the weed seeds in the deeper soil layers which reduce the weed seeds in the upper soil layers (Shivran *et al*., 2020). But, advancement of synthetic carbon based herbicides resulted in a reduction in the frequency of intensive tillage practices and led to zero tillage (Loddo *et al*., 2021).

In case of zero tillage the infestation of *Phalaris minor* can be reduced by adopting pre-emergence herbicides such as glyphosate or paraquat. The problem of *P. minor* was also reduced because the soil got less disturbed due to zero tillage which resulted in no germination of weed seeds those were present in the lower layer of soil (Buttar *et al*., 2022). Also, adopting zero tillage helps in reduction in the cost of field preparation (Chauhan *et al*., 2003). Although, burning the straw of rice helps in reducing the germination of weeds but it also reduces the efficacy of various herbicides. The efficacy of isoproturon and pendimethalin gets reduced by the ash of the rice straw. It should be left on the surface as it has various benefits like conservation of soil moisture,

Table 1: Major weed flora infesting wheat crop.

Type of weed	Scientific name
Wild oat	*Avena sterilis* L.
Canary grass	*Phalaris brachystachys* Link.
Black grass	*Alopecurus myosuroides* Huds.
Ryegrass	*Lolium multiflorum* L.
Bluegrass	*Poa annua* L.
Wild mustard	*Sinapis arvensis* L.
Catchweed bedstraw	*Galium tricornutum* L.
Corn buttercup	*Ranunculus arvensis* L.
Cut-leaved crane's-bill	*Geranium dissectum* L.
Canada thistle	*Cirsium arvense* (L.) Scop.
Sweet clover	*Chenopodium album* L.
Lawn grass	*Cynodon dactylon* L.
Knotweed	*Polygonum plebeium* L.
Cannabis	*Cannabis sativa* L.
Sleeping beauty	*Oxalis corniculata* L.
Asiatic pennywort	*Centella asiatica* L.
Black nightshade	*Solanum nigrum* L.
Common vetch	*Vicia sativa* L.
Yellow pea	*Lathyrus aphaca* L.
Dwarf copperleaf	*Alternanthera sessilis* L.
Goat weed	*Ageratum conyzoides* L.
Chick weed	*Stellaria media* L.
Coco-grass	*Cyperus rotundus* L.
Fineleaf fumitory	*Fumaria parviflora* L.
Shortawn foxtail	*Alopecurus aequalis* L.
Frog fruit	*Phyla nodiflora* L.
Meal weed	*Melilotus alba* L.
Groundsel	*Senecio vulgaris* L.
Floss flower	*Ageratum houstonianum* L.
Black jack	*Bidens Pilosa* L.
Bind weed	*Convolvulus arvensis* L.
White clover	*Trifolium repens* L.
Spiny amaranth	*Amaranthus spinosus* L.
Southern crab grass	*Digitaria ciliaris* L.
False daisy	*Emilia sonchifolia* L.
Asthma plant	*Euphorbia hirta* L.
Black medick	*Medicago lupulina* L.

(Pala and Mennan, 2021; Gyawali *et al*., 2022).

suppression of weeds and improvement in physical and chemical condition of the soil (Singh *et al*., 2015). It was reported that 14 percent of seedlings of weeds were reduced on the surface of soil with the use of each 1000 kg ha^{-1} of residue (Kaur *et al*., 2021). Hence retention of residue along with that of zero tillage is advantageous for controlling weed flora in wheat crop in controlling various weeds (Samedani and Meighani, 2022).

Mechanical control is also good for managing weeds in the field. In this, weeds are removed by different tools and it also includes hand weeding (Verma *et al*., 2015). Manual weeding is effective but there is an involvement of large amount of manpower, it is more time consuming and one of the old practice too. As various weeds are similar in morphology to the crop such as wild oats and *Phalaris minor,* it becomes very difficult to do mechanical weed control before flowering stages (Loddo *et al*., 2021). Chemical control for eradicating the weeds is best because it has good efficiency and also it is cost effective and requires less time as compared to other methods. Proper selection of herbicides for particular weed flora along with its application in required amount at right time using right technology can help in controlling the weed effectively (Gerhards *et al*., 2022).

Chemical weed control

Common practices such as hoeing, manual weeding are very costly and can't be adopted by farmers due to which use of herbicides is common among the farmers of India (Lee and Thierfelder, 2017). The efficacy of herbicides can be improved by applying at optimum dose and time with proper application method. The efficacy of foliar active herbicides can be improved by lowering carrier volumes, which concentrates the herbicide per volume of the spray solutions. Herbicide application in small droplets is more toxic than large ones because of their greater numerical coverage and translocation (Petroczi *et al*., 2002).

It was observed that application of isoproturon at 35 days after sowing there was significant control of weeds but it kept on losing its efficacy as the number of days got increasing (Balyan *et al*., 1988). Wild oats were best controlled when isoproturon was applied 25 days after sowing as compared to 35 days (Malik *et al*., 1984). Furthermore, the herbicides which are applied as foliar spray, their efficacy can be increased by decreasing volume of herbicide per spray (www.bluerivertechnology.com). Application of herbicides in the form of very small droplets as compared to larger droplets is more dangerous because smaller droplets have faster translocation and greater coverage (Loddo *et al*., 2021).

Herbicides which are effective against *P. minor* having isoproturon resistance are traloxydim, sulfosulfuron, atlantis, clodinaphop, pinoxaden and fenoxaprop (Jaiswal *et al*., 2020). Grassy and broad leaf weeds can be controlled by atlantis, sulfoosulfuron and pendimethalin, on the other hand tralkoxydim, clodinaphop and fenoxaprop can only control narrow weeds. Carfentrazone, 2,4-D and metsulfuron are helpful in controlling broad leaf weeds (Chhokar *et al*., 2007). 2,4-D has been used for long time to control broad leaves weed but its application at inappropriate time can result in reduction of yield in wheat because of malformation (Chhokar *et al*., 2007). Results have shown that injury is often caused to nearby broad leaf crops by the use of 2,4-D butyl ester because of its drifting and volatilization (Li *et al*., 2002). Recent studies have recommended the use of carfentrazone for controlling broad leaf weeds because of its fast action (Bhardwaj *et al*., 2022). Sometimes an herbicide is less effective against some weeds but has good efficacy for others. It has been observed that 2,4-D and metsulfuron is not effective for *Malva parviflora* and *S. nigigrum* (Chhokar *et al*., 2007; Mukherjee *et al*., 2011). Various other broad leaf weeds such as *Melilotus indica, Anagallis arvensis* and *Medicago denticulata* (Singh *et al*., 2002). Weeds like *Rumex spp*., *Vicia sativa, Anagalis arvensis, Circium arvensis* and *Convolvulus arvensisis* are resistant to isoproturon (Malik and Singh, 1993; Debangshi and Ghosh, 2022).

It was reported that *R. spinosus* was efficiently controlled by mixing metsulfuron and carfentrazone in a tank as compared to their application individually. This mixture was a boon as not a single formulation of 2,4-D was able to eradicate the *R. spinosus* (Singh *et al*., 2011). In some cases, mixing of herbicides was beneficial over their individual application as they help in saving the time of application as well as are cost effective. For a very complex weed flora herbicides mixture provided excellent control. The efficacy of broad leaf herbicides was reduced when they were mixed with grassy herbicides (Chhokar *et al*., 2013). Synergistic effect is seen in herbicides which belong to same chemical group such as sulfosulfuron + metsulfuron (Chhokar *et al*., 2007). But antagonistic effect has been seen in some herbicides such as pinoxadem, fenoxaprop, clodinafop and tralkoxydim when they are mixed in the sprayer together with metsulfuron or 2,4-D (Singh *et al*., 2011). This problem can be solved if we change the timing of their application or by applying broad leaf and grassy weeds herbicides sequentially.

Some pre-emergence herbicides of wheat are pyroxasulfone, trifluralin and pendimethalin. Selective eradication of weeds in wheat is seen by the application of trifluralin, but it adversely affect the wheat germination (Malik *et al*., 1995) which should be corrected by adjusting its time of application or by increasing the seed rate. Efficacy of some herbicides can be increased by their application with surfactant. It also increases the spectrum of control of weeds and reduces the dose of herbicide (Malik *et al*., 1988). Various studies have shown the increased efficacy of sulphonylurea herbicide by the use of surfactants (Chhokar *et al*., 2010; Chhokar *et al*., 2011). The cuticular layer which is waxy in nature alters with the penetration of herbicides which are foliar sprayed, various adjuvans helps interacting with these layers and enable good penetration of herbicides (Malik *et al*., 1995).

The succeeding crop can also be affected by long persistence of some herbicides such as sulfonyl urea

(Chhokar *et al*., 2006). Residual effect was seen on maize crop when sulfosulfuron and chlorsulfuron were applied to wheat crop (Chhokar *et al*., 2002). These two herbicides don't have any effect on rice when followed after wheat, but it should be noted not to use it when following cotton, maize or sorghum. Various other factors such as climatic conditions and pH of the soil also affect the carryover potential of herbicide (Kaur *et al*., 2016). The possibility of carryover of a herbicide is reduced by applying farm yard manure accompanied by irrigation and tillage. This will help in decreasing the bioavailability of chemical present in the herbicide to the succeeding crop, as it will help in increasing the degradation process (Kewat, 2014).

Herbicidal weed management

Various effects including bioaccumulation of chemical herbicides have been studied on *Ludvigia natans* and *Elodena densa.* There was a significant inhibition of growth that was seen in *E. densa* when the herbicide was used at a concentration of 10 μg lit^{-1}. When the concentration of isoproturon was 2 μg lit^{-1}, reduction in the amount of oxygen was reported after its exposure for 24 hours (Feurtet-Mazel *et al*., 1996). Similarly, phytotoxic effect of 75 WP isoproturon was observed when it was applied in wheat crop immediately after the sowing (Kaur *et al*., 2016). Phytotoxic effect on wheat crop was also seen under the application of isoproturon + diflufenican and metribuzin. The plants were smaller in size when exposed to these two herbicides as compared to any other herbicide. Along with their impact on overall growth, these were also reported to induce oxidative stress in crop plants (Ali *et al*., 2004). As a consequence of these chemical herbicides a reduction in nodulation was also seen when specific doses of isoproturon, atrazine and metribuzin in green gram was applied. Similarly, minimum amount of protein was observed at 400 μg kg^{-1} concentration of isoproturon (Khan *et al*., 2006). Application of phenyl urea herbicide chlortoluron resulted in oxidative stress in wheat crop. The plants those were treated with the herbicide were having the accumulation of oxygen free radical and hydrogen peroxide in their leaves which further peroxidised the lipids of plasma membrane (Song *et al*., 2007). Through many experiments it has been reported that use of isoproturon resulted in oxidative stress in wheat crop (Yin *et al*., 2008).

Application of isoproturon is able to control wide spectrum of weeds and it also provides flexibility in its application timings. Generally, it is very popularly used to control *P. minor* in wheat crop in India and has been accepted extensively (Gill *et al*., 1978). It was found that reduced dose of herbicides along with closer row spacing helps in reducing the number of weeds and also helps in increasing the yield of the wheat crop (Prakash *et al*., 1986). Another studies showed that when wheat was cross sown and when the fertilizers were placed just below the seed, the crop produced more yield and also decreased the weed population as compared to the sowing of crop in unidirectional along with broadcasted application of fertilizer (Ahuja and Yaduraju, 1989).

Resistance of weeds towards herbicides

Rice wheat cropping system in India is distributed across 10 million hectares which is more than 75% of the total 13.5 million hectares of land in South Asia (Debangshi and Ghosh, 2022). In late 1980's isoproturon was recommended which helped in reducing the yield losses in wheat due to *Phalaris minor* to a great extent but continuous use of isoproturon for 10 to 15 years resulted in development of resistance to this herbicide in rice wheat cropping system. It came out to be the most serious case of herbicide resistance in the world (Malik and Singh, 1995). Total area which showed resistance for herbicide was between 0.8 to 1 million hectares in Northwest India which was mostly distributed across Punjab and Haryana. Out of total 10 million hectares of India's land, these two states account for 35 percent of India's wheat production. Various biotypes of *Phalaris minor* were found resistant to isoproturon (Kumar *et al*., 2022). These resistant biotypes were not eradicated from single dose but required 5 to 12 times doses (Malik *et al*., 1995). The resistance to isoproturon kept on increasing with increased use of this herbicide (Yadav *et al*., 2002).

Phalaris minor is the most noxious winter season weed in case of irrigated wheat crop in our country (Rao and Chauhan, 2015). Earlier it was not a problem, but as our country entered green revolution it became a serious problem for every farmer in our country. High yielding dwarf varieties of wheat along with improvement in fertilizer practices and irrigation facilities were the main highlights of green revolution in India. These dwarf high yielding varieties of wheat can't provide competition to this weed. Other factors like improved fertilization practices and irrigation helped this weed to flourish and it became dominant in fields (Balyan and Malik, 1989). In 1970s herbicides such as methabenzthiazuron, nitrofen, isoproturon and metoxuron were recommended to control this weed (Mehra and Gill, 1988).

On the onset of 1990s different biotypes which were resistant to isoproturon were reported in different parts of the country. By the reports of some scientists, it came to the knowledge that for reducing the cost, farmers of Punjab and Haryana were spraying isoproturon at the rate less than the recommended dose (Malik and Singh, 1995). Many farmers burned their rice straw in the fields itself as it was not suitable for the cattle. The studies showed that if the rice straw is burned in the field itself, the ash formed from it increases the adsorption of herbicide and hence reduces efficacy of herbicides. These factors also favoured the dominance of *Phalaris minor* and reduction in the efficacy of isoproturon. Efficiency of herbicide is reduced in heavy soils as the adsorption of herbicides takes place (Rasool *et al*., 2022). Instead of this, spraying of herbicide results in better effect of herbicide rather than mixing it with sand (Singh *et al*., 1995). All these factors resulted in decreasing the efficacy of isoproturon and helped in development of resistance in *Phalaris minor* metabolically (Malik *et al*., 1995). It was experimentally proved that low volume of herbicide helps in development of metabolic resistance (Wrubel and Gressel, 1994).

Different management strategies should be adopted to stop the increasing the population of herbicide resistant weeds. Various ways by which this can be achieved are crop rotation, alternate use of herbicides and different agronomic practices which can provide a competitive benefit over weed. Rotation of herbicides and crop rotation lowers the selection pressure (Manisankar *et. al*., 2022). Crop rotation allows use of different agronomic practices which slows down resistance and also increases the weed flora diversity. Growing *Trifolium alexandrium* can suppress all the seeds of *Phalaris minor* present in the field (Silvestri *et al*., 2021).

Besides use of herbicides alternatively, changing the dose of herbicides can also help in reducing the resistance of weeds towards herbicide (Manisankar *et. al*., 2022). For this one thing need to be kept in mind that, different herbicides should be available which have different mode of mechanism of action. Rate and method of application along with time of application also helps in reducing the development of resistance. Adjustment of time of sowing of wheat in such a way that it could not coincide with the period in which weed germination is maximum is another way to improve the yield (Chhokar *et al*., 1999). The technique of stale seed bed can also be used for reducing the infestation of *Phalaris minor* which is resistant to isoproturon. As the strength of the soil is increased with zero tillage it can help in reducing the emergence of *P. minor* (Chhokar *et al*., 2007). If there is gap between the harvesting and sowing of rice and wheat respectively then non-selective pre-emergence herbicides such as glyphosate can be used to eradicate the grown *Phalaris minor.*

Wheat can be replaced by any other short duration crop for example pea or potato which can also help in the management of *P. minor* (Chhokar *et al*., 2008). If we replace the wheat with dicotyledonous crop also depletes the seed bank of this weed. Other rotations which can be adopted include lucerne, berseem and oat. Hence, crop rotation is very effective against seed bank of weeds as it influences germination and mortality in any plant population (Maxwell and O’Donovan, 2007). Various other scientists have also reported low germination of *Phalaris minor* which is resistant to isoproturon when crop rotations such as rice-berseem-sunflower-wheat, cotton-pigeonpea-wheat and sugarcane-vegetable-wheat were adopted instead of rice-wheat (Malik and Singh, 1995).

Integrated weed management (IWM)

Due to the increase in the awareness among the people for environmental pollution, the path of the weed management is shifting toward more eco-friendly ways of management. In today’s world, herbicides are being used mostly for weed control because of their high effectiveness. But excessive use of herbicides has resulted in formation of herbicides resistance weed biotypes (Heap, 2021). Due to this herbicide resistance weeds issue and awareness among people about the side effects of overuse of herbicides, a holistic multidisciplinary approach is urgently required for managing the weeds efficiently as well as in an eco-friendly way. For such demands, IWM is best approach which can provide a sustainable solution for weed problem (Storkey *et al*., 2021).

Integrated weed management (IWM) deals with the information about environment, technologies available to control weeds and the ecology as well as biology of the weeds while reducing the risk to environment as well as human beings (Sanyal, 2008). In IWM we use various management practices to control weeds which include both chemical methods and non-chemical methods. Effective weed control was seen when chemical herbicides were used with some other biological agents and the strategy was found effective to reduce weed population (Subramanian and Martin, 2006). Whereas, without using chemical methods a reduction in the population of sedges and grasses was observed when rice/wheat cropping system was integrated with intercropping of either green gram or sesbania (Singh *et al*., 2008). The current challenge for agricultural scientists is to introduce a very effective, eco-friendly and economically sound IWM systems which can be used in our present and future cropping practices (Rao and Nagamani, 2010).

CONCLUSION

Weed infestation is one the main limiting constraints among all biotic and abiotic factors which affect wheat production and productivity. Wheat is affected by a variety of weeds including grasses, sedges and broad leaved. Most of the wheat producers use chemical herbicides for weed control because of their cost effectiveness and more efficiency in comparison to manual and other cultural methods. But, due to the increasing risk by continuous use of chemical herbicides and more cost of other methods there is a need to adopt effective as well as an ecologically sound approach to reduce the yield losses by weeds. Adoption of correct method of sowing, sowing time, seed rate, selection of crop variety, application of fertilizers and herbicides in correct dose, correct time, at correct place and making correct choice of both fertilizers and herbicides, sowing weed free seeds and farm implements, crop rotations etc. are some key components of IWM which can be effective.

Conflict of interest

All the authors of article have no conflicts of interest.

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