

Review Article

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## Efficacy of Separate and Premix Formulation of Metsulfuron-Methyl and Carfentrazone-Ethyl on Weeds in Wheat: A Review

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### ABSTRACT

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India has a wide range of agro-climates regions and soil types. The highly diverse agriculture systems are beset with different types of weed problem. Weeds cause 10-80% crop yield losses besides deteriorating quality of products and causing health and environmental hazards. Traditionally, weed control has been largely dependent on manual weeding. However, increased labour scarcity and costs are encouraging farmers to adopting labour and cost saving options. Research on weed management in India is mostly centered on herbicide efficacy. Herbicides applied alone or in combination, have been regarded as essential tools in effective management of weeds in different ecosystem. To meet the demands of increasing population and avoid food import, crop productivity in India needs major improvement, which can be attained by identifying the constraints that hinder in achieving higher yields of wheat. Detailed review of weed flora and weed shift, factor of weed competition and management' options future in India is made under this chapter.

### Introduction

Wheat is an important crop in worldwide and in India, its production increased from a mere 11 MT during 1960-61 to 97.4 MT during 2016-17 (Singh *et al.*, 2017a). This more than 8-fold increase in wheat production was mainly due to adoption of short stature HYVs, use of fertilizers, irrigation and herbicides (Singh *et al.*, 2017b). High nutrient and water requirement along with less competitive nature of these HYVs have provided

conducive environment for increased weed infestation. Weeds are regarded as most the disdain to crop production and account for ~1/3<sup>rd</sup> of total losses caused by all pests (Chhokar *et al.*, 2012).

Weeds have a direct impact on crop productivity including costs of labour, equipment, chemical and other management input (Singh *et al.*, 2011a). Weeds also impact

wheat production indirectly by competing with crop for resources, harbouring crop pest, interfering with water management, reducing grain yield, quality and increasing cost of processing (Zimdahl, 2013). Major weeds associated with wheat are *Phalaris minor*, *Avena spp.*, *Chenopodium album*, *Melilotus spp.*, *Anagallis arvensis*, *Vicia sativa*, *Lathyrus aphaca* and *Rumex dentatus*. In recent years, a new species *Rumex sp.* has emerged as serious problem in irrigated wheat eco-system (Singh *et al.*, 2011b). Therefore, complexity and diversity of weed flora require more than one herbicide either in sequence or as mixture.

Low wheat productivity is due to delayed and sub-optimal wheat establishment, which is further due to late harvesting of long duration rice varieties and weed infestation (Maurya *et al.*, 2013 and Singh *et al.*, 2014). Continuous application of a similar herbicide or use of lower than recommended dose led to development of herbicide resistance (Yadav *et al.*, 2013). The weed flora of wheat consists of both grassy and broad leaf weeds and if uncontrolled; they interfere crop growth by competing for available nutrient, light and water (Jeet *et al.*, 2010a, b, c). Consequently such competition depends upon type of weed species, severity of weed infestation and climatic condition, which affects weed and crop growth (Rao, 2000). In India it has been estimated that out of total yield losses caused by the pests in wheat, weeds account ~33% and extent of yield reduction largely depends on growth and behavior of individual weed species in relation to agro-ecological condition. Eradication of weeds from crop is essential for obtaining the maximum returns. Various methods for eradication of weeds are hoeing, weeding, dabbing, tillage, harrowing, crop rotation biological and chemical control. Therefore, for sustaining food-grain production to feed ever-increasing population, ensuring food security, effective weed management is very essential.

### **Weed flora and weed flora shift**

Weed floras associated with wheat have been found variable in different agro-ecological regions of the country (Table 1). In general, *Phalaris minor* Retz., *Avena spp.*, *Chenopodium album*, *Melilotus spp.*, *Cyperus rotundus* and *Cynodon dactylon* have been observed in most wheat growing areas of India (Singh and Ghosh, 1992). A survey of wheat fields were conducted on farmers' fields in Eastern Indo-Gangetic region, Faizabad and revealed that crop was infested with *Phalaris minor*, *Anagallis arvensis*, *Cyperus rotundus*, *Lathyrus aphaca*, *Chenopodium album*, *Vicia sativa* and *Avena ludoviciana* (Vaishya and Kumar, 1993). Singh *et al.*, (1997) observed relative composition of weed flora as *Melilotus spp.* (24.2%), *Anagallis arvensis* (20.7%), *Phalaris minor* (18%) *Chenopodium album* (13.8%), *Cyperus rotundus* (11.1%) and *Cynodon dactylon* (8.3%) in wheat. Sidhu *et al.*, (2000) reported *Rumex spinosus* a hardy broad leaf weed, becoming very serious problem in several wheat growing areas of Punjab. In other instance, Sardana *et al.*, (2001) observed heavy infestation (73.4%) of *Medicago denticulate* in wheat field at Gurdaspur, Punjab. Malik *et al.*, (2001) reported infestation of *Avena ludoviciana*, *Chenopodium album*, *Phalaris minor*, *Melilotus indica*, *Fumaria parviflora* and *Convolvulus arvensis* in wheat crop at Hisar, Haryana, India. Thirteen weed spp. were found infesting wheat fields and of these *Phalaris minor*, *Polygonum monspeliensis*, *Poa annua*, *Rumex aspera*, *Medicago denticulata*, *Anagallis arvensis*, *Lepidium sativa* and *Malva neglecta* were the most common. Relative frequency, relative density, important value and dominance ratio of *Phalaris minor* has highest among different weed species (Brar and Walia, 2007). Jat *et al.*, (2007) found that major grassy weed of wheat are *Phalaris minor* Retz.(29.7%),

*Avena ludoviciana* L. (40.1%), whereas BLWs are *Lathyrus aphaca* L. (8.8%), *Chenopodium album* L. (8.2%), *Melilotus indica* L. (4%), *Rumex retroflexus* L. (4.0%), *Coronopus didymus* L. (2.7%), *Cirsium arvensis* L.(2.5%). Garg *et al.*, (2007) reported that *Phalaris minor* was the dominant weed (49% of the total weed density), followed by *Chenopodium album*, *Rumex retroflexus*, *Anagallis arvensis*, *Chenopodium murale*, *Melilotus indica* and *Coronopus didymus* in 31 wheat fields in Panipat district, Haryana, India. *Malva parviflora* infested 96% of the wheat fields (25.6 plants/m<sup>2</sup>) *Avena ludoviciana* [*Avena sterilis* sub sp. *ludoviciana*], which was the dominant weeds. *Poa annua*, *Anagallis arvensis* and *R. retroflexus* infested 6.4, 93.5 and 100%, respectively. Vashisht *et al.*, (2008) observed wheat infestation of 23 weed species comprising 14 families of grasses, sedges and BLWs. *Phalaris minor*, *Avena ludoviciana* [*A. sterilis* sub sp. *ludoviciana*], *Vicia sativa*, *Rumex* sp. and *Lathyrus aphaca* were the pre-dominant weeds of rice-wheat sequence, whereas *P. minor*, *A. ludoviciana*, *Chenopodium album*, *Asphodelus tenuifolius* and *Cirsium arvense* were the pre-dominant weeds of bajra-wheat and arhar-wheat sequences. Five major weeds with 100% event were *P. minor*, *A. ludoviciana*, *V. sativa*, *L. aphaca* and *M. indica*.

### **Factors of crop weed competition**

Weeds compete with crop plant for moisture, nutrients, light and space, thereby depriving crop of vital input. Therefore, weed competition is one of the most important constraints in crop production. Weed-crop competition begins, when crop plants and weeds grow in close proximity and their root or shoot system overlap. The competition becomes severe due to more smothering effect, when weeds emerge earlier than the crop. In rice-wheat system, due to enough soil

moisture after harvesting of rice, weeds emerge earlier than wheat. Losses in wheat yield are primarily due to reduction in tillering. Under ample soil water and plentiful nutrient supply condition light become the prime factor around which competition forces developed when two grasses grow in association at a nitrogen supply level the yield is limited by light. Cudeny *et al.*, (1991) observed that *Avena fatua* grew taller than wheat having plant height of 87 to 72 cm, respectively at anthesis under non limiting nitrogen and moisture condition and had a greater portion of their canopy above 80 cm at maturity (28 to 35 and 11.16%, respectively). Water is an essential factor for growth and development of crop plants. Wheat being post-monsoon crop, suffers from water scarcity due to presence of competing weeds if not managed. Competition between cereal crop and weed is primarily for N in early stage of crop growth and if weed is allowed to grow the growth and yield of crop adversely affected. Gautam *et al.*, (1975) from their studies on herbicide and interaction noted a loss of 40.5 kg N/ha in wheat due to weed competition. Weed control treatment increased the N, P and K uptake in crop 135.5, 149.0% and 148.6% compared to weedy check, respectively. Pandey and Singh (1983) observed when associated weeds were allowed to compete with the wheat crop up to harvest, they depleted 9.6, 1.13 and 5.12 kg of N, P and K<sub>2</sub>O/ha, respectively. Kundra and Singh (1985) found that quantity of N depletion by weed increased with advanced growth stage due to increased efficiency of applied herbicides and sugarcane of new flushes of weed resulting in increased weed dry matter production. Pandey *et al.*, (2000) summarized that an increasing fertilizer levels resulted significantly better crop performance along with higher weed count and weed dry weight than no fertilizer in wheat. Competition among plants depends on morphology differential response to

environmental parameters ability to extract nutrients and water from rain and other factors. Aldrich (1987) reported that reduction of yield includes environmental condition, time of emergence and possible allelopathic influence. Sage *et al.*, (1987) reported *Chenopodium album* was more productive at low nitrogen level and had greater nitrogen use efficiency than weeds like *Amaranthus retroflexus*. Martin and Field (1988) observed that emergence of wild oat 21 DAS did not affect yield of wheat such as simultaneous emergence of weed seed with wheat seedling. The critical period of weed control in wheat is 30-45 DAS and crop should be kept weed free during this period. Majority of farmers are not adhering to this critical period for management of weeds and they mostly delay the herbicide application.

#### **Effect of weeds on crop growth and yield**

Weed competitive efficiency in cereal crops depends more on root development, time of germination or development of large assimilation surface. Most of weeds had larger root systems and greater assimilation surface than cereals. Singh and Tondon (1966) reported yield reduction in wheat by individual of weed *i.e.* *Chenopodium album* and *Alium tenuifolius* were 25 and 13%, respectively. Nalawaja (1968) reported that densities of *Avena fatua* 70 and 160 yard<sup>2</sup> reduced wheat yield 20 and 39%, respectively compared to a weed free control. Gautum *et al.*, (1975) observed 60% wheat yield loss to unchecked weed growth. Reeves (1976) observed that number of fertile spikelets and dry matter production of wheat crop was reduced by presence of rye grass in wheat crop. Weed compete with crop plants for nutrients and other growth factors and in the absence of an effective control measure, remove considerable quantity of applied nutrients and decreased yield to a significant level. Tosh and Mishra (1977) observed that

grain yield of wheat was reduced by 66.7% due to the presence of *Digitaria sanguinalis*, *Phalaris minor*, *Eleusine indica*, *Acanthosperum trispidum* and *Eupatorium glandulosum*. Jalis and Brohi (1978) observed presence of weeds significantly reduced number and size of ears in wheat crop. Thomas and Yaduraju (1999) reported that increasing wild oat density from 0 to 288 m<sup>-2</sup> reduced leaf area of wheat at 60 DAS by 33-41% and at 90 DAS by 60-72% and dry matter production in range of 47-55 and 35-48% at 60 DAS and 69-73% at 90 DAS. Godel (1995) studies the effect of normal annual infestation of weeds on wheat and observed significant difference in number of tillers, length of ear weight of kernels and yield of crop due to weedy conditions. Verma and Pandey (2002) found weed competition results lowered crop yield by 27.2%. Verma and Pandey (2004) observed competition effect of wheat with canary grass, wild oat, blue pimpernel and lamb and reported crop yield loss up to 35%.

#### **Effect of herbicide mixture on crop growth and yield**

Chemical weed control method is preferred over other weed control methods because it is quick, more effective and relatively cheaper. Inorganic salts, copper sulphate, were used for controlling broad leaved weeds in cereals towards end of 19<sup>th</sup> century. Extensive use of relatively low dose (1-2 kg/ha) began with the launch of growth regulation herbicides MCPA. The success of these herbicides led to development and production of new herbicide groups and compound have their efficacy in minimizing weed menace in most crop including wheat. Today herbicides constitute integral part of weed management in crops for producing high economic yield. Further, increased use of herbicides can be attributed to increasing labour wages, unavailability of labours at critical period of weeding and to a

great extent infestation of weeds not easily distinguished from crop at early stages of growth (Yadav *et al.*, 2013).

## **2, 4-D**

The discipline of weed science began about 1945 with the introduction of selective, synthetic herbicides, beginning with 2, 4-D. The growing need for research to study the efficacy, mode of action, environmental effects, application technology, and other aspects of this herbicide led to extensive study in different parts of world. In India, since introduction of 2, 4-D as a herbicide has been widely used for the control of broad leaf weeds. Singh (1967) observed that 2,4-D sodium salt at 1.0 kg a.i./ha applied as pre-emergence and repeated post-emergence gave the best control of weeds and produced the highest yield of grain (34.1q/ha). Mishra and Mani (1968) recommended one spraying of 2, 4-D at 0.42 kg/ha applied 30 DAS for effective control of weeds and higher yield of tall wheat. Singh and Singh (1979) noted on increase of 24.6% in wheat grain yield due to application of 2,4-D ester salt. Nayak *et al.*, (2003) revealed that all the weed control treatments significantly decreased the dry weight of weeds at harvest of crop compared to weedy control. Among the herbicidal treatments 2, 4-D and metsulfuron-methyl alone and their combinations showed their superiority over isoproturon alone and combination of isoproturon with metsulfuron-methyl. Grain yield of wheat was recorded the highest with hand weeding followed by combined application of 2, 4-D and metsulfuron-methyl at 500 g/ha and 2 or 4 g/ha, respectively. Singh *et al.*, (2013) found that metsulfuron+2,4-D @ 6g and 500g/ha was most effective herbicide for controlling of both type of weed flora i.e narrow and BLWs throughout the growing season in wheat. Similarly, maximum yield was achieved with the application of metsulfuron

+2, 4-D, and increase in grain yield of wheat crop owing to better control of weeds.

## **Carfentrazone-ethyl**

Carfentrazone-ethyl belongs to aryl triazolinone family, which has been found effective to control BLWs in wheat by inhibiting activity of protoporphyrinogen oxidase in chlorophyll biosynthetic pathway was evaluated against these weeds and compared with existing recommended herbicides in wheat (Witkowsski and Halling, 1989). Recently, carfentrazone has been recommended for BLWs control and added advantage with this herbicide is that it has very fast action and control *Malva spp* and *Solanum nigrum*. Singh *et al.*, (2004) reported that Carfentrazone had better efficacy than 2, 4-D and was comparable with metsulfuron. The grain yields recorded in wheat treated with carfentrazone-ethyl and metsulfuron-methyl were similar to weed-free control. The total weed dry matter production in 2, 4-D treated plots was higher than that of carfentrazone-ethyl. Patel *et al.*, (2005) conducted field study at Anand, Gujarat and reported that Carfentrazone-ethyl at 20 g/ha recorded comparable yield to 2, 4-D at recommended rate. Punia *et al.*, (2006) reported that post-emergence application of Carfentrazone at 20 g/ ha provided (92-100) % control of all broadleaf weeds including hard controlling weeds *Malva parviflora* and *convolvulus arvensis* in wheat with no residual effect on succeeding sorghum crop. Chopra *et al.*, (2008) reported that carfentrazone 20 g/ha and metsulfuron 4 g/ha controlled 83.7 and 84.1% of broadleaf weeds-respectively and increased seed yield significantly. Carfentrazone at 10 and 20 g/ha and metsulfuron 4 g/ha did not cause any adverse effect on seed germination and vigour hence can be used in seed production plots of wheat.

### **Carfentrazone ethyl+other herbicide (mixture)**

Chopra and Chopra (2005) observed that tank mixture of clodinafop (60 g/ha) with carfentrazone (20 g/ha) controlled both grassy and BLWs resulting 88-90% weed control efficiency and significantly increase seed yield of wheat over sole application of clodinafop and fenoxaprop, tank mixture of metribuzin and isoproturon with carfentrazone and metsulfuron. Singh and Singh (2005) found clodinafop-propargyl was compatible with metsulfuron-methyl [metsulfuron] and carfentrazone-ethyl [carfentrazone] (tank mixture) with regard to the control of *Phalaris minor* and *Chenopodium album* in wheat. Fenoxaprop-P-ethyl was compatible with carfentrazone-ethyl but not with metsulfuron-methyl. Similarly, post-emergence (35-40 DAS) application of triasulfuron at 15 g/ha (with and without 1% surfactant) and 20 g/ha alone as well as carfentrazone-ethyl 20 and 25 g/ha controlled BLWs in wheat very effectively and produced grain yield at par with the already recommended herbicide *i.e.* 2, 4-D 0.5 kg/ha (Walia and Singh, 2007). Chopra *et al.*, (2008) studied the effect of different herbicides as sole and their tank mixtures on wheat (*Triticum aestivum*) and reported that highest grain yield of 4.49 t/ha was recorded with fenoxaprop-*p*-ethyl + carfentrazone (100+10 g/ha) applied 30 days after sowing, which was at par with weed-free treatment. Although tank mixture of isoproturon + carfentrazone showed greater control of BLWs, it gave significantly lower control of grassy weed (*Phalaris minor*) compared with fenoxaprop-*p*-ethyl + carfentrazone. Metsulfuron alone at 4 and 8 g/ha was superior to 2, 4-D and carfentrazone 10 g/ha for dry weight of weeds and weed control efficiency. There was a reduction of 25.7% in the seed yield under weedy control conditions. Yadav *et al.*, (2009) evaluated the

compatibility of fenoxaprop-P-ethyl with carfentrazone-ethyl for the control of complex weed flora in wheat. Among all the treatments, maximum number of effective tillers and grain yield were recorded with fenoxaprop + carfentrazone 120 g/ha (5: 1). Carfentrazone was compatible with fenoxaprop as tank mixture and there was no adverse effect on efficacy of both the herbicides. Fenoxaprop + carfentrazone 120 g/ha (5: 1) appeared to be best combination for achieving maximum WCE (%) and improved grain yield. Metsulfuron 2, 4-D Ester and Na salt had antagonistic effect on efficacy of fenoxaprop when applied as tank mixture with it. Mustari *et al.*, (2014) reported carfentrazone-ethyl + Isoproteuron contributed to the highest grain yield.

### **Metsulfuron-methyl**

Sharma and Ahuja (2001) evaluated bio-efficacy of chlorsulfuron, metsulfuron-methyl and metribuzin and reported yield obtained with the application of chlorsulfuron at 30 g/ha, metsulfuron-methyl at 8 g/ha and alone and combine application of chlorsulfuron at 15 g/ha and Metribuzin at 100 and 200 g/ha were statistically similar to weed free. Similarly, Singh and Ali (2004) assessed efficacy of metsulfuron-methyl against *Chenopodium album*, *Chenopodium murale*, *Lathyrus aphaca*, *Melilotus alba*, *Rumex dentatus*, *Convolvulus arvensis*, *Vicia hirsute*, *Medicago denticulate*, *Avena ludoviciana* [*Avena sterilis sub sp. Ludoviciana*], *Cynodon dactylon* and *Cyperus rotundus* in wheat and its residual effects on succeeding soybean crop. Results revealed application of metsulfuron-methyl was very effective against the broad leaved weeds and did not have any residual effect on succeeding soybean crop. Metsulfuron-methyl 4 g /ha was most effective in controlling BLWs and was greater than 2,4-D and farmers' practice in increasing wheat yield. Hooda *et al.*,

(2007) reported that all the yield attributes remained statistically at par with each other in plots treated with various doses of metsulfuron-methyl (2,4 and 8 g/ha). However, among different doses of metsulfuron-methyl, 8.0 g/ha recorded maximum value for yield attributes. Among the plots treated with metsulfuron-methyl, these differences were, however, non significant because wheat might have metabolized herbicide with time. Nayak *et al.*, (2003) also reported similar results. Malik *et al.*, (2008) reported chlorsulfuron 30 g/ha, metsulfuron 4 g/ha and triasulfuron 60 g/ha reduced density of different BLWs in wheat to the extent of 90-100% and proved better than sulfosulfuron (20 and 25 g/ha) and 2, 4-D Na salt (500 and 750 g/ha). Chopra and Chopra (2010) reported sequential or tank mixture application of fenoxaprop (100 g/ha) and clodinafop (60 g/ha) with metsulfuron at 4 g *a.i.* /ha were more effective than their individual application.

#### **Metsulfuron-methyl + other herbicide (mixture)**

Advantage of combination of metsulfuron and carfentrazone over alone application of metsulfuron and carfentrazone will be in situations having the diverse infestation BLWs particularly *M. parviflora*, *S. nigrum* and *L. aphaca*. Ready mix combination of metsulfuron + carfentrazone will provide the control of these weeds. Kurchania *et al.*, (2000) revealed that the higher grain yield of wheat was obtained with the application of metsulfuron-methyl at 4 g/ha+2,4-D @ 500 g/ha or metsulfuron-methyl at 4 g/ha +2,4-D at 250 g/ha and HW under weedy control. However, yield differences amongst metsulfuron-methyl at 2 and 4 g/ha either alone or in mixed application with, 2, 4-D was not significant. Pandey *et al.*, (2000) reported that effect of Metsulfuron methyl, 2, 4-D and their tank mix on weeds. All the

weed control treatments significantly decreased weed dry matter production, where in the combined application of metsulfuron methyl+2, 4-D was lower than 2, 4-D alone and Isoproturon. Combined application of 4 g Metsulfuron-methyl/ha and 500 g 2, 4-D Na salt/ha had the highest grain yield compared to other treatments. Nayak *et al.*, (2003) revealed weed control treatments significantly decreased dry weight of weeds compared to weedy control. Among herbicidal treatments 2, 4-D and metsulfuron-methyl alone and their combinations showed their superiority over Isoproturon alone and combination of Isoproturon with Metsulfuron-methyl. Yadav *et al.*, (2009) found tank mix or sequential application of sulfosulfuron with carfentrazone being at par reduced density and dry weight of *P. minor* similar to sulfosulfuron alone. Hence, carfentrazone was found compatible with sulfosulfuron as tank mixture against complex weed flora in wheat with no loss of herbicidal efficacy. Jat *et al.*, (2007) found that metsulfuron-methyl alone and in combination with clodinafop, fenoxaprop and sulfosulfuron provide excellent control of BLWs. Sulfosulfuron alone controlled both grassy and BLWs but its efficacy against grasses was lower than clodinafop and fenoxaprop and against BLWs than metsulfuron. Sequential application of clodinafop *fb* metsulfuron and fenoxaprop *fb* metsulfuron efficiently controlled complex weed flora and produced maximum grain yield and minimum weed population. Kaur *et al.*, (2007) reported new alternative post emergence herbicides *i.e.* pinoxaden, sulfosulfuron+metsulfuron, mesosulfuron+iodosulfuron and trifluralin as pre emergence herbicides were found significantly superior to sulfosulfuron and clodinafop for controlling isoproturon resistant *P. minor*. Brar and Walia (2009) recorded significant reduction in population of *Phalaris minor* as well as broad leaf weeds and increased grain yield of wheat were observed with post

emergence application of clodinafop 60 g/ha followed by 2,4-D 0.5 kg/ha and metsulfuron + iodosulfuron 12 g/ha than clodinafop 60 g/ha alone and control. Among weed control practices sulfosulfuron 25 g/ha recorded highest yield of wheat. Similarly, Singh *et al.*, (1999) reported improved control of hard weed Canada thistle (*C. arvensis*) with tank mix application of herbicides. Paighan *et al.*, (2013) observed among chemical treatments, application of metsulfuron-methyl 4 g/ha gave significantly higher growth and yield attributes of wheat.

Amanpreet and Walia (2010) revealed tall doses of Atlantis 3.6 WDG (metsulfuron + iodosulfuron) *i.e.* 12 g, 18 g, and 24 g/ha were at par with respect to yield of wheat, irrespective of variable soil moisture levels present at the time of their application and gave an effective killing of weeds resulting in 100% reduction of weeds dry matter compared to unsprayed control. Herbicide applied to wheat showed no adverse effect on germination and growth of succeeding *kharif* crops including summer moong, cotton, okra and *sesbania*. Walia *et al.*, (2010) evaluated the performance of new herbicide mixture AEF 04-6340-8% + DIC 1468-14%-22% EC (fenoxaprop-p-ethyl + metribuzin) for control of grassy and broad leaf weeds. Application of this herbicide at 1.25 and 1.5 liter/ha of commercial product provided effective control of *P. minor* and BLWs of wheat crop and were found statistically at par with Atlantis (metsulfuron-methyl + iodosulfuron-methyl) 3.6 WDG 400 g/ha of commercial product with respect to dry matter accumulation by *Phalaris minor* and BLWs. Yasin *et al.*, (2010) reported fenoxaprop-p-ethyl (Puma Super-75 EW) at 45 g a.i./ha produced relatively less weed biomass and grain yield (4.2 t/ha) *fb* fenoxaprop-p-ethyl (Chinlima-6.9 EW) at 85 g a.i./ha, which was statistically at par with fenoxaprop-p-ethyl (Gramicide-6.9 EW) at 85 g a.i./ha. Singh *et*

*al.*, (2011) reported better control of *R. spinosus* (92%) with metsulfuron + carfentrazone tank mixture compared to sole application of either metsulfuron (85%) or carfentrazone (78%). This mixture was better than 2, 4-D formulations as none of the 2, 4-D formulations was effective against *R. spinosus*.

### **Effect of surfactant on efficiency of herbicides**

Surfactants are used as additives to herbicidal sprays to enhance effect of herbicides on target species. Herbicide spray containing surfactants produce smaller droplets, which spread more uniformly on the plant surface, improve wetting of leaves and spreading of on leaf by lowering surface tension. Most of the leaf surface covered with waxes; surfactants dissolve the circular waxes and enhance foliar retention and penetration of herbicide. They also reduce rate of evaporation and thereby increase herbicide uptake.

Glyphosate providing only 14% control of *Richardia brasiliensis*, tank mix application of 2, 4-D increased the efficiency to 83% and addition of surfactant increased mortality by 96-100% (Sharma and Singh, 2001). Tank mixing of non-ionic and organ silicone surfactants with glyphosate decreased surface tension and contact angle and disrupted or dissolved the waxy layer present at leaf surface to allow greater penetration of glyphosate. Sharma and Singh (1999) assess the effect of metsulfuron-methyl [metsulfuron] (MSM; at 1 and 4 g/ha) alone and in combination with 2, 4-D at 250 and 500 g/ha and surfactant (Triton) at 0.1% on non grassy weeds in wheat cv. UP 2338. Results revealed WCE of MSM at 4 g/ha applied alone was similar to MSM at 2g/ha applied with surfactant. Ready mix formulation of MSM+2,4-D at 2+250 g/ha + surfactant had weed control efficacy similar

to ready mix formulation of MSM+2,4-D at 2.0 +500 g/ha + surfactant or MSM+2,4-D at 4.0+500 g/ha. MSM alone was relatively better than 2,4-D applied alone. Application of ready mix formulation of MSM applied alone or in combination with 2,4-D and surfactant, being at per among them, had

significantly more grain yield compare to application of 2,4-D alone at 500 g/ha ethyl ester or sodium salt. Saini and Angiras (2000) determined the optimum rate of sulfosulfuron (15, 22, 30, 37.5 g a.i. /ha) for controlling weeds in rained wheat (*Triticum aestivum*) cv. Surbhi.

**Table.1** Major weeds in different wheat growing zones in India

S.No.	Zone	Weed species mostly infesting
1.	NHZ [J&K (except Jammu and Kathua); H.P. (except Una and Paonta Valley); Uttaranchal (except Tarai area); Sikkim and hills of West Bengal and N.E. States]	<i>Anagallis arvensis</i> L., <i>Avena fatua</i> L., <i>Avena ludoviciana</i> Dur., <i>Capsella bursa-pastoris</i> (L.) Medik., <i>Chenopodium album</i> L., <i>Convolvulus arvensis</i> L., <i>Coronopus didymus</i> L., <i>Fumaria parviflora</i> Lamk., <i>Juncus bufonius</i> L., <i>Lathyrus aphaca</i> L., <i>Lolium temulentum</i> L., <i>Medicago denticulata</i> L., <i>Melilotus alba</i> Lamk., <i>Phalaris minor</i> Retz., <i>Poa annua</i> L., <i>Polygonum nepalense</i> Meissn., <i>Ranunculus spp.</i> , <i>Sorghum halepense</i> (L.) Pers., <i>Stellaria media</i> (L.) Vallars, <i>Veronica persica</i> Poir., <i>Vicia sativa</i> L.
2.	NWPZ [Punjab, Haryana, Delhi, Rajasthan (except Kota and Udaipur divisions) and Western UP (except Jhansi division), parts of J&K (Jammu and Kathua distt.) and parts of HP (Una distt. and Paonta valley) and Uttaranchal (Tarai region)]	<i>Alhagi pseudoalhagi</i> (Beib.) Desv., <i>Anagallis arvensis</i> L., <i>Argemone mexicana</i> L., <i>Avena fatua</i> L., <i>Avena ludoviciana</i> Dur., <i>Asphodelus tenuifolius</i> Cav., <i>Carthamus oxycantha</i> Beib, <i>Chenopodium album</i> L., <i>Chenopodium murale</i> L., <i>Convolvulus arvensis</i> L., <i>Coronopus didymus</i> L., <i>Cirsium arvense</i> L., <i>Daucus carota</i> L., <i>Euphorbia helioscopia</i> L., <i>Fumaria parviflora</i> Lamk., <i>Lathyrus aphaca</i> L., <i>Malva neglecta</i> , <i>Malva parviflora</i> , <i>Medicago denticulata</i> Willd, <i>Melilotus alba</i> Lamk., <i>Melilotus indica</i> All., <i>Phalaris minor</i> Retz., <i>Poa annua</i> L., <i>Polygonum plebejum</i> R. Br., <i>Polypogon monspensis</i> (L.) Desf., <i>Rumex dentatus</i> L., <i>Solanum nigrum</i> , <i>Spergula arvensis</i> L., <i>Stellaria media</i> (L.) Vallars, <i>Trigonella incise</i> Benth., <i>Trigonella polycerata</i> , <i>Veronica agrestis</i> L., <i>Vicia sativa</i> L., <i>Vicia hirsute</i> Koch.,
3.	NEPZ (Eastern UP, Bihar, Jharkhand, Orissa, West Bengal, Assam and plains of N.E. States)	<i>Ageratum conyzoides</i> L., <i>Alternanthera sessilis</i> (L.), <i>Anagallis arvensis</i> L., <i>Argemone mexicana</i> L., <i>Asphodelus tenuifolius</i> Cav., <i>Avena fatua</i> L., <i>Brachiaria mutica</i> , <i>Brachiaria ramosa</i> , <i>Cannabis sativa</i> L., <i>Celosia argentea</i> L., <i>Chenopodium album</i> L., <i>Chenopodium ficifolium</i> , <i>Chenopodium murale</i> L., <i>Cirsium arvense</i>

		<p>(L.), <i>Commelina benghalensis</i> L., <i>Convolvulus arvensis</i> L., <i>Coronopus didymus</i> (L.), <i>Cyanotis cuculata</i>, <i>Cynodon dactylon</i> Pers., <i>Cyperus iria</i> L., <i>Cyperus rotundus</i> L., <i>Desmodium triflorum</i> (L.) DC., <i>Digitaria ciliaris</i> (Retz) Koel., <i>Digitaria sanguinalis</i> (L.) Scop., <i>Drymaria vilosa</i>, <i>Echinochloa colona</i> (L.) Link, <i>Eclipta alba</i>, <i>Eclipta prostrata</i> L., <i>Eleusine indica</i> Gaerts., <i>Eragrostis ferrogina</i> Beauv., <i>Euphorbia dracunculoides</i>, <i>Fibristylis miliacea</i>, <i>Fumaria indica</i> Pugsley, <i>Fumaria parviflora</i>, <i>Galinsoga parviflora</i> Cav., <i>Gnaphalium pensylvanicum</i> Willd., <i>Gnaphalium purpureum</i>, <i>Grangea maderaspatana</i> (L.) Poir., <i>Lathyrus aphaca</i> L., <i>Lathyrus sativa</i> L., <i>Leucas aspera</i>, <i>Ludwigia perennis</i>, <i>Medicago denticulata</i>, <i>Melilotus alba</i> Lamk., <i>Melilotus indica</i> All., <i>Mimosa pudica</i> L., <i>Murdannia nudiflora</i>(L.) Brenan, <i>Oxallis corniculata</i> L., <i>Panicum repens</i> L., <i>Parthenium hysterophorus</i> L., <i>Paspalum scorbiculatam</i> L., <i>Phalaris minor</i> Retz., <i>Physalis minima</i>, <i>Poa annua</i> L., <i>Polygonum barbatum</i> L., <i>Polygonum erectum</i>, <i>Polygonum plebejium</i> R. Br., <i>Polypogon monsplensis</i> (L.) Desf., <i>Rumex dentatus</i> L., <i>Scirpus articulatus</i>, <i>Solanum nigrum</i>, <i>Spergula arvensis</i> L., <i>Sporobolus indicus</i> (L.) R.Br. Var.diader, <i>Stellaria media</i> (L.) Vallars, <i>Vicia hirsute</i> Koch., <i>Vicia sativa</i>, <i>Xanthium stumarium</i>,</p>
4.	CZ (Madhya Pradesh, Chhattisgarh, Gujarat, Kota and Udaipur divisions of Rajasthan and Jhansi division of Uttar Pradesh)	<p><i>Achyranthus aspera</i> L., <i>Alhagi pseudolhagi</i> (Beib.) Desv., <i>Amarantus viridis</i> L., <i>Anagallis arvensis</i> L., <i>Argemone maxicana</i> L., <i>Asphodelus tenuifolius</i> Cav., <i>Avena fatua</i> L., <i>Avena ludoviciana</i> Dur., <i>Boerhaavia</i> spp., <i>Brassica kaber</i>, <i>Brassica sinensis</i>, <i>Chenopodium album</i> L., <i>Chenopodium murale</i> L., <i>Chrozophera perviflora</i> L., <i>Cichorium intybus</i> L., <i>Cirsium arvense</i> L., <i>Convolvulus arvensis</i> L., <i>Cynodon dactylon</i> Pers., <i>Cyperus iria</i> L., <i>Cyperus rotundus</i> L., <i>Dactyloctenium aegyptium</i> L., <i>Digera arvensis</i>, <i>Digitaria adscendens</i>, <i>Dinebra retroflexa</i> (Vahl.) Panzer, <i>Echinochloa colona</i> (L.) Link, <i>Eclipta alba</i>, <i>Eleusine indica</i> Gaerts., <i>Eragrostis cilienensis</i> (All) Link., <i>Eragrostis major</i>, <i>Euphorbia geniculata</i> Ortega, <i>Euphorbia hirta</i> L., <i>Fumaria parviflora</i>, <i>Lathyrus aphaca</i> L., <i>Launaea asplenifolia</i> (willd.) Hook. f., <i>Medicago denticulata</i>, <i>Melilotus alba</i> lamk., <i>Melilotus indica</i> All., <i>Melilotus parviflora</i>, <i>Melilotus sativa</i>, <i>Melotropicum</i></p>

		<i>indicum</i> , <i>Parthenium hysterophorus</i> L., <i>Phalaris minor</i> Retz., <i>Phyllanthus fraternus</i> Webster., <i>Physalis minima</i> , <i>Ranunculus acutus</i> , <i>Rumex dentatus</i> L., <i>Solanum nigrum</i> , <i>Sonchus asper</i> (L.) Hill., <i>Spergula arvensis</i> L., <i>Sphaeranthus indicus</i> L., <i>Stellaria media</i> (L.) Scop., <i>Suaeda maritime</i> (L.) Dum., <i>Tephrosia pururea</i> , <i>Tribulus terrestris</i> L., <i>Tridax procumbens</i> L., <i>Vicia hirsute</i> Koch., <i>Vicia sativa</i> , <i>Xanthium strumarium</i> ,
5.	PZ (Maharashtra, Karnataka, Andhra Pradesh, Goa, plains of Tamil Nadu)	<i>Alternanthera sessilis</i> L., <i>Amarantus graceizans</i> L., <i>Anagallis arvensis</i> L., <i>Argemone mexicana</i> L., <i>Asphodelus tenuifolius</i> Cav., <i>Avena fatua</i> L., <i>Bidens pilosa</i> , <i>Brachiaria eruciformis</i> L., <i>Brassica arvensis</i> L., <i>Cassia</i> spp., <i>Celosia argentic</i> , <i>Chenopodium album</i> L., <i>Commelina benghalensis</i> L., <i>Convolvulus arvensis</i> L., <i>Chrozophera perviflora</i> L., <i>Cynodon dactylon</i> Pers., <i>Cyperus rotundus</i> L., <i>Digera arvensis</i> , <i>Digitaria adscendens</i> , <i>Dinebra retroflexa</i> , <i>Echinochloa colona</i> (L.) Link, <i>Euphorbia hirta</i> L., <i>Lactuca runcinata</i> DC., <i>Lagascea mollis</i> , <i>Leucas aspera</i> , <i>Melilotus alba</i> Lamk., <i>Parthenium hysterophorus</i> L., <i>Phyllanthus</i> spp., <i>Portulaca oleracea</i> L., <i>Physalis minima</i> , <i>Setaria verticillata</i> , <i>Sonchus wightianus</i> DC., <i>Spergula arvensis</i> L., <i>Sphaeranthus senegalensis</i> DC., <i>Trianthema portulacastrum</i> , <i>Zizipus jujube</i> Lamk.

The dominant weeds in the experimental field were *Avena fatua*, *Phalaris minor*, *Lolium temulentum*, *Coronopus didymus*, *Anagallis arvensis*, *Stellaria madia* and *Vicia sp.* Sulfosulfuron at 30 g a.i. /ha was par with sulfosulfuron 30 g a.i./ha + surfactant and sulfosulfuron at 37.5 g a.i./ha or without surfactant in significantly reducing weed dry weight and increasing crop yield. A field experiment was conducted to assess effect of Metsulfuron-methyl alone and in combination with 2,4-D. Application of metsulfuron-methyl alone was relatively better than 2,4-D applied alone. Application of ready mix formulation of metsulfuron-methyl alone or in combination with 2,4-D and surfactant, being at par among them had significantly more yield compare to application of 2,4-D alone (Singh *et al.*, 2002). Singh (2006) conducted an experiment to evaluate effect of growth stage and surfactant

on the efficacy of sulfosulfuron against some grass and BLWs. Effect of sulfosulfuron was more when applied at 2 to 3 leaf stage compared to 4 to 6 leaf stage, particularly for BLWs. Surfactants significantly increase the herbicidal activity of sulfosulfuron; the effect was more conspicuous on broad leaf weeds.

In conclusion, weeds pose severe competition with the crops for various growth resources. Besides reduction in grain yield, weeds also reduce the quality of produce and act as alternate host for disease causing organisms and insect-pests. Hence, various weed management practices need to be integrated in an appropriate manner during critical period of crop-weed competition. Research on herbicide mixture, post-emergence herbicides in pulses and oilseed, management of parasitic weeds, weed competitive crop cultivars with acceptable yield

potential, weed management in changing climate scenario and conservation agriculture, effect of herbicides on soil microorganisms need to be strengthened. Considering several advantages of using herbicide resistant crop, it is worthwhile exploring their possible use under Indian conditions.

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