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Dr. Satya Narayan
Department of Agronomy
Amar Singh P.G. College,
Lakhaoti, Bulandshahr, Uttar Pradesh, India

Correspondence
Dr. Satya Narayan
Department of Agronomy
Amar Singh P.G. College,
Lakhaoti, Bulandshahr, Uttar Pradesh, India

Herbicide resistance in weed and its management

Dr. Satya Narayan

Abstract
Due to their superior efficacy and time-saving nature, herbicides are the most popular and effective weed control products. However, prolonged use of herbicides has resulted in a slew of issues, including weed resistance, shift weed in shift flora, and environmental risks. Herbicide resistance is a very important problem in the globe today as a result of all of these issues. The major causes of herbicide resistance are a lack of rotation and the use of herbicides with a protracted residue period. Herbicide resistance is a global problem, and the number of resistant weed biotypes is growing at an alarming rate. There are 480 occurrences of herbicide resistance in 252 plant species at the moment. Weed resistance to herbicides should be reduced as much as possible because it is a major limiting factor in food security. A thorough understanding of development and resistance mechanisms would aid in its control. Integrated weed management approaches, including as crop and herbicide rotations, herbicide combinations, and cultural, mechanical, and biological weed control, are used to combat herbicide resistance.

Keywords: Weed, mechanism, resistance, management

Introduction
Resistance is described as a shift in a pest population's sensitivity to a pesticide, resulting in the pesticide's failure to control the pest despite proper administration. Pesticide resistance has evolved in over 600 species of pests around the world. When resistance to a particular pesticide or "family" of pesticides arises, these products can no longer be used successfully, limiting pest management alternatives. When the same pesticide or comparable ones with the same method of action are applied repeatedly, resistance might develop. Pests are supposed to change or mutate in order to become resistant. However, it is the population of herbicide resistance that changes, not the individual pest (insect, weed, or microorganism). Herbicide resistance is the inherited ability of a biotype of a weed to survive a herbicide application to which the original population was susceptible, and biotype is a group of plants within a species that has biological traits (such as herbicide resistance) not common to the rest of the species. In basic words, resistance occurs when a specific herbicide once controlled a particular weed population when sprayed at the specified rate and timing, but after repeated usage, the herbicide no longer does so. It's critical to understand the distinction between weed population shifts and herbicide resistance whenever herbicides are applied on a regular basis. Weed population changes and resistance are both undesirable and complicate weed control.

- Herbicide susceptibility refers to how vulnerable a plant is to harm or death from a specific herbicide.
- Herbicide tolerance is a species' hereditary ability to survive and reproduce after being treated with a herbicide.

The plants were not selected to be tolerant; they simply have a natural tolerance. When the herbicide to which those individuals are resistant is used regularly, resistant biotypes develop up in the weed population, starting at very low frequencies.

Resistance in weeds to herbicide In India
During 1992-93, *Phalaris minor* (littleseed canary grass) developed resistance to is oproturon. Malik and Singh contributed to the report (1993, 1995). This was the world's worst case of herbicide resistance (Malik and Singh, 1995), resulting in totol crop failure, especially under severe infestation (2000-3000 Phalaris plants/m2). In the early years of reporting and confirmation, Phalaris minor resistance was a serious concern, and the country's economy suffered a significant loss due to poorer wheat production because no substitute herbicide had

been developed, evaluated, or recommended. Resistance caused P. minor control to drop from 78 percent to 27 percent in three years from 1990 to 1993 (Malik and Singh, 1995), resulting in yield losses of 40-60 percent in impacted areas.

The resistance expanded over 1.0 million hectares, mostly in Punjab and Haryana's rice-wheat cropping systems (Malik and Singh, 1995). Herbicide resistance, according to WSSA (1998), is "a plant's inherited ability to live and reproduce after exposure to a dose of herbicide typically deadly to the wild type." Resistance in plants can arise naturally or be generated through approaches such as genetic engineering or the selection of variations produced through tissue culture or mutagenesis." Herbicide resistance, according to HRAC (2015), is described as the "naturally occurring inheritable ability of some weed biotypes within a particular weed population to survive a herbicide treatment that should, under normal use settings, efficiently control that plant population." Herbicide resistance, according to the WSSA (1998), is "a plant's inherited ability to live and reproduce after exposure to a dose of herbicide typically deadly to the wild type." Resistance in plants can arise naturally or be generated through approaches such as genetic engineering or the selection of variations produced through tissue culture or mutagenesis." Herbicide resistance is defined by HRAC (2015) as the "naturally occurring inheritable ability of some weed biotypes within a particular weed population to survive a herbicide treatment that, under normal use settings, should effectively control that weed population." Herbicide resistance, according to the WSSA (1998), is "a plant's inherited ability to live and reproduce after exposure to a dose of herbicide typically deadly to the wild type." Resistance in plants can arise naturally or be generated through approaches such as genetic engineering or the selection of variations produced through tissue culture or mutagenesis." Herbicide resistance, according to HRAC (2015), is described as the "naturally occurring inheritable ability of some weed biotypes within a particular weed population to survive a herbicide treatment that should, under normal use conditions, effectively control that weed population." Herbicide resistance is also defined by the WSSA (1998) as "the inherited ability of a plant to survive and reproduce following exposure to a dosing regimen that should, under normal use conditions, effectively control that weed population." Resistance in plants can emerge naturally or be generated using techniques such as genetic engineering, tissue culture, or mutagenesis." Herbicide resistance is defined by HRAC (2015) as the "naturally occurring inheritable ability of some weed biotypes within a particular weed population to survive a herbicide treatment that, under normal use settings, should effectively control that weed population." Herbicide resistance, according to the WSSA (1998), is "a plant's inherited ability to live and reproduce after exposure to a dose of herbicide typically deadly to the wild type." In a plant, resistance may be naturally occurring or induced by such techniques as genetic engineering or selection of variants produced by tissue culture or mutagenesis". HRAC (2015) also defined herbicide resistance as "naturally occurring inheritable ability of some weed biotypes within a given weed population to survive a herbicide treatment that should, under normal use conditions, effectively control that weed population".

Table 1: Herbicide-Resistance Weeds by site of action

S. No	Herbicide group	HRAC Group	Example Herbicide	Dicots	Monocots	Total
1	ALS inhibitor	B	Chlorsulfuron	101	64	165
2	Photosystem II inhib Itors	C1	Atrazine	51	23	74
3	EPSP synthase inhibitors	G	Glyphosate	24	26	50
4	ACCase inhibitors	A	Sethoxydim	0	49	49
5	Synthetic Auxins	O	2,4D	33	8	51
6	PSI electron Diverter	D	Paraquat	22	10	32
7	PSII inhibitor (urea and amide)	C2	Chlorotoluron	11	18	29

Source: http://weedscience.org

Selection and selection pressure

- Control strategies that prefer resistant biotypes over susceptible biotypes are referred to as selection.
- The intensity of the selection is referred to as selection pressure.

Mode of action and target site or mechanism of action

- The herbicide's mode of action (MOA) explains the plant processes it affects, or the full sequence of events that leads to the death of vulnerable plants. This includes absorption, transport, metabolism, and interaction at the site of action.
- The exact location of inhibition, such as interfering with the activity of an enzyme within a metabolic pathway, is known as the target site of action, and herbicides are classified into families that share a common chemical structure and exhibit similar herbicidal activity on plants. There are hundreds of different herbicides on the market today, and many of them work in the same way or in similar ways. Herbicides now influence less than 30 plant development processes.

The ALS inhibitors have produced the biggest number of resistant biotypes worldwide (imidazolinone, triazolopyrimidines), Photosystem II inhibitors are the second most common group of resistant biotypes (primarily triazines), and to yet, no resistance biotypes to some methods of action have been reported. Part of this is undoubtedly related to the widespread use of certain herbicide families.

For example, there are various ALS inhibitors that have been widely used. On the other hand, cellulose inhibitors are scarce and have been utilised on a small number of acres. Some types of action, on the other hand, are more prone to resistance than others. ALS inhibitors and ACCase inhibitors appear to be particularly dangerous; this should be factored into management strategies. Herbicides like dinitroaniline and triazine appear to have a medium degree of inherent risk, while chloroacetamides and synthetic auxins appear to have a low amount.

It's vital to keep in mind that a low intrinsic risk of resistance combined with frequent use can result in a larger risk. Glyphosate, for example, was formerly thought to have a minimal chance of resistance evolution. However, because of the widespread usage of Roundup Ready crops, glyphosate is being used widely in the lack of other weed control strategies, resulting in a significant increase in resistance.

Types of herbicide resistance

The effective control of weed plants is not possible manually due to physical similarities with crop plants. When the morphological and physical growth habits of the crop and weed plant differ significantly, manual weeding is preferred. Herbicides are frequently administered to both weed plants and crop plants on the same plot of land in order to increase agricultural productivity. Herbicide resistance develops in one or more weed plant species at a specific herbicide application site. When an herbicide is used on one weed species, it usually affects nearby weed plant species as well. Regular administration of the herbicide causes weed plants to develop resistance to it, and the weed plants are no longer impacted by it. Only when the location of action of herbicides does not respond to any administered chemical does resistance develop in weed plants. Herbicide impacts more than one spot in a weed plant, disrupting its growth potential and other activities. Herbicides work on protein cells, enzymes, and biological mechanisms that entail cell division and elongation as their targets. Herbicide resistance is a mutative reaction in which multiple genetic features are transformed (Powles and Yu) (2010). The number of resistant genes, their mechanism of action, and their relationship with other genetic features of the weed species implicated in herbicide resistance facilitation are all factors to consider. Resistance is also determined by the weed plant's species, such as whether it is cross pollinated or self-pollinated, as well as the herbicide's administration method. Herbicide doses applied under specific environmental circumstances also play a role in the development of herbicide resistance in weed plants. Weeds are noxious plants that can evolve resistance to herbicides in order to maximise their growth potential. They may develop tolerance to one or more herbicidal dosages' active components. On the basis of herbicide mode of action and the method by which it affects weed species, herbicide resistance can be divided into two types (Kim *et al.*, 2015) [4].

1. Cross Resistance: It's a form of herbicide resistance that's only resistant to one herbicide class. Cross resistance can occur within a group of herbicides or between groups of herbicides. Cross resistance is described as a change in the expression of a weed plant's genetic character in response to different herbicide classes. It refers to a shift in weed plant species' genetic expression in response to a given herbicidal dose. Herbicide selection pressure on target sites targets the acetolactase synthase (ALS) enzyme, which causes resistance in weed species (Vargas and Wright, 2004). In a review, it was discovered that if a weed plant develops resistance to excessive usage of herbicide A on the same plot of land, it will also develop resistance to herbicide B, which has never been treated to that region previously (Won *et al.*, 2015a). As a result, cross resistance is a significant manifestation that restricts the mechanism of herbicide action within weed plant species. It is a significant phenomenon that has implications for agricultural production as well as economic losses in agricultural productivity. There will be a significant loss in agricultural economics and output if this resistance diminishes herbicides' effectiveness to control weeds. Herbicide cross resistance has an advantage over herbicide administration to promote resistance in seeds and pollen grains (Hall *et al.*). (1994). Herbicide resistance refers to the undifferentiated behaviour of weed plant species that resist herbicide application on a given piece of land. Herbicide resistance diminishes crop yield by limiting the growth potential of crop plants. Cross resistance is further divided into two categories:

- Target site cross resistance
- Non target site cross resistance

Herbicide cross resistance in weed plant species makes it easier for resistance to develop at the above-mentioned site of action. This method of herbicide cross resistance is critical for scientific and experimental purposes. If herbicides limit weed control actions in weed plant species, agriculture and other agrochemicals manufacturers will suffer a significant economic loss. Herbicide resistance has become a difficulty for scientists all over the world in terms of achieving strong potential and productivity in terms of crop growth and output.

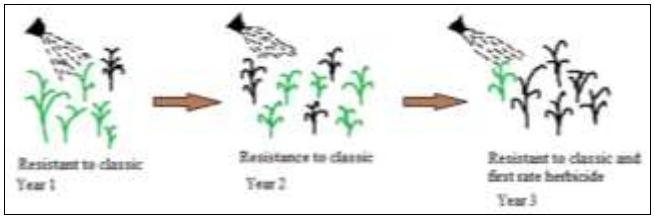

Fig 1: Cross Resistance

Target Site Cross Resistance When the site of herbicide action is manipulated, cross resistance of herbicides occurs at the target site. In weed plant species, the biochemical site of herbicidal action generates a distinct chemical class that impacts the location of herbicidal activity. Target site cross resistance affects crop plant species by inhibiting the biochemical site of action of comparable herbicides. This sort of resistance isn't found in all herbicide classes or mechanisms. Target site cross resistance does not stimulate all herbicidal classes, but it does affect the same herbicide mechanism of action. Many reviews have looked into the examples and mechanisms of herbicide target site cross resistance in weed plants.

Non Target Site Cross Resistance The different herbicidal class and method of action in the plant are linked to non-target site cross resistance. The mode of action of a different herbicide, rather than the enzymes engaged in the target site, increases resistance in this type of cross resistance. Non-target site cross resistance occurs when a herbicide's mechanism of action is not on the target site. Various investigations have shown that L. rigidum and A. myosuroides are herbicide resistant but have no target cross resistance for insecticides (Brattsten *et al.*, 1986; Georghiou, 1986) [3].

Table 2: Weed resistant to various herbicide groups

Herbicide group	Resistant weeds	Country
Triazines	Amaranthus spp. Polygonum spp. Chenopodium spp.	North America
ALS inhibitor	Amaranthus spp., Avena fatua Conyza Canadensis, Xanthium sp. Cuscuta spp., Lolium rigidum	Israel Canada USA Australia
Bipyridilliums	Conyza canadensis	Japan
Phenyl ureas/Amides	Phalaris minor Echinochloa spp.	India USA
Synthetic auxins	Daucus carota Commelina diffusa	Canada Hawaii
ACCase inhibitors	Avena fatua	Austarlia, Canada, USA

Mechanisms of herbicide resistance

The four known mechanisms of resistance to herbicides are:

1. **Altered target site**
- An herbicide works by disrupting a specific plant process or function at a specific place (target site of action) (mode of action).
- If this target site is slightly changed, the herbicide loses its ability to attach to the site of action and exert its phytotoxic effect.
- Herbicide resistance is most commonly caused by this method.

2. **Enhance Metabolism**
- A foreign substance, such as an herbicide, is detoxified by the plant's metabolism.
- The capacity to rapidly breakdown an herbicide could render it inactive before it reaches its target within the plant.

3. **Compartmentalization or sequestration**
- Some plants have the ability to limit the movement of compounds (herbicides) within their cells or tissues in order to prevent the substances from causing harm.
- In this situation, an herbicide is inactivated by binding (for example, to a plant sugar molecule) or by removing it from metabolically active organisms.

4. **Over-expression of the target protein**
- If the target protein, on which the herbicide acts, can be produced in large quantities by the plant, then herbicide becomes insignificant.

Management of herbicide resistant population's alternate herbicides If herbicide resistance is confirmed or strongly suspected, several herbicide resistance control measures must be included into weed control. It is safer to stop using herbicides with the same mode of action. However, in many circumstances, the herbicide continues to work on a vast number of weeds and is still the best option for overall weed control. If it is decided to keep applying the herbicide, there are numerous options:

a. Using a combination or pre-pack of a herbicide tank with at least one mechanism of action known to control the resistant weed for proactive (pre-plant or pre-emergence) weed management.
b. Using post-emergence herbicides only in tank blends or pre-packs that contain at least one known resistant weed control mechanism. Plants and weeds are morphologically similar in the early phases of plant growth, making identification challenging.

Hand weeding in wheat, for example, will be difficult due to the presence of P. minor weed in the mix. Weeding with machines, on the other hand, is expensive and labour management is tough. As a result, using pesticides to manage weeds, particularly in wheat crops, is a successful strategy. Rotation of herbicides with diverse modes of action can help to delay the evolution of weed resistance. The application of two different modes of action of herbicides, for example, can lead to resistance in the P. minor population, which is resistant to the new herbicide group. During the control of resistant biotypes in Punjab and Haryana in 1997, herbicides such as fenoxaprop, clodinafop, and sulfosulfuron were created (Yadav *et al.*, 2002; Yadav and Malik, 2005). These herbicides are quite successful at controlling P. minor, and they are commonly employed in herbicide-resistant areas. For the most part, these herbicides are quite effective against weeds. After 8-10 years of consistent use, these begin to exhibit signs of wear and tear. After nearly 8 years of frequent spraying, these alternative herbicides are exhibiting resistance (Bhullar *et al.*, 2014). When these herbicides fail to have any impact, pinoxaden, a category of herbicides, can be used to reduce the weed population in wheat crops. In today's wheat crop, pendimethaline is commonly used to control P. minor. Some herbicide formulations are also used to control the population of P. minor in wheat crops. Mesosulfuron + iodosulfuron, fenoxaprop + metribuzin, and other herbicidal mixes are employed to suppress the weed population of P. minor and other weed species. These are effective against weed species and, in particular, decrease the incidence of P. minor in crop fields. Metribuzin, an herbicide that inhibits photosystem II, has been shown to be effective in controlling herbicide resistance in P. minor populations (Kaur *et al.*, 2015). However, if this chemical is applied after rain, it can cause damage to the crop. As a result, it causes toxicity in specific wheat species or varieties, which can harm the wheat crop. These herbicide formulations are available in a variety of combinations, but due to the presence of sensitive wheat varieties in the field, their use is limited. They may have an impact on the wheat crop's growth in the field. Metribuzin in combination with fenoxaprop-p-ethyl is one of the available acceptable mixes, however it is not commonly utilised due to its toxicity. Herbicide-resistant cultivars include PBW 550, HD 2967, and HD 2854. Chhokar and Sharma claimed that IPU resistant P. minor is susceptible to triazine and dinitroaniline (2008). In a previous review, Malik *et al.* (1995) observed that pendimethalin was effective in controlling IPU resistant biotypes of P. minor. Pendimethalin, trifluralin, pyroxasulfone, and metribuzine, among other pre-emergence herbicides, have shown to be effective against resistant P. minor. Pendimethalin is somewhat effective against resistant populations when used in conjunction with ACCase/ALS inhibitor herbicides and metribuzine in the tank or pre-mix.

Pyroxasulfone is a significant new herbicide that has been found to be effective against numerous resistant populations of P. minor in India. Pyroxasulfone has been used to manage group A and B resistant perennial ryegrass in wheat in Australia for around ten years (Boutsalis *et al.*, 2014). As a result, more research is urgently needed to evaluate this pesticide in the field and make it available to local farmers. Rasool found flufenacet, an oxyacetanilide, to be effective against P. minor in wheat (2016). To control the weed population in the wheat crop, an alternate herbicide and herbicide mixture are utilised. These are employed in order to postpone herbicide resistance in wheat crop species. In diverse locations of Punjab and Haryana, P. minor developed resistance to herbicides except pendimethaline and metribuzin. Trifluralin can also be used to manage P. minor in wheat fields. Two or more herbicides having diverse modes of action and degradation routes should be applied in rotation or as a tank-mix, pre-mix, or series to delay the onset of herbicide resistance. At least one more MOA would be added to both of these solutions to assist prevent the resistant weed from spreading further.

1. If the resistant weed is limited to a small region, take steps to stop seed production. If the weed is still small enough to control, use different herbicides to treat the afflicted areas. Alternatively, the weed might be

manually eliminated, or the crop could be sacrificed in affected sections and the weed monitored by disruptive tillage or a non-selective spot herbicide spray. Allowing resistant weeds to go to seed is not a good idea.
2. Stop transferring seeds or vegetative propagules to neighbouring fields and farms. Use a power washer or compressed air to assist remove seed and plant parts from any field apparatus. If any fields have a history of herbicide resistance, they should be avoided.
3. To assist with the long-term preparation of weed control in subsequent crops, seek guidance from the Cooperative.

Conclusion

Weeds use a variety of strategies to resist herbicides' fatal effects. NTSR (Non target site resistance) mechanisms, in comparison to target site resistance mechanisms, involve more complex pathways since NTSR mechanisms are the result of a mixture of deviations from multiple physiological processes. A better knowledge of NTSR processes can provide much-needed information regarding the steps involved in herbicide resistance. These insights could help to clarify the concept of herbicide resistance and improve our present understanding of how these herbicides work. These findings can also be used to increase herbicide efficiency and develop more effective management strategies for herbicide-resistant populations.

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