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Challenges of Herbicide Resistant Weeds in Wheat in India and its Management: A Review

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ABSTRACT

Agriculture is an important part of the India's economy. India ranks first in net cropland area in the world with 179.8 mha which is 9.6% of global net cropland area and India's agriculture sector makes up 16% of the country's economy, while accounting for 49% of employment (FAOSTAT, 2020). The rice-wheat cropping system (RWCS) is extensive in the subtropical areas of the Indo-Gangetic Plains of India while maize-wheat is widespread in tropical, sub-tropical and warm temperate regions. In north India, rice is grown in the summer season (June/July to September/October) whereas wheat is grown in the winter season (October/November to February/ March). The area under wheat in India was 30.59 mha with an annual production of 99.78 mt and average productivity of 3.22 t ha^{-1} (Anonymous, 2019). The weeds are accounting as a major factor in yield reduction of wheat. The mechanical weed control is not so much effective in controlling weeds in wheat because of narrow inter row spacing. Further, the manual weeding is not much feasible because of mimicry weeds like *Phalaris minor* which are very much similar to wheat during initial stages. Therefore, the role of herbicides cannot be neglected. But the continuous application of herbicides with same mode of action year by year has resulted in evolution of herbicide resistance in weed species. The management of herbicide resistant weeds in crop production is a major challenge. This review mainly focuses on the current status of herbicide resistant weeds in India associated with wheat along with their management strategies.

Key words: Herbicides, Integrated weed management, Phalaris minor, Resistance, Wheat.

Weeds menace in agriculture

Weeds are the major biological constraints that halt potential productivity of any crop. Weeds can be defined as the plants growing out of place which interfere with intended land use and water resources. They are having specific features or characters which make them different from the other growing plants such as seed dormancy, abundant seed production and rapid establishment with highly competitive nature. The multiple adaptations and plasticity of weeds provide them an advantage over cultivated crops. Also, the practice of intensive agriculture with high yield and dwarf varieties provided favorable conditions for better growth of weeds compared to the earlier taller cultivars (Sharma and Kaur, 2012). They are perennial problems and numerous resources spent on them by the farmers to reduce their impact. In India, the highest loss is caused by weeds *i.e.* about 33% followed 26% by pathogens, 20% by insects, 7% by storage pests, 6% by rodents and 8% by others (Oerke, 2006). The losses due to weeds depend on type of weed species, weed density, duration of infestation, cropping system, soil and environmental conditions (Chhokar *et al.* 2012). It has been calculated that weeds cause a total economic loss in arable crops equivalent to approximately USD 11-13 billion per annum (Rao, 2018).

Major weed flora of wheat

Wheat (*Triticum aestivum*) is invaded with composite weed flora consisting of grass along with broadleaf weeds. Amongst grasses, *Phalaris minor, Avena ludoviciana, Poa annua* and *Polypogon monspeliensis* are dominant and *Chenopodium album, C. murale, Rumex dentatus, Rumex spinosus, Coronopus didymus, Anagallis arvensis, Medicago denticulata, Melilotus indica, Malva parviflora* and *Convolvulus arvensis* amongst broad leaf weeds are dominant weed species (Punia *et al.,* 2017). A shift in the weed flora in wheat has been observed with time. During 1960s, *Carthamus oxycantha* was the major weed to wheat but it got eliminated with increase in irrigated area (Chhokar *et al.,* 2012).

With the advancement of high yielding dwarf wheat varieties along with higher doses of fertilizers and assured irrigation, resulted in replacement of several broadleaf weeds by *P. minor* and *Avena ludoviciana.* With time *P. minor* became the major weed in the RWCS and *A. ludoviciana* in

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irrigated, well drained, lighter textured soils in the other cropping systems. Morphological similarities between these grass weeds and wheat along with closer row spacing of the crop makes manual weed removal very difficult. *P. minor* now became a nuisance for sustainable wheat production in the rice-wheat growing regions of different states in India. As, area under zero till conditions is increasing, it also led to the infestation of broad leaf weeds such as *R. dentatus* (Chhokar *et al.,* 2012).

Losses caused by weeds in wheat crop

Weeds are a serious problem responsible for lowering the wheat productivity to the tune of 15-80% or even higher based upon their type, intensity of infestation and management practices but in extreme cases there could be complete crop failure (Yaduraju *et al.* 2006). The weeds in different wheat growing regions causing a yield loss of about 20-30% and may reach up to 60% (Mongia *et al.* 2005, Chhokar *et al.* 2008). Weed infestation also increases cost of cultivation, impair crop produce quality, interfere with farm operations and spread several insect pests, diseases and nematodes by acting as alternate hosts (Rana and Rana, 2016).

Weed management practices

Cultural practices

Cultural practices comprise of crop rotation, increased crop density, crop geometry, stale bed and manipulation of sowing time. By adopting these practices, we can reduce the herbicide use in crop production. The following cultural practices can be adopted for effective management of weeds in wheat.

Planting time

Planting time considerably influences the germination and establishment of weeds. Early sowing of wheat in the last week of October to first week of November reduces in-crop infestation of *P. minor* as warmer temperature at that time is not favorable for the germination of this weed (Bhullar *et al.* 2017). Under these situations, *P. minor* seeds will germinate with the first irrigation and encounter strong competition by wheat. The early sowing of wheat may encourage infestation of wild oat in non-rice growing area but it can be controlled effectively with available herbicides.

Crop rotation

Crop rotation helps in lowering down the weed infestation by disrupting the life cycle of weeds by rotating the crops which require different management practices. For example, the seed bank of *P. minor* can be eliminated within a span of 2 to 3 years by replacing wheat with berseem (*Egyptian clover)*, potato, rapeseed and mustard, winter maize, autumn sugarcane, sunflower in winter season, or by replacement of rice with cotton, maize and sugarcane in summer season. The adoption of rice-potato/vegetable pea-wheat, rice-potato-sunflower and rice-berseem in place of rice-wheat system significantly reduce the infestation of *P. minor* compared to rice-wheat system. Including fodder crops such as berseem in cropping system significantly reduced the seed bank of *P. minor* within three years (Banga *et al*., 1997). In potato-based crop rotations, manual removal of *P. minor* plants at potato harvest reduced *P. minor* infestation by >90% in succeeding wheat (Walia and Brar, 2004):

Treatment (rotation)	Dry matter of *Phalaris minor* (g/m^2)
Rice-wheat (herbicide)	20.9
Rice-wheat (control)	455.3
Rice-potato-wheat	0.0
Rice-potato-sunflower	0.0
Rice-berseem	0.0
Rice-gobhi sarson	1.3
LSD (P= 0.05)	4.0

Sowing method and seed rate

Sowing of wheat at narrow spacing (15 cm) is helpful in reducing the infestation of P. minor and other grass and broad leaf weeds. Also, bi directional sowing of wheat at 22.5 ×22.5 cm reduced density of *P. minor* as compared to broadcast, closer (15.0 cm) and normal sowing (22.5 cm) (Singh and Singh, 1996). Increased seed rate of wheat (150kg/ha) also reduced biomass of *P. minor* by >40% and increased grain yield of wheat compared to wheat sown at the recommended seed rate (100 kg/ha) (Bhullar and Walia, 2004). The use of higher crop seed rate shifts the use of resources in favor of crop plants and reduces availability for weed plants (Yaduraju and Ahuja, 1997). Planting techniques of wheat also affect the dry matter accumulation of *Phalaris minor* (Brar and Walia, 2007):

Planting techniques	Dry matter accumulation by P. minor (g/m^2)	Dry matter accumulation by broadleaf weeds (g/m^2)
Conventional tillage	7.89 (61.3)	6.75 (44.6)
Zero till sowing (without stubbles)	7.28 (52.0)	6.93 (47.1)
Zero till sowing (in standing stubbles)	5.25 (26.5)	4.81 (22.1)
Zero till sowing after partial burning	6.04 (35.6)	5.50 (29.3)
Bed planting	5.52 (29.5)	5.18 (25.9)
LSD (P= 0.05)	1.57	1.24

*Data were transformed to square root and values in parentheses are original values.

Competitive variety

The different wheat cultivars have their different competitive ability to compete with weeds. The different characteristics of wheat cultivars such as greater early vigour along with high tillering capacity help them to compete with weeds. The tall wheat varieties resulted in better weed control as compared to dwarf ones although they cannot be adopted

Treatment	Weed density (No./m²)		Weed dry wt (g/m²)	Grain yield (kg/ha)
	Grasses	Broadleaves		
No stale seedbed	54	68	185	540
Stale seedbed with one irrigation	30	28	70	1684
Stale seedbed with two irrigations	12	12	25	2620
No stale seedbed + HW	18	14	39	2236
Stale seedbed with one irrigation + HW	14	7	23	2638
Stale seedbed with two irrigations + HW	3	2	5	2930
LSD (P=0.05)	7	9	19	305

because of their poor yield. It was reported that wheat cultivars namely HD 3086, PBW 677, PBW 725, HD 2967, PBW 621 and PBW 550 resulted in more suppression of *P. minor* due to their quick growing and vigorous nature as compared to DBW 17 and WH 542 (Sharma and Kaur, 2012).

Stale seed bed

Under this technique, double pre-sowing irrigation is given before field preparation for the wheat to stimulate the germination of the weeds. Then these germinated weeds are killed with the help of non-selective herbicide or uprooted by shallow cultivation before sowing. This practice played a significant role in reducing the weed seed bank in the soil. Kumar *et al.* (2013) studied the effect of stale seedbed technique and hand weeding on weed density and dry weight at 60 DAS and grain yield of DSR rice:

Soil mulch

The soil mulch is having multiple effects including the weed control. After the seed bed preparation with conventional tillage, the upper layer of the soil is allowed to dry thus forming a soil mulch before wheat sowing and wheat seeds are sown at a depth of 4 to 5 cm (Ramakrishna *et al.* 2006). The most of the weed seeds are present in the top soil and they will not germinate until the first irrigation.

Mechanical

The mechanical tillage is associated with cultivating tillage and plays a significant role in weed control. The cultivating tillage is performed after the crop sowing and weeds are removed by shallow tillage with the help of hoes or harrows. It consists inter row, intra row and whole crop cultivation. It helps in tearing weeds into small pieces, uproots them and mixed them into the soil (Kurstjens and Kropff, 2001). It controls the weeds propagated with seeds during their early developmental stages.

Herbicide

Globally, herbicides are the key tool for management of weeds in wheat crop due to its high economical efficiency and quick knockdown effect. But sole dependence on herbicides resulted in appearance of multiple problems associated with injudicious and frequent use of herbicides such as weed shift, residue accumulation in soil, environmental pollution and accelerated herbicide resistance that limit the potential wheat production globally (Chhokar *et al* 2012). Herbicides act on the weeds and inhibit enzyme activities responsible for essential plant processes like amino acid synthesis (sulfosulfuron, metsulfuron), fatty acid synthesis (pinoxaden, clodinafop, fenoxaprop), photosynthesis (isoproturon, metribuzin) or cell division (pendimethalin) leading to their death. Punia *et al.* (2017) evaluated the various herbicides alone and in combination for controlling the different weed population in wheat crop:

Treatment	*Phalaris minor* (No./m²)	BLW (No./m²)
Pinoxaden 50 g/ha	5.2 (26.7)	6.4 (41.3)
Clodinafop 60 g/ha	9.9 (97.3)	6.3 (38.7)
Fenoxaprop 120 g/ha	10.4 (107)	6.6 (42.7)
Sulfosulfuron 25 g/ha	7.5 (56.0)	3.7 (13.3)
Mesosulfuron + iodosulfuron (14.4 g/ha)	3.2 (12.0)	2.9 (8.0)
Fenoxaprop + metribuzin (100+175 g/ha)	6.8 (45.3)	3.2 (9.3)
Clodinafop + metribuzin (60+210 g/ha)	6.0 (34.7)	3.2 (9.3)
Sulfosulfuron + metsulfuron (32 g/ha)	2.9 (9.3)	2.7 (8.0)
Weedy check	11.8 (139)	6.6 (42.7)
LSD (P=0.05)	1.4	1.1

Herbicide resistance

Herbicide resistance is defined as the inherited ability of a weed biotype to survive and reproduce after exposure to rate of herbicide which would normally give good control of wild type or to which the original population was susceptible. However, with continuous use of herbicides with same mode of action resulted in evolution of herbicide resistance in different weed species (Delye *et al* 2013).

Evolution of resistance in weeds against herbicide is a global hazard and at present, there are 510 herbicide resistant weeds (unique cases), in 262 weed species (152 dicots and 110 monocots). 70 countries have been reported having cases of herbicide resistant weeds in 93 crops (Heap 2021). Across the world, 341 unique cases of herbicide resistance amongst 75 weed species have been reported in wheat crop. Out of which 68, 19, 10 and 9 weeds have evolved herbicide resistance against ALS inhibitors, ACCase inhibitors, synthetic auxins and PSII inhibitors (ureas and amide), respectively (Heap 2021).

Herbicide resistance mechanisms

i) Target site resistance

The target site resistance (TSR) involves a change in the molecular target of the herbicide action which decreases its binding for the herbicide. This type of herbicide resistance can also occur by amplification or over-expression of the target gene which results in reducing the herbicidal activity (Powles and Yu 2010, Sammons and Gaines 2014). The extent of decrease in herbicidal binding to its target site depends on structural alteration in the target protein, resulting into high or moderate resistance (Yu *et al* 2014). Long *et al* (2019) reported that resistance in *Sisymbrium orientale* against ALS inhibitor herbicides was due to mutation at Pro197 and Trp574 in ALS gene.

ii) Non-target site herbicide resistance

Non-target site herbicide resistance (NTSR) includes all other resistance mechanisms except alteration in the target site which reduces the amount of herbicide that reaches the target site or that changes the effect of the herbicide instead of its target site inhibition. It comprises reduced uptake or translocation of herbicide, increased metabolism of herbicide, herbicide sequestration and/or decreased rate of herbicide activation (Devine and Shukla 2000). In metabolism based NTSR, there is increase in the activity of enzyme complexes which detoxify or metabolize the herbicide such as cytochrome P450s. esterases, glutathione S-transferases (GSTs) or uridine 5-diphospho-glucosyl transferases (Powles and Yu 2010). This type of NTSR is polygenic *i.e.* controlled by many genes and may results in evolution of herbicide resistance with completely different modes of action (Delye *et al* 2013, Preston 2003). However in many herbicide resistant weeds, there are also reports of monogenic inheritance of NTSR (Huffman *et al* 2015).

Resistance due to plant detoxification involves four-phases *i.e.* detoxification, conjugation, transport and degradation (Liu *et al* 2018). In detoxification, oxidation process is carried out by cytochrome P450 mono-oxygenases or oxidases and in second phase there is conjugation of xenobiotic by the addition of thiols or sugars, or directly by GSTs and glycosyltransferases. Transport involves movement of conjugated molecule into the vacuole or in extracellular space by most common group of transporters *i.e.* ATP-binding cassette (ABC) transporters and the last phase comprises degradation of the conjugated molecule (Liu *et al.* 2018, Gardin 2015). The evolution of herbicide detoxification mechanism of NTSR is a serious threat to crop production as it can leads to multiple herbicide resistance. Duhoux *et al* (2015) reported NTSR in *Lolium spp.* against ALS inhibitor herbicides was due to increased activity of cytochrome P450 and glycosyl-transferase.

Status of herbicide resistance in India

Earlier herbicide resistance was limited to only *Phalaris minor* in wheat against substituted ureas during 1990s in north-western India (Malik and Singh 1995). It was found that resistance emergence was associated with delay in herbicide application, poor selection of spray nozzle and continuous reliance on a single herbicide or similar mode of action (Singh 2007, Chhokar *et al.,* 2012, Bhullar *et al* 2017). This subsequently resulted in multiple resistance in some *P. minor* biotypes against three modes of action: photosynthesis at the photosystem II site A (PS-II), acetyl-CoA carboxylase (ACCase) and acetolactate synthase (ALS) (Chhokar and Sharma 2008). The situation gets further deteriorated with addition of herbicide resistance in *Rumex dentatus, Chenopodium album, Polypogon monspliensis, Avena fatua* (Singh, 2016, Singh *et al.,* 2017, Chhokar, 2014). Chhokar *et al.* (2013) reported the first case of herbicide resistance against broad leaf weed *Rumex dentatus.* It was found resistant to metsulfuron and also exhibited cross resistance to florasulam, pyroxsulam, iodosulfuron and triasulfuron whereas *Chenopodium album* was found resistant to metsulfuron only (Chhokar *et al.,* 2017). Recently resistance in *R. dentatus* has been confirmed to metsulfuron methyl from the rice-wheat belt of Punjab state (Dhanda *et al*., 2020).

Integrated weed management

Integrated weed management (IWM) involves combination of all weed control measures like chemical, cultural and mechanical means to get effective control of weeds and reduced the dependence on solely herbicides. The IWM can be an effective tool in managing weeds and to delay the evolution of resistance in weed species.

FUTURE PROSPECTS

The weed management practices need to focus on reducing the selection pressure such that herbicide resistance in the weed species can be delayed. In this way the presently available herbicides can be used for long. The proper monitoring of the fields for the herbicide resistance can play a vital role as a warning sign and can help in reducing the further spread. The ecological weed management needs to be developing for the effective management of herbicide problem. The faulty herbicide application has been observed as one of the major reasons behind the poor efficacy of herbicide at farmer's fields. Thus, field demonstration should be conducted at farmer's fields for effective herbicide spray technology. There is a need to strengthen the IWM practices mainly focusing on agronomic measures, herbicide rotation and herbicide mixtures, hence the evolution of herbicide resistance can be reduced.

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