Chapter 11

Nanotechnology in Herbicide Resistance

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Additional information is available at the end of the chapter

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Abstract

Herbicide market in agriculture is a multi-billion dollar industry with sophisticated multi-impact issues, with increased weed resistance at the topmost. Nanoherbicides under development in the current decade could be a new strategy to address all the problems caused by the conventional non-nanoherbicides. With polymeric nanoparticles often used as nanocarriers for herbicide delivery, the current era has seen the rise of new nanoparticles-based delivery systems. As the potential use of nanostructured materials enables the use of herbicides effectively and rules out the emergence of weed-resistant population at an early stage, these very desirable nanotechnological practices in agriculture are reviewed here.

Keywords: herbicide, nanoherbicide, nanotechnology

1. Introduction

The genetically acquired capacity of the weed population to survive a herbicide exposure under normal usage conditions could be stated as herbicide resistance. The resistance brings the illustration of Darwin's 'survival of the fittest' principle. In a population of weeds exposed to herbicide, only a few individuals develop resistance, while the rest dies due to the herbicide action. This set resistant weed that survives eventually becomes a population of weeds with acquired resistance to a particular herbicide. The uncontrolled and repeated application of same herbicide will also select resistance plants. In some cases, multiple resistances can also appear due to sequential selection. Over the globe, nearly 249 herbicide-resistant weedy biotypes have been identified in over 47 countries. This number constantly grows on an annual basis giving rise to new resistant weeds. Likely, some management practices also give a rise to the development of herbicide-resistant weeds.

The herbicide-resistant management mostly involves a proper weed control program, with the aid of strategies such as usage of necessary herbicide specifically at recommended dosage rate, rotation of herbicides within herbicide groups and usage of herbicides mixtures. These strategies are followed for achieving the goal of effective control of resistance weed population. The system of integrated weed management (IWM) combines the application of all the possible weed control tools with accompanied economic crop production. Among the used tactics for weed resistance, the use of herbicide mixtures and rotations was found to be most useful. As weeds also have a hectic period to adapt to the management practice that keeps changing, the reliability on the cultural control could be of great importance. In spite of the reliance on the resistant management strategies, if the overuse of herbicides is controlled, then herbicide resistance will soon become archaic.

Nanotechnology offers exciting ways for averting the herbicide overuse and also a safe and effectual delivery [1]. The usage of nanostructured systems in agriculture has increased tremendously in the current era for the controlled release of agrochemicals as well for plant nutrients (**Figure 1**). The nanostructured herbicide could substantially reduce the herbicide consumption rate and promise increased crop productivity. This technology of exploiting nanomaterials guarantees to improve the current agricultural practices via the enrichment of management methods [2]. Nanoherbicides are one of the new-fangled strategies for combating the problems of conventional herbicides. These are being developed for addressing the issues in annual weed management and also for fatiguing the weed seed collection. The nanostructured formulation performs action through controlled release mechanism. The nanoherbicides comprise a wide range of entities such as polymeric and metallic nanoparticles. Nanoherbicides require a glance in order to place nanotechnology at the premier level.

Advancements in nanotechnology could be boon for mitigating the unsolvable herbicide resistance prevailing for centuries (**Figure 2**). The high penetration efficiency of nanoherbicides helps in eliminating the weeds before resistance could develop. The nanocarriers required for preparing nanoherbicides provide short- and long-residual herbicides based on the need by averting the lethal dose at which the plant could develop herbicide resistance. The preparation of nanoformulation with appropriate carriers would provide a basis for sustainable and economic agriculture. Nanoherbicides will start a high localization of the active substances only within the target plants avoiding the evolution resistance to particular herbicide at the basic level. Hence, the application of these nanotechnology-based miracle workers, nanoherbicides, for combating the herbicide resistance evolution is prodigious.

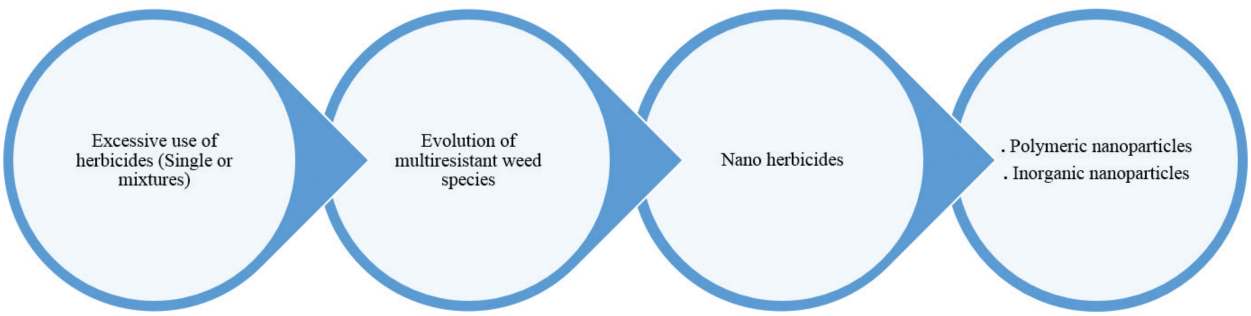

Figure 1. Hierarchy of the nanoherbicides evolution.

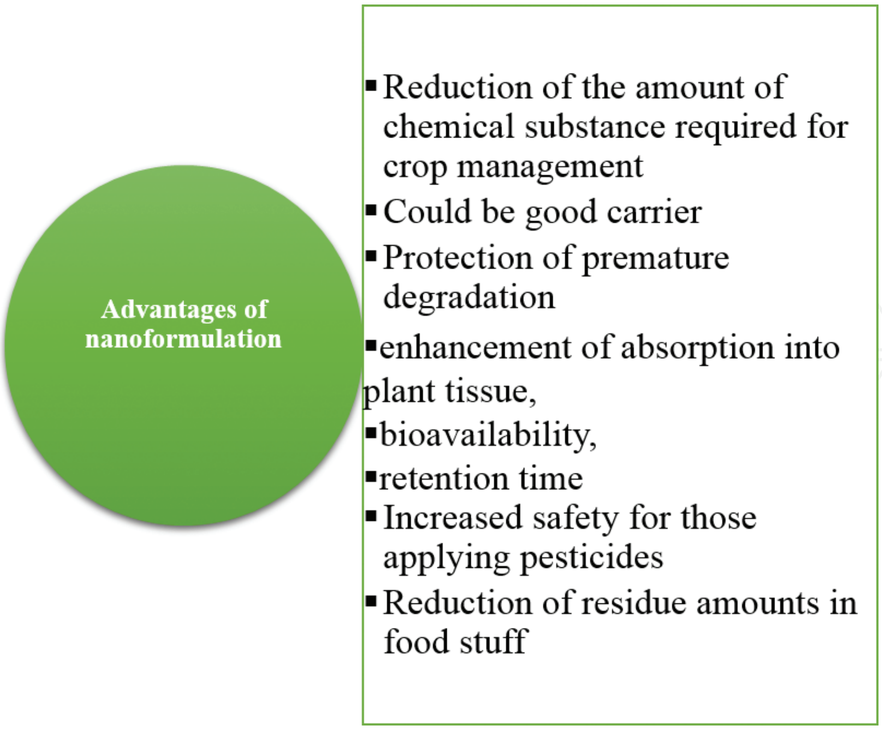

Figure 2. Advantages of nanoformulation over conventional herbicide formulation.

2. Nanoherbicides

Nanoherbicides are formulated by exploiting the nanotechnological potential for effectual delivery of chemical or biological pesticides with the help of nanosized preparations or nanomaterials-based herbicide formulations. Nanomaterials or nanostructures materials-based formulations could improve the efficacy of the herbicide, enhance the solubility and reduce the toxicity in comparison with the conventional herbicides. Early weed control with the use of nanoparticle-based herbicide release systems could reduce the herbicide resistance potential, maintain the activity of the active ingredient and prolong their release over a longer period [3]. The development of specific herbicide molecule encapsulated with nanoparticle aims at specific receptors present at the root of the targeted weed. The developed nanoparticle enters the root system of the weed and gets translocated to perform its action which in turn inhibits the glycolysis of the plant root system. The targeted action creates starvation of the plant and thus kills it. These nanoherbicides could also be used in rain-fed areas where herbicides get dissipated through vapourisation due to insufficient soil moisture. With the help of controlled release of herbicides via encapsulation, the weeds can be utterly destroyed. Apart from herbicides, adjuvants normally used to enhance the herbicidal activity are currently claiming to include nanomaterials. A glyphosate-resistant crop was reported to be made susceptible to glyphosate upon addition of a nanotechnology-based surfactant on to a soybean micelle. Nanoparticles can act as good carrier and also can form nanoformulation when added with herbicides. These nanoformulations assist in overcoming the main drawback of herbicide industry such as evolution of herbicide resistant plants. The nanoparticle systems for herbicide delivery are mostly composed of polymeric substances which are biodegradable with non-toxic metabolites.

2.1. Polymeric nanoparticles

Among the various types of nanoparticles used for formulating nanoherbicides, polymeric nanoparticle prepared either in the form of nanospheres or nanocapsules, is the most attractive form. Poly(epsilon caprolactone) is one polymer repeatedly used for the encapsulation of atrazine herbicide. Poly(epsilon caprolactone) possesses good physico-chemical properties along with enhanced bioavailability and biocompatibility. The polymeric nanoparticles containing atrazine herbicide were prepared and were characterized for size, polydispersity index, pH and encapsulation efficiency. The stability of the nanoparticles was found to be for a period of 3 months. The nanoparticle formulations reduced the mobility of the herbicide in soil but enhanced its herbicidal activity in comparison with free atrazine [4]. When tested against target plant, *Brassica* sp., the polymeric nanoparticles encapsulated with atrazine were proven effective. In another study, Grillo et al. [5] used the polymer for encapsulated three triazine herbicides such as atrazine, ametryn and simazine to reduce the environmental impact caused by them. The encapsulated polymeric nanoparticles of triazines possessed better association efficiency over 84%. The nanoparticles were found to have stability of size, zeta potential, pH and polydispersity for nearly 270 days. The triazine herbicide formulations revealed that the nanocapsules release the triazine *via* controlled release by relaxing the polymeric chains in vitro release experiments. The polymeric herbicide nanoparticles showed relatively less genotoxicity in *Allium cepa* chromosome aberration assay.

Alginate/Chitosan (Ag/Cs) nanoparticles were chosen for the encapsulation of parquet herbicide [6]. This polymeric complex has simple preparation methods adding further to their alternative use in agricultural applications. The Ag/Cs nanoparticle carrier system showed significant difference in the release profiles of free paraquat and the herbicide nanoparticles. The herbicide nanocarrier has altered the interaction of the herbicide in soil and indicated the effective means of averting the negative impacts of the herbicide induced by paraquat herbicide. Soil sorption studies with Ag/Cs herbicide paraquat nanoparticles exhibited dependence on the quantity of present soil organic matter. The enhanced interaction of paraquat released from Ag/Cs system in comparison with free paraquat revealed the effective of these polymeric nanoparticles as an excellent choice for eliminating the herbicide usage–associated ill effects. In a different study, the paraquat herbicide was encapsulated onto chitosan/tripolyphosphate nanoparticle and was proved efficient with this polymeric nanoparticle system as well. The herbicidal efficiency of paraquat was not found reduced even after encapsulated with very less toxicity. Cell culture viability tests and *Allium cepa* chromosomal aberration tests testified to the increased safety of the polymeric herbicide systems against non-target organisms [7]. Few works reported till date on polymeric nanoparticles encapsulated with herbicide provides a safe basis for using herbicides by reducing the adverse environmental impacts caused by them on human health as well on the environment.

2.2. Inorganic nanoparticles

Silica dioxide nanoparticles (SiNP) were explored as inorganic herbicide carriers in the recent past for active substances which are pH sensitive. These SiNPs maintain optimal herbicide concentrations with accompanied reduction in frequency of herbicide consumption rate.

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These systems protect and stabilize the herbicide and reduce their wastage with easy deposit on the plant leaves. Rani et al. [8] stated the possible use of silica nanoparticles as herbicide carriers via a dynamic adsorption mechanism and sustained release. Though hypothesized, the use of SiNPS as herbicide carrier is yet to be explored in means of leaching behaviour, controlled release and toxicity.

2.2.1. Agro industrial waste based nanoparticles

In a study by Abigail et al. [9], an attempt was made to nanosized rice husk waste and was used as nanocarrier for 2,4-dichlorophenoxyacetic acid herbicide (2,4-D). The rice husk waste was brought down to nanosize and was surface adsorbed with 2,4-D to act as herbicide nano-carrier. The rice husk nanocarrier showed enhanced and reversible sorption of 2,4-D, illustrating its uniqueness to act as good carrier for encapsulating herbicides. The adsorption of 2,4-D on to the rice husk was not found to minimize the herbicidal activity when tested against target weed, *Brassica* sp. in comparison with free 2,4-D (**Figure 3**). The rice husk-based herbicide delivery system could be a boon due to its multiple advantages of utilizing the waste constructively apart from effectively using the herbicide with environmental contamination. Thus, the evolution of weeds with acquired resistance due to the uncontrolled use of herbicides could be eradicated with the help of these nanostructured herbicide carriers.

Figure 3. Bioactivity of rice husk-based 2,4-D nanoformulation against target weed *Brassica* sp. in comparison with other conventional methods [9].

3. Conclusions and future directions

Thus, in the current scenario, the overuse of herbicides to boost the crop production has left the soil, ground water and food products polluted. Although increasing the agricultural products is vital, the indirect damage on the environment cannot be unnoticed. Nanotechnology with promising results in the agricultural sector with its unique way of applying the pesticides, fertilizers etc., could enable the human population to finally visualize the dream of attaining sustainable and eco-friendly agricultural technology. This dream of exploiting the nanotechnological methods in agriculture is still in nascent stage. Therefore, development of systems that would improve the release profile of herbicides without altering their characteristics and novel carriers with enriched activity without significant environmental damage is the focus areas that require further investigations.

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