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Evaluating the role of nano fertilizers for enhancing global food security

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1. Introduction:

Agriculture, including horticultural crops, is a major economic sector responsible for providing food, feed, and ornamental crops globally. However, limited cultivable agricultural resources and the ever-increasing human population are pushing the sector to develop highly efficient agriculture to reduce poverty and hunger worldwide. The use of efficient mineral fertilizers is necessary to fulfil the increase in food production while avoiding environmental issues caused by chemical fertilizers. Therefore, the application of nanotechnology in the development of new types of fertilizers has been considered a promising option to boost global horticultural production sustainably under the current scenario of climate change (Raliya et al., 2017; Feregrino-Pérez et al., 2018). Recent studies have highlighted the potential benefits of nano fertilizers in promoting plant growth and development. For instance, studies by Li et al. (2020) and Lin et al. (2021) showed that the use of nano fertilizers improved crop yields and nutrient absorption. Furthermore, nano fertilizers have been shown to enhance enzyme activities, nitrogen cycle functions, and soil plant friendly microbes (Garcia-Sanchez et al., 2018; Li et al., 2020). However, the use of these fertilizers has also raised concerns over their potential negative impact on human health and the environment. Studies by Alghuthaymi et al. (2021) and Liu et al. (2022) have highlighted the need for careful evaluation of the potential risks associated with the use of nano fertilizers in agriculture. This includes potential bioaccumulation and toxicity issues, as well as possible negative impacts on soil microbial communities and soil organic matter. Therefore, it is crucial to conduct thorough risk assessments and research to ensure the safe and sustainable use of nano fertilizers in agriculture (Figure 1). In summary, the development of nano fertilizers holds great potential for enhancing sustainable horticultural production to meet the increasing global food demands. However, this technology must be carefully evaluated and tested to ensure its safety and effectiveness in promoting plant growth while avoiding negative impacts on human health and the environment.

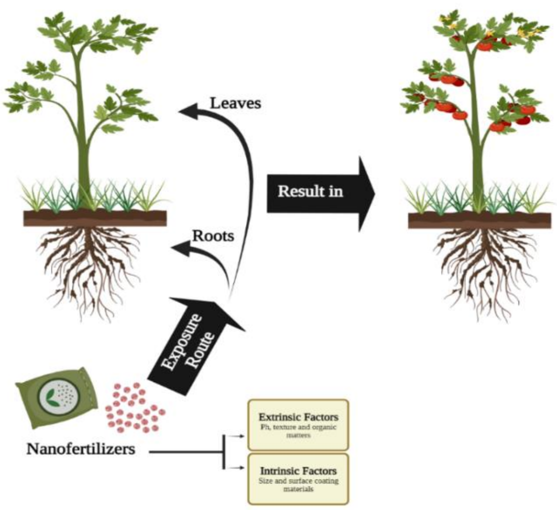

Figure 1: Application of nano fertilizers for better productivity

2. Some commercialized nano fertilizers:

Various commercial nano fertilizers are available globally, including nitrogen (IFFCO Nano Urea), phosphorus (TAG Nano Phos), potassium (NanoMax Potash), zinc (Geolife Nano Zn), calcium (Nano Calcium Chelate Fertilizer, Fertile Calcium 25, and Lithical), iron and magnesium (Nubiotek®HyperFe+Mg), magnesium, molybdenum, and zinc (Nanovec TSS 80), silicon (Nano Land Baltic), potassium and phosphorus (Fosvit K30), boran (Nano Bor20%), and silver (Nano-Ag Answer®) (Dimkpa and Bindraban, 2017; Rajput et al., 2021; Kalwani et al., 2022).

3. Methods involved in preparation of nano fertilizers

Nano fertilizers can be synthesized using different methods, including physical and chemical approaches. Physical methods involve the reduction of bulk materials to nanoscale particles using milling techniques. However, this approach has limitations, including low control over the size of the nanoparticles and the presence of impurities (Table 1). Chemical methods involve building up nanoparticles from atomic or molecular scales using controlled chemical reactions. This method offers better control over the size and purity of the nanoparticles (Table 2). In addition to physical and chemical methods, nanoparticles can also be synthesized using biological approaches, such as biosynthesis using plants, fungi, or bacteria. This method allows for greater control over particle size and toxicity. For mass production of nanoparticles with controlled physicochemical properties, the bottom-up approach is usually preferred. This approach allows for the synthesis of homogeneous and target-specific nano formulations (Singh and Rattanpal, 2014; Raliya et al., 2017).

Table 1: List of different types of physical methods for preparation of nano fertilizers

S. No.	Physical methods	Advantages	Disadvantages	Reference
1.	**Gas condensation method**	Very fine particles can be produced (100nm).	Processing is very slow and	Tissue and Yuan (2003); Rajput (2015)
2.	**Inert gas Condensation**	Nanoparticles are produced into small disk and nanoparticles of Mn, AuPd and CoO were achieved.	Needs of inert gas pressure and regular examine the rate of evaporation and the composition of gas is needed.	Nieman et al. (1089)
3.	**Aerosols synthesis method**	Highly pure with exact size and shape of nanoparticles can be produced even at low temperature.	Monitoring of gas flow rate is needed properly and yield is also very low (1 g per year)	Raliya and Tarafdar (2013)
4.	**High energy ball mill**	Nanoparticles of some metals and alloys in the form of powder is formed.	High temperature and impurities of O_2, N_2 gases released here.	Maissel and Glang (1970)
5.	**Bottom up**	Ultra-fine nanoparticles, nanoshells, nanotubes can be organized.	Huge level manufacture is not easy and chemical distillation is required.	Garrigue et al. (2004)
6.	**Top down**	Chemical purification is not required and used for large scale production.	Broad size particle is complicated to attain and it is costly method.	Garrigue et al. (2004)
7.	**Mechanical alloying**	Nano-meter-sized particles can be obtained.	Risk of contaminating powders by elements from the atmosphere.	Koch (2006)
8.	**Molecular beam epitaxy**	Elemental dots, wells, wires etc deposited in a very controlled manner.	The rate of deposition is kept very low.	Gryaznov and Trusov (1993)
9.	**Thermolysis method**	Additional reducing agent does not require.	The size of the nanoparticle controlled by polymers and capping agents.	Palacios-Hernández et al. (2012)
10.	**Vaccum arc deposition**	It is conventional process for the formation of nanoparticles.	Low-voltage, high-current self-sustaining arc is produced.	Schulz et al. (2004)
11.	**Expansions cooling method**	Very fine size particles 100 nm gained with a maximum production rate.	Converging nozzles have to produce nanoparticles.	Kruis et al. (1998)

Table 2: List of different types of chemical methods for preparation of nano fertilizers

S. No.	Chemical methods	Advantages	Disadvantages	Reference
1.	**Chemical vapor deposition**	Efficient productivity of highly pure nanoparticles in controlled manner.	The reaction is activated in high temperature (above 900 °C).	Milani and Iannotta (2012)
2.	**Chemical precipitation**	Less time and less place are required.	Reaction kinetics does not control.	Nalwa (1999)
3.	**Sol-gel technique**	Low temperature process, less energy utilization and less pollution too.	High experience.	Jones (1990)
4.	**Electrodeposition**	Can yield porosity-free finished products and 3D-nanostructures.	Grain sizes in nano-meter range obtained.	Kruis and Fissan (1998)
5.	**Photochemical method**	Equipment's involved are simple and cheap.	High-pressure indium lamp has to apply.	Dong et al. (2004)
6.	**Spray pyrolysis**	Multicomponent particles are easily prepared.	Material which is to be sprayed should be dissolvable.	Kruis and Fissan (1998)

4. Role of nano fertilizers

4.1. Role of nano fertilizers in soil

Nano fertilizers offer dual benefits of soil improvement and increased plant productivity by facilitating better nutrient absorption by roots. Root development is influenced by various soil factors such as nutrient availability, pH, texture, and aeration. The uptake and accumulation of nanoparticles by plants can occur via different pathways, including root uptake and aerial surface absorption. The controlled release of nutrients from nano fertilizers is regulated by the high surface tension of nanoparticles on the surface of fertilizer particles. Recent research has shown that TiO2 nanoparticles at low concentrations are non-toxic to soil microbes and can enhance root elongation, while CuO, ZnO, and Ag nanoparticles can be toxic to the soil microbial population (Mahapatra et al., 2022; Mittal et al., 2020; Adisa et al., 2019; Asadishad et al., 2018).

4.2. Role of nano fertilizers in plants

Nano fertilization have been found to significantly improve the physiological and biochemical indices in crop plants, including chlorophyll content, photosynthetic activity, nitrogen metabolism, and soluble proteins. Recent studies have shown that nano fertilizers can enhance plant productivity in sunflower, maize, and other crops. The wide surface area of nano fertilizers enables excess sorption capacity and controlled release kinetics with intelligent delivery mechanisms, which may increase stomatal penetration. However, some studies suggest that nanoparticles may induce DNA damage indirectly by stimulating reactive oxygen species (ROS). Therefore, further research is needed to fully understand the potential risks and benefits of using nano fertilizers in agriculture. (Pirvulescua et al., 2015; El-Saadony et al., 2021; Fellet et al., 2021; Perez-de-Luque, 2017; Rameshaiah et al., 2015; Mandal and Lalrinchhani, 2021).

5. Advantages and disadvantages of nano fertilizers:

Nano fertilizers have emerged as a promising tool for enhancing crop productivity and addressing global food security challenges. One of the key advantages of nano fertilizers is their ability to provide nutrients gradually in a controlled manner, thus extending soil health and fertility with nutrient balance, and reducing the risk of toxicity (Solanki et al., 2016). In addition, nano fertilizers have been found to increase fertilizer use efficiency, minimize volatilization and leaching, and reduce environmental hazards (Solanki et al., 2016; Rameshaiah et al., 2015). They can also enhance seed germination, seedling growth, photosynthesis, nitrogen metabolism, and protein and carbohydrate synthesis, ultimately improving stress tolerance and increasing crop productivity (Fellet et al., 2021; El-Saadony et al., 2021; Pirvulescua et al., 2015). Furthermore, it can be applied in smaller amounts, reducing transport expenditures and increasing ease of application, making them a cost-effective alternative to conventional fertilizers (Rameshaiah et al., 2015). Some researchers have even suggested that nano fertilizers may be the preferred form of fertilizers over conventional ones (Iavicoli et al., 2017; Dimkpa and Bindraban, 2017). Recent studies have also shown promising results for the use of nano fertilizers in different crops, such as date palm (Jubeir and Ahmed, 2019) and maize (El-Saadony et al., 2021).

Despite their numerous benefits, the use of nano fertilizers also comes with potential risks and challenges. For example, excessive use of nano fertilizers may have negative impacts on human health and the environment, including potential toxicity (Seleiman et al., 2021). Additionally, nano fertilizers may release nutrients at a slower rate than conventional fertilizers, which may delay plant growth and crop yield (Seleiman et al., 2021). They may also induce DNA damage indirectly by stimulating reactive oxygen species (ROS) (Mandal and Lalrinchhani, 2021) (Figure 2).

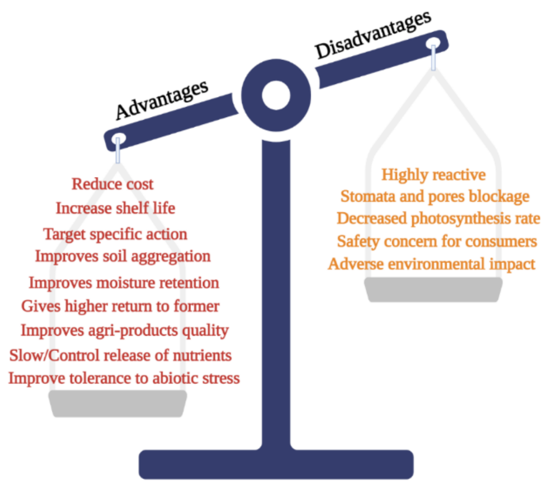

Figure 2: Advantages and disadvantages of nano fertilizers

6. Conclusion:

In conclusion, the use of nano fertilizers represents a promising approach to address global food security challenges. While their benefits are numerous, further research is needed to fully understand their potential risks and to develop safe and effective application methods. Scientists are currently exploring new nanotechnology applications in agriculture and the food industry, with the aim of developing innovative fertilizers that can provide balanced nutrition and combat various environmental variables with significant advantages for plant performance and human health.

7. Author contribution statement

All authors listed have significantly contributed to the development and the writing of this article.

8. Competing interest statement

The authors declare no conflict of interest.

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