

Future Prospect in Nano Technology for Herbicides Production

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Received 19 February 2024; Accepted 20 March 2024; Published 26 March 2024

ABSTRACT: Since frequent application of herbicide to foliar of the targeted plants proves inefficient in weed control a quick revert to method of weed control with a great potential to control weeds that are hard to be controlled, reduce herbicide phytotoxicity and effectively control weeds with 10-fold lower dose and less or no trace of environmental pollution and harms to grown crops should be encouraged. Such qualities have been discovered in Nanotechnology. This technique, as a science, is effective in the production of slow release Nano encapsulated pre-emergence herbicides, which aid in weed control for an extended period of time with no negative environmental consequences. Nano-herbicides have the potential to address perennial weed management issues as well as the exhaustion of weed seed banks. The purpose of this review is to address the feasibility of generating nanoencapsulated herbicides for effective weed control, the idea of using nanotechnology into weed seed science, the possibility of using nanoparticles for herbicide resistance testing, and Nano-Harvest weed seed control (nHWSC).

Keywords: Nano-herbicides, herbicide resistance, weed seed, weed seed bank, Nano formulations

Citation: Ebube, O., C., Amira, G., and Ngozi-Cynthia, C. (2024). Future Prospect in Nano Technology for Herbicides Production. *Direct Res. J. Agric. & Food Sci.* Vol. 12(1), Pp. xx-xx. <https://doi.org/10.26765/DRJAFS342006782>. This article is published under the terms of the Creative Commons Attribution License 4.0.

INTRODUCTION

Although most herbicides has been prohibited by the environmental protection agencies in the last few decades, its use is still vital for crop production if the goal to meet the food needs of the ever increasing human population must be met (Duke, 2012 and Mishra, et al., 2016). This brings us to the importance of method that encourages less herbicide use in weed reduction and possibly eradication. Such method if any should encourage the use of the active ingredient with a keen or precise delivery method. By such methods, herbicides will be dispensed only when needed and as occasion requires on the areas it is mostly needed. Such efficacy in herbicide application can only be achieved through nanotechnology an application of Nano science. This technology, deal with minute materials. Here, materials are measured in a billionth of a meter called nanometer or

at the atomic, molecular and supra - molecular levels. By nanometer, we are talking of 1/80,000 approximately ten hydrogen atoms wide or the diameter of a human hair. At these levels, properties of these minute materials (physical, chemical and biological) may be different from their relativelarge materials (NNI, 2007 and Manjunatha et al., 2019). It has been predicted that the next agricultural revolutionary breakthrough might come from nanotechnology a new interdisciplinary venture-field that has managed to bring together science and engineering into agriculture and food systems (Lal, 2008). This revolution in agriculture and food industry has with it new tools for molecular treatment of diseases, rapid disease detection, boost the capability of plants nutrients intake, crop pathogen and viruses eradicationand of late pest and weed management by increasing the efficiency of

pesticides and herbicides as it allows keen delivery method at lower doses (Pradeesh and Chinnamuthu, 2020). This technology is found worthy to serve as a new phase of weed control as the use of chemical control method brought alongside with it challenges such as herbicide resistance, and these chemical tend to display harmful outcomes that are detrimental on the environment, living organism, agro workers and crops produced as well as reduce soil water, and air quality. The Russian Federation about 329 species of vascular plants grows in 65 Russian farmlands is cereals, spring and winter crops, industrial crops, row crops and perennial grasses (Tretyakova et al., 2020). 13% of Agricultural land are occurred with wheat, sugar beet, potatoes and cereals (maize, barley, oats and rye) as the most grown crop (MOHC, 2011 and RFICRFCC, 2002) but are invaded by a dataset of about 24,284 observed occurrences of weed plants and a total of 2,049 relexify of seges field of weed plant community throughout the seven regions of the European part of Russia. It is expedient to control this weed in order to reduce the competition between crops and weed as well as increase the yield of all most grown crops in Russian Federation (Chhokar et al., 2012; Van der Meulen and Chauhan, 2017; Chaudhary et al., 2020). Since frequent application of herbicide to foliar of the targeted plants has proved inefficient in weed control it important we all focus on method of weed control with a great potential to control weeds that are hard to be controlled, reduce herbicide phytotoxicity and effectively control weeds with 10-fold lower dose and less or no trace of environmental pollution and harms to grown crops (Dhillon, and Mukhopadhyay, 2015, Yadav and Srivastava, 2015 and Oliveira et al., 2015 and Grozi, 2016). Therefore, this review aims to (i) discuss the use of Nano encapsulated herbicides for effective weed control, (ii) discuss the possibility of adopting nanotechnology in weed seed science (iii) Use of Nanoparticles for herbicide resistance test (iv) unveiling nano-Harvest weed seed control (nHWSC)

Nano encapsulated herbicides for effective weed control

Readily available herbicides are designed to kill top soil sections of weeds, with no effects on growth and development of the sub soil viable sections like tubers or rhizomes which are basically the regenerative part of weeds (Dashora and Kanika, 2018). The development of particular molecules of the herbicides encapsulated with Nano particles focuses on target receptors in the weed roots, these receptors passing through the weed roots and its networks as it blocks or stops the glycolysis process in roots, leading to the death of the specified weeds (Hess, 2018).

Nanoparticles are 'magic shots', packed with herbicides, chemicals or nucleic acids and targeting specific plant tissues or areas to release their charge (Perez-de-Luque and Rubiales, 2009). These technologies usually come with a high localization of the active ingredient only within the target plants as it avoids evolution of resistance to particular herbicides at the basic level. Therefore, the use of this technology could be considered as scientific magic for fighting herbicides resistance which is a mind blowing evolution in agriculture (Jiang et al., 2021). According to Statistic Bank products database (StatNano, 2023), over 11,171 nanotechnology-based products commercialized, only 260 agriculture Nano products of 38 various types launched of which most of these products are Nano-fertilizers (43%), and Nano formulations classified into animal husbandry, fertilizers, plant breeding, plant protection, and soil improvement sub-industrial sectors with few or little Nano herbicides. Nano encapsulated herbicides are materials targeted for weed control with different sizes in Nano range are used to wrap active ingredients and released in a controlled way long term weed control is achieved. The material being coated or encapsulated is identified as core material, filler or internal phase while the coating material is identified as shell, external phase or coating membrane. Herbicide suspension diffuses through the encapsulated coats at a rate controlled by the membrane system and for these controlled release of active ingredients encapsulated to take place their properties is to be considered and examples of such properties includes; specific release, moisture release, heat-release, pH release, ultrasound release, magnetic release, selective release; and release by DNA profile (LI *et al.*, 2007).

Nanotechnology application of nanotechnology in weed seed science

In plant biology, a seed is a self-perpetuating biological unit that can survive in difficult conditions on its own. Nanotechnology can be utilised to both harness and unlock a seed's full potential. According to Natarajan and Sivasubramanian (2007), technology such as encapsulation and controlled release approaches have transformed pesticide and herbicide applications. A nanoparticle has the capacity to sustain the vigour and viability during storage by reducing losses caused by biotic and abiotic stress. Anandaraj & Natarajan (2017). The weed seed bank is the storage of viable weed seed in the soil profile that is spread across it (Singh et al., 2012; Begum et al., 2006). This storage consists of both old and newly shed new weed seeds in the soil. These banks include plant root systems for perennial weed proliferation, such as tubers, bulbs, rhizomes, and other vegetative structures. An agricultural field can have thousands of weed seeds and a dozen or more

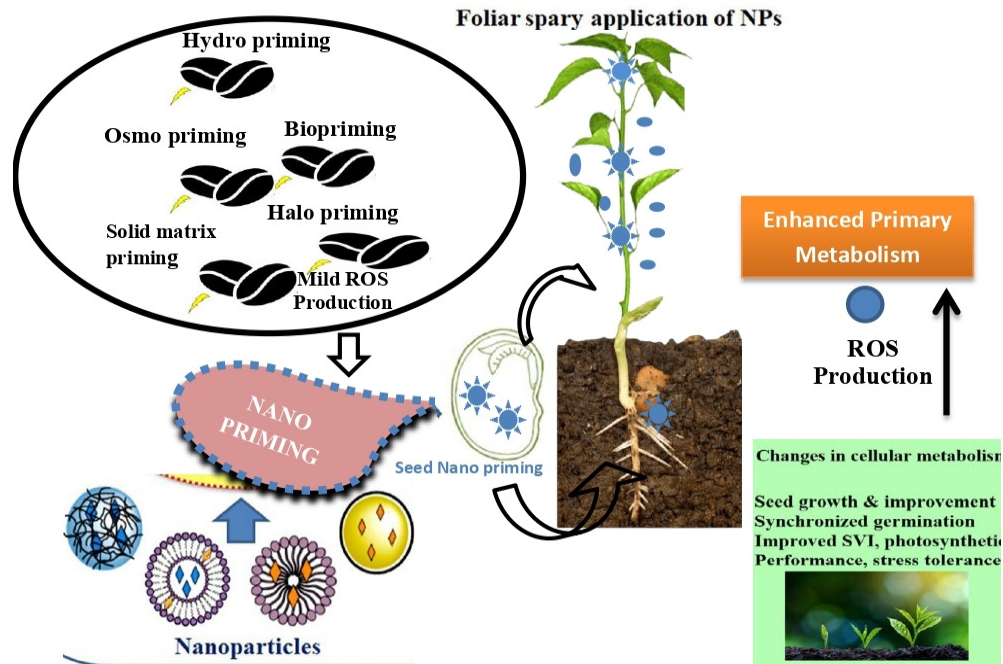


Figure 1: Impact of different types of seed priming in the growth and physiological changes in plants. ROS: reactive oxygen species. Source: Chandrasekaran, 2020 modified by Author

vegetative weed propagules per square foot (Menalled, 2013). Knowing how long soil seeds last is essential for effective weed management.

In weeds classification on the basis of their life habits some are annual while some are perennial. Annual weeds regenerate out of the seeds dropped in the soil or environment during the previous seasons, whereas the perennial weeds regenerate from existing plants, dormant buds, roots, stolons, rhizomes, tubers, etc. As weeds persistently emerge and compete with grown plants because of the existence of viable propagule bank. Any attempt towards eradication of weed plants without insight on the long-lived vegetative propagules, seed production and the length of time that seeds survive in soil is an incomplete program (Conn, et al., 2006). Working knowledge of seed-bank persistence is key to determining how effective, feasible a control measures is and its continuity (Panetta and Timmins 2004). It is important to have a weed seed longevity data for assessing weed invasiveness potential (Daehler et al. 2004). Seed dormancy is a highly intricate mechanism that significantly influences the timing of seed germination. Despite this, the characteristics of weed seed dormancy and their persistence in the seed bank are not commonly linked (Thompson et al., 2003). This is due to the fact that seed dormancy can only control germination when all necessary germination conditions

are met. Oftentimes, not all ideal conditions are available and seeds that are not dormant cannot germinate. Factors like intrinsic dormancy of seed population, depth of seed burial, seed distribution frequency, environmental condition (light, moisture, temperature), biological processes such as predation, allelopathy, and microbial attack can lead to actual seed longevity in the soil (Davis et al., 2005; Liebman et al., 2001). In order to address the problem of weed agricultural stakeholder has to maximize the knowledge of soil conditions especially in the residence time of viable seeds and introduce current methods that can cause physiological change in the seed. One of such methods is called seed priming. A pre-sowing treatment that causes a physiological change in the seed which allows seed to germinate more rapidly (Bruce, et al., 2007) as it enhances crop activity by stimulating the resistance of plants against abiotic and biotic stresses (Arnott et al., 2021). Priming using nanoparticles (nano-priming) has been proven to be more promising than traditional priming approaches for achieving feasible agricultural yields (AbbasiKhalaki, 2021). Nano-priming uses nanoparticles (NPs) with a size of less than 100 nm, and "priming" relates to the development of stress tolerance under moderate and recurring stress (Chandrasekaran et al., 2020).

Different types of Nano-priming were shown in (Figure 1). It has been reported that seed germination and

seedling vigor are potentially induced in various crops upon nano-priming (Chandrasekaran et al., 2020, Zhu, et al., 2019, and Maharramov et al., 2019). Seed dormancy can be reduced by conducting seed priming and can be useful for forest reclamation or declamation purposes. Studies has proved it as one of the best methods to sort out the dormancy problems and increase the germination as well as decrease the rate of germination of seeds in forest species (upland boreal) (Feizi et al., 2013). One of such studies is the use of nano-priming in lipid metabolism. No research has been carried out on application of nanoparticles on any plant weed seeds, but data collected from limited studies on phyto-toxicity of nanoparticles on plant species especially in the area of seed germination and root elongation as shown both progressive and regressive performance (Seeger, et al., 2008). Germination percentage (GP) and seedling vigor index (SVI) reported of phyto toxicity on of metal NPs on higher plant has shown positive and negative effects (Lin, and Xing, 2007 and Kumar, et al., 2013). A study carried out by López-Moreno et al. (2010) on germination of corn, tomato, and cucumber seeds when nanoceria was applied at 2000 mg/L showed a significant decrease (approximately 30%, 30%, and 20%, respectively).

Nanoceria was found to extend the roots of cucumber and maize while inhibiting the roots of lucerne and tomato (El-Temsah and Joner, 2021). Feizi et al. (2013) observed the germination value, vigour index, and mean daily germination of fennel (*Foeniculum vulgare* Mill) seeds and discovered that nanosized TiO₂ at low and intermediate concentrations boosted germination indicators. Nanoparticles such as ZnO-NPs and CuO-NPs were also found to significantly reduce seed germination, emergence, plumule lengths, and the principal and seminal roots of maize (*Zea mays*) (Acharya et al., 2020; Ahmed et al., 2021). The basis of seed priming using metal NPs especially in researches on seed germination and seedling vigor of agricultural species, is understanding the metabolic mechanisms associated with seed germination, including the up regulation of aquaporin genes, α -amylase activity, reactive oxygen species (ROS) production, and antioxidant systems (Arnott et al., 2021 and Mahakham et al., 2018).

Nano priming in lipid metabolism for breaking seed dormancy

Lipid metabolism modulation in plants can be induced by NPs (Yang, et al., 2017 and Shang, et al., 2019). Studies on cell membrane lipid modifications could be used for alleviation of seed dormancy in field crops (Ali, et al., 2020 and Matilla, 2020). Germination in soybeans plastidic lipids acts on the seed membrane lipids at the site where the content of phosphatidic acid (PA) (Yu, et

al., 2015). In *Amaranthus albus*, fatty acids variation and an alteration in linoleic acid was observed in the seeds embryo before and after dormancy (Chadoeufhannel, and Taylorson, 1987). In weeds like upland boreal forest plant species (buffaloberry (*Schepherdian canadensis* L.) and green alder (*Alnus viridis* L.), a study on the roles of lipid metabolism on the seed membranetowards breaking seed dormancy was conducted using NPs priming about 12 membrane lipid classes was quantitatively detected from these weeds alongside with other molecular species. Examples of such lipids are lysophosphatidylcholine (LPC), cardiolipin (CL), PA, lysophosphatidylethanolamine (LPE), phosphatidylethanolamine (PE), phosphatidylcholine (PC), phosphatidylinositol (PI), sulfoquinovosyldiacylglycerols (SQDG), phosphatidylglycerol (PG), digalactosyldiacylglycerol (DGDG), phosphatidylserine (PS), and monogalactosyldiacylglyceride (MGDG) (Ali et al., 2020).

The utilization of MWCNT-COOH in priming and layering Green alder seeds (*A. viridis* L.) resulted in a significant improvement of approximately 90% in the germination rate, with the seed membrane lipidome effectively integrating with seed dormancy (Matilla, 2020). This reconfiguration led to an increase in germination, seedling vigor, and the breaking of seed dormancy in both the embryo and seed coat of upland boreal forest species. Specifically, the enrichment of C18:3 fatty acids in the seed membrane lipid moieties, such as PG16:1/18:3, PC18:1/18:3, PE18:3/18:2, and DGDG18:3/18:3, contributed to these positive outcomes. Furthermore, nano-priming using carbon NPs (CNPs) in broccoli was found to enhance aquaporins, ions, and water movement in cell membranes. CNPs were observed to aid in balancing electrostatic interactions in cell membranes, leading to the development of new lipid domains or rafts as a result of the activation of lipid metabolism by CNPs (Shivraj et al., 2022).

Possibilities of application nanotechnology in harvest weed seed control (nHWSC)

In considering preventive weed management, the focus is on halting the introduction of new weeds and minimizing the development and reproduction of existing weed populations. It is crucial to promote effective, precise, and efficient methods that aim to discourage and reduce weed pressure (Palou, et al., 2008). One such method is the prevention of weed seed production and shedding, wherein strategies are employed to prevent weed seeds from being shed and stored in the soil seed bank. This approach, known as harvest weed seed control, involves practices such as chaff carts, narrow-windrow burning, Harrington seed destructor, weed seed milling, and bale-direct systems, all of which are mechanized and effective

in reducing the soil weed seed bank, particularly in smallholder conservation agriculture systems (Schwartz, et al., 2018). However, it is important to acknowledge the drawbacks of non-chemical and low-cost weed control methods. For instance, narrow-windrow burning poses environmental challenges such as reduced burning temperatures due to summer rain, unburnt residue heaps, potential soil erosion, and nutrient redistribution and loss through smoke (Kleemann et al., 2014). Additionally, caution must be exercised with regard to the Fire Danger Index (FDI), as errors in detecting FDI can lead to undesirable outcomes such as smoldering rows and still viable weed seeds (Peltzer and Douglas, 2018). It is worth noting that burning standing stubble may not effectively kill weed seeds and is therefore not recommended (Walsh and Newman, 2007). In exploring innovative approaches, nanotechnology presents opportunities for fabricating slow-release nano-encapsulated pre-emergence herbicides that can effectively control weeds without adverse environmental effects. The incorporation of nanotechnology in harvest weed control could potentially address the limitations associated with traditional methods and introduce a new dimension to weed management by focusing on the intricacies of perennial weed management and depleting the weed seed bank.

Possibility of application of nanoparticles for herbicide resistance test

Herbicides one of the classes triazine and ureic is extensively used in agriculture for grass and unwanted plants eradication to remove grasses in the quest to achieve crop yield increase and thereafter secure global food security. Alongside with the advantages of herbicide in agriculture is a heavy detriment on animals and ecosystems, as these chemicals are bio-magnificent and have persistent ability in the ecosystem (Antonacci et al., 2021). Year in year out, over 2 million tons of pesticides are used worldwide with a sum of about 360, 000 tons sold per year in the EU from 2011-2018 with the Russian Federation producing close to 156 thousand metric tons of pesticide In 2021 putting the country in a state of increasing pesticide production volume and a leading country in pesticide consumption worldwide (Statista Research Department, 2022). Before this production in 2020 the Russian Federation consumed about 41211 thousand metric tons of this herbicide (*Gianessi, and Williams, 2011*). Nano materials such as carbon black nanoparticles, carbon nanotubes, gold, gold nanoparticles, reduced graphene oxide, and poly (3,4-ethylenedioxythiophene) (PEDOT) have shown promise in the development of versatile technology for algae-based biosensors. These materials, when integrated with smart substrates like paper, have demonstrated the

ability to be utilized in portable sensing prototypes with dual transduction systems. This technology has exhibited the capability to recognize various toxic chemicals including herbicides and chemical weapons. Furthermore, it has been found to have reverse mechanisms for herbicide detection, presenting solid results that eliminate the need for sample pre-treatment (Antonacci et al., 2021; Attaallah et al., 2020; Elisabeth et al., 1987; Giardi et al., 2013; Scognamiglio et al., 2019).

Nanoherbicide translocation

Research on the molecular mechanism of nanoparticles' action on seeds has not yet yielded definitive clarity. However, it is evident that this mechanism is influenced by the type of Nano-agent used, the specific plant species involved, and the mode of interaction, including translocation and absorption. Unlike herbicide translocation, Nano-herbicide translocation is characterized by short-range transport. Herbicide translocation, on the other hand, involves long-range delivery and requires both phloem and xylem vascular systems in plants. The ability of translocation is important as it allows the herbicide to reach both treated and untreated parts of the plant. The movement of water, sugars, and other compounds through the phloem is facilitated by active loading of sugars into sieve elements by companion cells, creating a pressure gradient that pushes water from source leaves to sink organs. Solutes enter the sieve elements via both the apoplast and symplast systems. The symplastic system involves the passage of solutes through cell channels, while the apoplastic system consists of cell walls and extracellular spaces, with active pumping of sugars driven by specific channels and the proton-motive force. Cell membranes play a crucial role in maintaining homeostasis and regulating internal processes, including the movement of herbicides through the plasmalemma via diffusion or specific transport mechanisms. While carrier-mediated, energy-requiring herbicide transport through the cell membrane is a possibility, herbicide diffusion remains a significant mechanism of transport, particularly in lipophilic fast-penetrant herbicides.

Conclusion

Nano-priming has the potential to induce coordinated germination, aid in plant growth stimulation, and augment tolerance to abiotic stresses. Nanoherbicides, formulated using nanotechnological potential, effectively deliver chemical or biological pesticides through nanosized preparations or nanomaterials-based herbicide formulations. These formulations could improve herbicide efficacy, enhance solubility, and reduce toxicity compared to conventional herbicides.

Specifically encapsulated herbicide molecules aim at the root receptors of targeted weeds, entering the root system and inhibiting glycolysis, ultimately leading to weed starvation and death. Applying nano herbicides in rain-fed areas prone to herbicide dissipation due to insufficient soil moisture can be beneficial. Controlled release of herbicides via encapsulation can effectively destroy weeds. Additionally, nanomaterials are claimed to enhance herbicidal activity as adjuvants, acting as carriers and forming nanoformulations when combined with herbicides. These nanoformulations help overcome the challenge of herbicide-resistant plants. The nanoparticle systems for herbicide delivery are primarily composed of biodegradable, non-toxic polymeric substances. Furthermore, understanding the forces that select resistant individuals and the processes that accelerate or delay resistance, along with experience gained in various growing conditions and countries, will be advantageous in studying and implementing herbicide resistance control. This paper aims to inspire researchers and farmers to innovate better solutions for local weed problems by recording and analyzing their experiences.

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