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Nanoherbicides: A New Paradigm in Weed Management

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Abstract

Weeds have the ability to interfere in the life cycle as well as the management practices involved with the crop plants. Integrated weed management is considered the best option to limit their population, but when it comes to managing them at a large scale, herbicides are considered as the easiest method of weed management. But there are negative of herbicides even when their formulations or rotations are used to control weeds, of which their persistence is one. Their overuse has also made the weeds familiar to these chemicals, evolving out resistance in weeds. Weed management through the use of nanoencapsulated herbicide formulations can be a solution to the problem of weed menace. Nanoherbicides with properties like high penetration capacity and an effective delivery system can be helpful to solve such problems.

Introduction

Herbicides are widely used as a weed management tool in agriculture that generally requires light, water as well as nutrients for their proper functioning and thus can often compete with crops. However, overexploitation and indiscriminate application of herbicides in order to increase crop yield have caused hazardous impact on environment some of which include water body's contamination, toxicity in non-target organisms as well as detrimental effects on human health. Encapsulation of herbicides in nanomaterials minimizes the loss of herbicide along with its sustained release and increased specificity toward target weed. Several polymeric nanoparticles, nanocapsules and nanospheres are used as carriers for herbicides. Polymers such as alginate, chitosan, pectin, poly (epsilon-caprolactone), poly (methylmethacrylate) and poly (lactic-co-glycolic acid) are considered as ideal nanocarriers for several herbicides such as paraquat, 2,4-dichlorophenoxyacetic acid, diuron, ametryn, atrazine and simazine, whereas other nanocarriers such as rice husk nanosorbents, mesoporous silica nanoparticles and nanoclay can be applied for fabrication of nanoherbicides. Nanoherbicides are effective against a variety of weed species some of which include *Echinochloa crus-galli*, *Chenopodium album*, *Bidens pilosa*, *Amaranthus viridis* and *Raphanus raphanistrum*. Hence, nanoherbicides can become an efficient strategy in overcoming drawbacks of excessive use of conventional herbicide formulations for agricultural practices.

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 (Figure 1). It develops target specific herbicides, which may enter the roots and get transported in all plant parts, restricts the glycolysis, thus ultimately causing the death of the target due to starvation. Moreover, due to their tiny size, nanoherbicides are being able to mix easily in soil and eradicate the target species without leaving any contradictory effects.

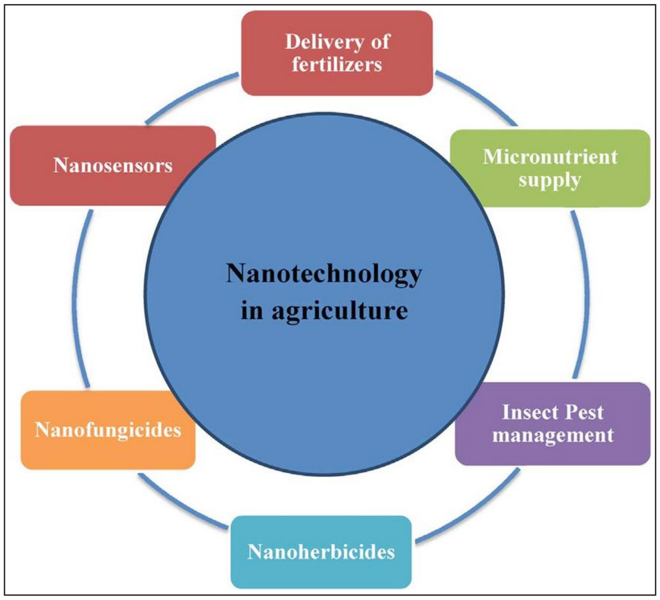

Figure 1: Application of Nanotechnology in Agriculture

Importance of Nanoherbicides in Agriculture

Herbicides are used to eliminate weeds. A weed is a plant that interferes with the growth of crop plants and causes significant problems for farmers. In the early days when humans discovered agriculture (10,000 BC), weeds were removed by hand. Over time, in about 6,000 BC, primary hand tools were used to remove weeds. In 1,000 BC, oxen and horses that pulled harrows were employed for this purpose. Since 1920, with the development of the agricultural industry, cultivators have been used and in 1930 and 1947, biological and chemical herbicides were developed, respectively.

Herbicides are chemicals that are toxic for plants and are mainly used to destroy unwanted plants like weeds in the crop. Herbicides have got immense importance in the agriculture sector and production of it is one of the biggest business industries. Nanoherbicides are formed by nano-based particles used for the synthesis of herbicides and on the other hand, by effective application for synthesis of herbicide through nano particles based delivery system. Advantages of nanoherbicides are reduction in the quantity of synthetic chemicals, effective delivery system, the safety of personals and effective reaction time. Nanoherbicides are novel technology to address all the shortcomings of traditional herbicides. One of the biggest problems that conventional herbicides are facing is resistance developed in weeds which requires strategic planning for its complete removal.

Role of Nanoherbicides in Weed Management

Nanoparticles based on biodegradable polymers have been shown to be excellent herbicide carriers, improving weed control and protecting the active ingredient in the crop fields. 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 nanoparticles-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. 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 glycolsis of the plant root system. The targeted action creates starvation of the plant and thus kills it. These nanoherbicides could also be used in rainfed areas where herbicides get dissipated through vapourization 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. Nanoparticle systems for herbicide delivery are mostly composed of polymeric substances which are biodegradable with non-toxic metabolites.

Herbicides: Mechanism of Action

A mode of action is a functional or anatomical change that occurs when a living organism is exposed to a substance. A mechanism of action, on the other hand, explains such changes at the molecular level.

• **Acetyl-coenzyme A carboxylase (ACCase) inhibitors:** These herbicides inhibit the activity of the enzyme ACCase and are used to control weeds during the cultivation of broadleaf plants. Aryloxyphenoxypropionates (FOP), cyclohexanedione (DIM) and phenyl pyrazoline (DEN) are a few examples of these herbicides (Takano *et al.,* 2021).

• **Acetolactate synthase (ALS) inhibitors:** ALS is an enzyme that is involved in the synthesis of branched chain amino acids (leucine, isoleucine and valine) and the suppression of this enzyme causes the plant to wither and eventually die (Zagnitko *et al.,* 2015).

• **Root growth inhibitors:** These herbicides inhibit cell division, thus preventing root growth and development. The purpose of these herbicides is to block the polymerization of microtubules, which disrupts the process of chromosome segregation during mitotic division, resulting in cell death (Zagnitko *et al.,* 2015).

• **Plant growth regulators:** This group includes hormonal herbicides (synthetic auxins), which are used to protect wheat and corn against broadleaf grasses. This group of herbicides targets the ATP protein pump. By activating this pump, the metabolism of nucleic acids and the integrity of the cell wall are compromised. These herbicides are also called indole acetic acid (IAA) imitators (Zagnitko *et al.,* 2015).

• **Photosynthesis/ photosystem II (PS II) inhibitors:** The target of these herbicides is the photosynthetic pathways (especially the photosystem II pathway). As a result of the loss of chlorophyll and other pigments such as carotenoids from the cell membrane, the production of $NADPH_2$ and ATP, which are essential for plant growth, is disrupted, eventually leading to plant death (Vats, 2016).

• **Shoot growth inhibitors:** These herbicides are applied to the soil prior to the emergence of the weeds. The functional site of these herbicides is on very long-chain fatty acids (VLCFA) (Sany *et al.,* 2015).

• **Aromatic amino acid inhibitors:** This group of herbicides inhibits the synthesis of amino acids. This action is specifc to glyphosate. These herbicides destroy any plant they come in contact with, although they are only licensed for corn, cotton, canola and soybeans. Glyphosate inhibits the enzyme essential for the production of 5-enolpyruvylshikimate 3-phosphate (EPSP), resulting in a decrease in aromatic amino acids *i.e.*, tryptophan, tyrosine, and phenylalanine and eventually cell death (Zagnitko *et al.,* 2015).

• **Glutamine synthetase inhibitors:** These herbicides suppress the activity of glutamine synthetase, which is involved in the conversion of glutamate and ammonia to glutamine, thus increasing the level of ammonia and lowering pH on both sides of the cell membrane. This activity disrupts various cellular functions, especially the uncoupling of photophosphorylation (Zagnitko *et al.,* 2015). One example of these herbicides is glufosinate.

• **Pigment synthesis inhibitors:** These herbicides destroy chlorophyll, which is essential for photosynthesis in plants. As a result, they cause the plant tissues to turn white, which eventually causes the weeds to die (Zagnitko *et al.,* 2015).

• **Protoporphyrinogen oxidase (PPO) inhibitors:** These herbicides damage cell membranes by inhibiting the enzyme PPO. This enzyme is implicated in chlorophyll and heme-biosynthesis. Lipid peroxidation occurs following the inhibition of this enzyme, which destroys cell membranes and leads to plant death (Zagnitko *et al.,* 2015).

Benefits of Nanoherbicides in Weed Management Strategies

The development of agro-nanotechnology along with biotechnology could revolutionise agriculture, feed a rapidly growing world population, and improve the living standards in the developing world. 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. 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.

Environmental Impact

Herbicides are the pesticides most commonly detected in the environment due to the large volumes applied in cropping fields. Environmental effect of nanotechnology is the conceivable impacts that the utilization of nanotechnological materials and gadgets will have on the earth. As nanotechnology is a rising field, there is awesome level headed discussion in regards to what degree mechanical and commercial utilization of nanomaterials will influence creatures and environment. Nanotechnology's ecological effect can be isolated into two viewpoints. Nanotechnological developments to help enhancing the earth and the likelihood the novel kind of contamination and pollution that nanotechnological may bring about if discharged into environment.

Conclusion

Overuse of herbicides to boost the crop production has left the soil, ground water and food products polluted. Nanotechnology with promising results in the agricultural sector with its unique way of applying the herbicides, fertilizers and pesticides *etc*., could enable the human population to finally visualize the dream of attaining sustainable and eco-friendly agricultural technology. Weed control was effective even at the lower dose of nanoencapsulated herbicide formulations, which was consistent with the higher efficiency of nano formulation compared to the conventional herbicides in the inhibiting activities and decreasing pigment levels. Overall, nanoherbicide formulations are a low environmental risk, with higher the weed control efficacy.

Future Directions

• Development of smart nanopesticide formulations to combat the limitations of conventional formulations.

• Development of environmentally sustainable nanopesticide developing technologies using green chemistry.

• Development of technologies for reducing the cost of production of nanopesticides.

• Activity comparison of nanoformulations with conventional analogues at field level to determine their practical utility.

• Ecotoxicological assessment of nanopesticides;

• Establishment of a legislative and regulatory framework for the safe introduction of nanopesticides in agriculture and in other spheres.

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