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Chemical Weed Management in Wheat- A review

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Abstract

Wheat (*Triticum aestivum* L.) is one of the major cereal food crops of the world and has very important role in attaining food security. Introduction of dwarf wheat varieties coupled with intensive input (assured irrigation and fertilizers) use after Green Revolution led to complex problem of both grassy and broad leaved weeds. Weed management is very important for achieving higher wheat production. Mechanical, cultural, biological and chemical methods can be adopted for weed management in wheat. Due to industrialization, labour is becoming scarce and costly. Among these methods, chemical weed control is more efficient, less costly and less time consuming. Pre-emergence herbicides cannot control the late flushes of weeds especially, grassy weeds. Post emergence herbicides are very effective against weeds in wheat. However, herbicides are effective against some weed groups due to mode of action and they do not kill other weeds. To control other weeds, another herbicide is needed which involves more cost, time and labour. To overcome this, sequential application of herbicides, herbicidal mixtures and herbicidal combinations are used. The herbicidal combinations could be very effective against both grassy as well as broad leaved weeds and help to reduce cost, time and labour. Application herbicidal combinations viz. clodinafop + metsulfuron (vesta) 60 g ha^{-1}, sulfosulfuron + metsulfuron (total) 32 g ha^{-1} and mesosulfuron + iodosulfuron (atlantis) 14.4 g ha^{-1} as well as tank mixture of pinoxaden + carfentrazone (50 + 20 g ha^{-1}) is the best way for managing complex weed flora in wheat as of now. Modification in application method like tank mixture with micronutrients also have potential of increasing the weed control efficiency of herbicides and yield of wheat. To give precise and concise information weed management in wheat, his article reviews the latest herbicides recommended for weed management in wheat. Recent advances in herbicidal mixture, combinations and application techniques are also being included in this review.

Key words : Wheat, complex weed flora, herbicides, herbicidal combinations, tank mix.

Wheat (*Triticum aestivum* L.) is one of the major cereal food crops of the world and has very important role in attaining food security. About 19 per cent of the calories and 21 per cent of protein needs of human are satisfied by wheat day by day on the planet (Braun *et al*., 2010). Because of its wide adaptability, it tends to become established under different agro-climatic conditions. It is grown on about 215 million hectares (mha) with an annual production of about 700 million tonnes (mt) of wheat in the world (FAO, 2018). It is estimated that demand of wheat will be 900 mt by 2050 (FAO, 2006). Besides this, there is a prediction of decline in cultivated area of wheat in India and China due to climate change (Nelson *et al*., 2010).

It is the second most important source of staple food grain next to rice in India. It contributes upto 35 - 40% of total food grain production. Wheat is cultivated on an area of 30 mha in India having production and productivity of 97 mt and 3230 kg ha^{-1}, respectively (USDA-FAS, 2018).About 35 per cent of India's wheat production comes from the two north-western states i.e. Haryana and Punjab. In Haryana, it is cultivated on an area of 2.56 mha with a production and productivity of 12.4 mt and 4841 kg ha^{-1}, respectively (Anonymous, 2018).

Introduction of dwarf wheat varieties coupled with intensive input (assured irrigation and fertilizers) use after Green Revolution led to complex problem of both grassy and broad leaved weeds. There is more noteworthy extension to build wheat efficiency by conquering any hindrance among potential and accomplished yield. Wheat efficiency is an after effect of numerous components, yet weed administration is one of the major and less minded reasons for low yield. Weeds utilize the available nutrients as well as moisture and they also compete for space and sunlight with the crop plants. Diverse type of weed flora attacks wheat due to diverse growing conditions and cultivation practices. Major grassy weeds like *Phalaris minor* and *Avena ludoviciana*, and broad leaved weeds like *Chenopodium album, Rumex dentatus, Angallis arvensis, Convolvulus arvensis, Fumaria parviflora, Malva parviflora* etc. are affecting wheat productivity in wheat growing areas of Haryana, Punjab, parts of Delhi, Uttrakhand and Uttar Pradesh states in north-western Indian Plains, and other wheat growing areas. Grassy weeds, broadleaf weeds and complex flora reduce wheat yield upto 30, 24 and 48 percent, respectively and wheat yield varies upto the extent of 22 per cent due to the weeds (Khan and Haq, 2002). Yield losses not only depend on weed factors like species and density but also varies with crop factors such as time of sowing &emergence, cultivar, planting density, soil and environmental factors (Malik and Singh, 1993; Khera *et al*., 1995; Malik and Singh, 1995; Afentouli and Eleftherohorionos, 1996; Chhokar and Malik, 2002) and under very severe infestation the losses could be as high as 80 per cent to even total crop failure leading to immature harvest for fodder (Malik and Singh, 1995).Along with reducing the yield,weeds hinder the harvesting operation also (Chhokar *et al*., 2012).

Therefore, weed management is very important for achieving higher wheat production. Mechanical, cultural, biological and chemical methods can be adopted for weed management in wheat (Chhokar *et al*., 2012). Due to industrialization, labour is becoming scarce and costly. In addition, grassy weeds can't be controlled efficiently by mechanical/manual methods due to lesser spacing and morphological similarities. Among these methods, chemical weed control is more efficient, less costly and less time consuming. However, herbicides are effective against some weed groups due to mode of action and they do not kill other weeds. To control other weeds, another herbicide is needed which involves more cost, time and labour. To overcome this, herbicidal combinations, herbicidal mixtures and sequential application of herbicides are used. These herbicides could be very effective against both grassy as well as broad leaved weeds and help to reduce cost, time and labour.

Weed flora associated with wheat : Wheat is generally infests with complex weed flora (grassy, broad-leaved weeds and sedges). Weed flora is not always same at all locations, but it varies over time and location. After green revolution, weed flora has shifted more towards more grassy weeds than broad-leaved weeds (Bhan, 1972). However weeds like *Cersium arvense* and *Convolvulus arvensis* are also reported as major weed of wheat growing areas of Punjab and Haryana (Gill and Brar, 1975). In Punjab, the weed flora of wheat consists mainly of grassy weeds like *Phalaris minor*, *Avena ludoviciana* and broad leaf weeds like *Chenopodium album, Cirsium arvense, Medicago denticulataand Convolvulus arvensis* (Singh *et al*., 1993). In Haryana, grassy weeds particularly *Phalaris minor* and *Avena ludoviciana* as well as *Medicago denticulata*, *Circium arvense Rumex maritimus, Melilotus indica* and *Convolvulus arvensis* dominates the weed flora of wheat in eastern Haryana whereas in western Haryana, weeds like *Chenopodium album, Asphodelus tenuifolius, Trigonella polycerata, Fumaria parviflora, Sisymbrium irio, Euphorbia dracunculoides, Sapponaria vaccaria,* *Desmostachya bipinnata, Zizyphus rotundifolia and Aerva javanica dominates* (Singh *et al*., 1995). Weed population of wheat field comprises of complex weed flora (Table 1).

Economic losses caused by weeds : Weeds have potential of 100 per cent grain yield loss and use of wheat crop as fodder (Malik and Singh, 1995). *P. minor* causes highest grain yield reduction in wheat (39.25%) followed by (29.14%) by *Melilotus* spp. (Singh *et al*., 1997). Wheat yield varied to the extent of 22 per cent due to weeds (Khan and Haq, 2002). Weed causes 2nd highest economic losses in wheat after rice in monetary terms and weeds caused yield losses upto the extent of 41 per cent in wheat. However, spatial variability in losses caused by weeds is observed which is attributed to soil and climatic conditions (Gharde *et al*., 2018). Reduction in yield depends upon weeds species and density (Table 2).

Chemical weed management : Weed control is critical for increasing wheat yields. Weed control in wheat can be accomplished through mechanical, cultural, biological, and chemical means (Chhokar *et al*., 2012). Labor is becoming scarce and expensive as a result of industrialization. Furthermore, because to their smaller spacing and morphological similarities, grassy weeds are difficult to control mechanically or manually. Chemical weed management is the most efficient, least expensive, and least time-consuming of these approaches. Herbicides, on the other hand, are effective against particular weed groups and do not kill other weeds due to their method of action. Another herbicide is required to control other weeds, which adds to the expense, time, and effort. Herbicide combinations, herbicide mixes, and sequential application of herbicides are employed to combat this. These herbicides have the potential to be quite effective against both grassy as well

Table 1. Major weed flora of wheat

Weeds	References
Avena ludoviciana, Phalaris minor (30 and 10 %), *Chenopodium album* (30 %), *Melilotus* spp. (15 %), *Fumaria parviflora, Rumex retroflex, Convolvulus arvensis* (7, 5, 3 %)	Yadav *et al*. (2004).
Phalaris minor, Melilotus indica, Medicago denticulata, Chenopodium album and Rumex acetosella (56.0, 12.4, 8.2, 7.5 and 6.3 %, respectively). *Coronopus didymus, Lathyrus aphaca, Fumaria parvifloraa, Vicia sativa, Polygonum plebeium and Cyperus rotundus*. (9.6 %)	Shyam *et al.* (2009)
Grassy weeds (79 %) and broad leaf weeds (21%). Major weeds - *Chenopodium murale*, *Chenopodium album, Phalaris minor, Melilotus alba, Avena fatua, Asphodelus tenuifolius* and *Setaria tomentosa*	Patel *et al.* (2017)
Major broad leaved weeds - *Chenopodium album, Anagallis arvensis, Melilotus alba* and *Convolvulus arvensis. Grassy weeds - Phalaris minor, Cynodon dactylon and Cyperus rotundus*	Kushwaha *et al.* (2018)

Table 2. Economic losses by weeds in wheat

Weeds	Grain yield reduction (%)	References
Broad leaved weeds	7-50%	Kurchania *et al*. (2002)
Complex weed flora	48%	Khan and Haq (2002)
Grassy weeds	30%	
Broad leaved weeds	24%	
P. minor	47-48%	Dhima and Eleftherohorinos (2003)
Complex weed flora	20-32 %, 38%, 58.3%, 50%	Mongia *et al*. (2005); Gopinath *et al*. (2007); Sharma *et al*. (2009); Malik *et al.* (2012)

as broad leaved weeds and help to reduce cost, time and labour.

Pre-emergence herbicides : Use of pre-emergence herbicides in wheat is uncommon. Application of pre-emergence herbicides in wheat does not provide satisfactory weed control consistently especially, control of grassy weeds as they emerge late in the season. Weed control efficiency due to use of pre-emergence herbicides in wheat varies from 37.6% to 82.4% (Table 3).

Post emergence herbicides : Use of post-emergence herbicides in wheat is very common. They are generally sprayed at 30-35 days after sowing. They consistently controls the weeds in wheat. However, they are applied in four ways for enhancing their efficacy-

1. Sequential application of herbicides
2. Herbicidal mixtures
3. Herbicidal combinations
4. Herbicides tank mixed with other agrochemicals

Sequential application of herbicides- Some herbicides can't be tank mixed as they are antagonist to each other, thereby reducing their efficacy. To use two or more antagonist herbicides, sequential application of herbicides is recommended in wheat. Sequential application of pendimethalin 1000 g ha^{-1} or trifluralin 1000 g ha^{-1} just after sowing followed by clodinafop 60 g ha^{-1} or sulfosulfuron 25 g ha^{-1} (35days after sowing) provides 90-100%

Table 3. Weed control efficiency of pre-emergence herbicides in wheat

Herbicides	Dose	Weed control efficiency (%)	References
Pyroxasulfone	0.15 kg a.i. ha^{-1}	39.8	Naseer-ud-Din *et al*. (2011)
Terbutryn + Triasulfuron	0.18 kg a.i. ha^{-1}	37.6	
Flufenacet + Pyroxasulfone	0.24 + 0.15 kg a.i. ha^{-1}	38.2	
Pendimethalin	0.75 kg ha^{-1}	54.4	Kaur *et al*. (2017)
Pendimethalin	1.0 kg ha^{-1}	73.5	
Metribuzin	0.175 kg ha^{-1}	52.9	
Metribuzin	0.21 kg ha^{-1}	69.1	
Pendimethalin + Metribuzin	0.75 + 0175 kg ha^{-1}	73.5	
Pendimethalin + Metribuzin	1.0 + 0.175 kg ha^{-1}	82.4	
Pendimethalin	2.5 l ha^{-1}	72.6	Kaur *et al*. (2018)
Pendimethalin	3.75 l ha^{-1}	76.9	

Table 4. Weed management by sequential application of herbicides in wheat

Herbicides	Dose	WCE (%)	References
Pendimethalin (PE) *fb* 2,4-D (PoE)	1 kg ha^{-1} *fb* 2 kg ha^{-1}	80.6	Ghosh *et al.*
Pendimethalin (PE) fb Metsulfuron methyl (PoE)	1 kg ha^{-1} *fb* 4 g ha^{-1}	81.9	(2017)
Metribuzin (PE) *fb* Metsulfuron methyl (PoE)	175 g ha^{-1} *fb* 4 g ha^{-1}	80.3	
Pendimethalin + pyroxasulfone *fb* pinoxaden	1500 + 102 g ha^{-1} g *fb* 60 g ha^{-1}	84.4-88.7	Punia *et al*.
Pendimethalin + pyroxasulfone *fb* mesosulfuron + iodosulfuron	1500 + 102 g ha^{-1} *fb* 14.4 g ha^{-1}	87.5-93.5	(2020)
Pendimethalin + metribuzin *fb* mesosulfuron + iodosulfuron	1000 + 175 g ha^{-1} *fb* 14.4 g ha^{-1}	66.8-72.3	
Pendimethalin + metribuzin *fb* pinoxaden	1000 + 175 g ha^{-1} *fb* 60 g ha^{-1}	51.9-66.7	

control of herbicide resistant *P. minor* along with broadleaf weeds in wheat (Yadav *et al*., 2016). Sequential application of pendimethalin (0.75 1.0^{-1} kg ha^{-1}, pre-emergence) followed by sulfosulfuron (0.018 kg ha^{-1}, post emergence) provides weed control efficiency (WCE) > 90% (Kaur *et al*., 2017). Sequential application of pendimethalin + metribuzin (2000 g ha^{-1}, pre-emergence) followed by post emergence application of sulfosulfuron (25 g ha^{-1}), sulfosulfuron + metsulfuron (32 g ha^{-1}), pinoxaden (50 g ha^{-1}) and mesosulfuron + iodosulfuron (14.4 g ha^{-1}) provides WCE > 85% (Raseed *et al*., 2020). Sequential application of pre and post emergence herbicides is also done (Table 4).

Herbicidal mixtures and herbicidal combinations- The herbicidal mixtures and combinations have advantage of expanding the scope of control of weed flora. Use of these products provides simultaneous control of grassy as well as broad leaved weeds. These provides management of herbicide resistance to some extent. These reduce the dose of herbicide required for effective weed control; thereby, are economical and ecologically safe. There are various herbicidal mixtures found compatible to each other as tank mixed. For instance, the herbicidal mixtures fenoxaprop + chlorsulfuron @ 100 + 20 g ha^{-1}, clodinafop + chlorsulfuron @ 50 + 20 g ha^{-1}, tralkoxydim + chlorsulfuron @ 250 + 20 g ha^{-1}, sulfosulfuron + chlorsulfuron @ 15 + 10 g ha^{-1} and isoproturon + 2, 4 - D sodium salt @ 750 + 500 g ha^{-1} provides more than 70 percent control of complex weed flora (Yadav *et al*., 2004). Tank mixed application of isoproturon + metsulfuron methyl (500 + 4 g ha^{-1}), isoproturon + carfentrazone ethyl (500 + 10 g ha^{-1}), fenoxaprop-p-ethyl + metsulfuron methyl (100 + 4 g ha^{-1}) and fenoxaprop-p-ethyl + carfentrazone ethyl (100 + 10 g ha^{-1}) as post-emergence spray result into higher WCE than their sole application (Chopra *et al*., 2008). Tank mixture of carfentrazone + isoproturon (20 + 650 g ha^{-1}) controls the weeds of wheat crop most effectively. The herbicides are compatible

Table 5. Weed management by herbicidal mixtures in wheat

Herbicidal mixtures	Dose	WCE (%)	References
Clodinafop + metsulfuron-methyl	60 + 4 g ha^{-1}	83.2	Choudhary (2016)
Clodinfop + metribuzin	60 + 210 g ha^{-1}	92	Kushwaha *et al.* (2018)
Pinoxaden + metribuzin	40 + 210 g ha^{-1}	83.9	
Sulfosulfuron + metribuzin	25 + 210 g ha^{-1}	86.8	
Isoproturon + 2, 4-D	1000 + 500 g ha^{-1}	80.5	

Table 6. Weed management by herbicidal combinations in wheat

Herbicidal mixtures	Dose	WCE (%)	References
Sulfosulfuron + metsulfuron (Total)	32 g ha-1	86.2-87.7	Sasode *et al*. (2017)
Pinoxaden + metsulfuron (premix)	64 g ha-1	87.1-89.7	
Mesosulfuron + iodosulfuron (Atlantis)	14.4 g ha-1	87.6-88.4	
Clodinafop + metsulfuron (Vesta)	64 g ha-1	82.1-85.1	
Sulfosulfuron + metsulfuron (Total)	32 g ha-1	> 90	Chaudhari *et al*. (2017)
Mesosulfuron + iodosulfuron (Atlantis)	14.4 g ha-1		
Clodinafop + metsulfuron (Vesta)	64 g ha-1		
Fenoxaprop + metribuzin (Accord Plus)	330 g ha-1	85.6	Kushwaha *et al.* (2018)

with each other. Weed control efficiency increases from 73 per cent with carfentrazone alone, 80 per cent with isoproturon alone to 96 per cent with carfentrazone + isoproturon tank mix. Herbicides have synergistic effect on herbicidal activity when applied as mixture (Chippa and Nepalia, 2014). Application of herbicides as tank mixed are more effective than alone application. Application of clodinafop (60 g ha^{-1}) + metsulfuron (2.5 g ha^{-1}) as tank mixed provides grain yield of wheat very close to weed free. Weed control efficiency of 85.1 per cent can be achieved by tank mix application of sulfosulfuron + metsulfuron whereas efficiency of sulfosulfuron alone is 62.2 per cent. Similar results are obtained by tank mix application of clodinafop + metsulfuron and sulfosulfuron + carfentrazone-ethyl (Tomar and Tomar, 2014). Ready mix herbicidal combinations have advantage of compatibility of herbicides and lower dosage as compared to tank mixing. Some viable and economical weed management options as herbicidal mixtures are given in Table 5. However, some of the herbicidal mixtures are antagonistic and can't be used as tank mixed such as clodinafop + 2, 4 - D (60 + 400 g ha^{-1}) and isoproturon (1000 g ha^{-1}) + 2, 4 - D (400 g ha^{-1}) (Choudhary, 2016).

Herbicidal combinations eliminate the problem of information on compatibility of herbicides as herbicidal tank mixtures. For instance, ready mix herbicidal combinations of clodinafop-propargyl 15% + metsulfuron-methyl 1% (75 g ha^{-1} + 0.2% surfactant) provides satisfactory weed control and higher grain yield as compared to sequential application of ingredient herbicides of ready mix formulation (Kaur *et al*., 2015). The ready mix application of mesosulfuron + iodosulfuron (24.0 + 4.8 g ha^{-1}) effectively checks the complex weed flora of wheat and does not causes any significant injury to crop. Application of mesosulfuron (18.0 g ha^{-1}) + iodosulfuron (3.6 g ha^{-1}), sulfosulfuron (20 g ha^{-1}) + metsulfuron (4.0 g ha^{-1}) and clodinafop (60.0 g ha^{-1}) + metsulfuron (4.0 g ha^{-1}) also gave satisfactory weed control (Pal *et al*., 2016). Ready mix herbicidal combinations viz. clodinafop propargyl 15% + metsulfuron-methyl 1% (Vesta) @ 300, 400, 500 and 800 g ha^{-1}, mesosulfuron + iodosulfuron (Atlantis) @ 400 g ha^{-1}, sulfosulfuron + metsulfuron methyl (Total) @ 32 g ha^{-1}, fenoxaprop + metribuzin (Accord Plus) @ 1250 g ha^{-1} and clodinafop (60 g/ha) + 2, 4 - D (500 g ha^{-1}) are effective and economical weed management option in wheat (Tiwari *et al*., 2016). Efficient weed control in wheat was achieved with application of ready mix herbicidal combinations as compared to application of single herbicide. Even 100 per cent weed control efficiency is achieved with ready mix

Table 7. Compatibility of herbicides with other agrochemicals in wheat

Herbicides	Agrochemical	Compatibility
Tribenuron	Zinc	Compatible
Isoproturon	Urea	Not compatible
2, 4 - D + MCPA	Iron, Zinc and Mangnese	Compatible
Bromoxynil + MCPA		
Tribenoron-methyl		
Florasulam + 2,4-D	Azoxystrobin/	Compatible
Bromoxynil + 2,4-D	trifloxystrobin + prothioconazole	Not compatible
Sulfosulfuron + metsulfuron	Zinc	Compatible
Mesosulfuron + iodosulfuron	Or / and	
Clodinafop + metsulfuron	Iron	
Pinoxaden + carfentrazone		

application of sulfosulfuron (75%) + metsulfuron-methyl (5% WG) @ 32 g ha^{-1}, clodinafop (15%) + metsulfuron-methyl (1% WP) @ 64 g ha^{-1} and mesosulfuron (3%) + iodosulfuron (0.6% WDG) @ 14.4 g ha^{-1} whereas weed control efficiency of application of metsulfuron-methyl (4.0 g ha^{-1}), clodinafop-propargyl (60 g ha^{-1}) and sulfosulfuron (25 g ha^{-1}) is only 23, 62 and 97 per cent, respectively. However, injurious effects of application of mesosulfuron (3%) + iodosulfuron-methyl sodium (0.6% WDG) are also observed (Patel *et al*., 2017). Herbicidal combinations are effective against *P. minor* which was found to be resistant to single herbicide application. Weed control efficiency is only 40-50% by single herbicide application which increased to 85-90% by herbicidal combinations (Punia *et al*., 2017). Some of best recommended herbicidal combinations in wheat are given in Table 6.

Herbicides tank mixed with other agrochemicals- Now a days, co-application of herbicides along with other agrochemicals is becoming popular due to following advantages-

1. Reduced cost of application
2. Increased efficacy of herbicides
3. More favourable soil conditions

Herbicides can be used as tank mixed with other agrochemicals. Compatibility of herbicides should be tested before use. Time of spray of post emergence herbicides coincides with time of foliar the application of micronutrients in wheat. Therefore, herbicides should be tested for compatibility with other agrochemicals.

Conclusion

From the review of available literature, it can be concluded that chemical weed management in wheat is more effective and economical than their counterparts. For chemical weed management, we have option of using sole herbicide, sequential application of herbicide, use of herbicidal mixture and herbicidal combinations. Among these options, use of herbicidal combinations is more economically viable, ecologically safe and environmentally sound. Efficacy and efficiency of herbicidal combinations can be increased by using them as tank mixed with compatible agrochemicals, especially micronutrients.

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