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Utilizing Nanomaterials Linked With Plant Growth-Promoting Bacteria For Agricultural Advancements A Short Review

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Abstract

Growing concerns about food supply sustainability and security are driving exploration of eco-friendly approaches in agriculture. One promising method involves using microbe-based biofertilizers – beneficial bacteria that enhance nutrient uptake and promote plant growth in soil and plants. Nanotechnology is also valuable, as nanoparticles can boost biofertilizer effectiveness in natural environments. Review examines how nanoparticles affect plant bacteria for sustainable agriculture.

Keywords -Nanobiofertilizers, Nanoparticles, Plant growth promoting bacteria(PGPB)

Introduction

Economic progress and population growth boost food demand surge (Ma et al.,2018). Excessive chemical use harms ecosystems; seeking eco-friendly alternatives is vital (Gurikar et al.,2016). Utilizing bio fertilizers, bio pesticides, and eco-friendly water practices can enhance agricultural yields while preserving soil health (Glick., 2020). Bacteria in roots and within plants aid growth, enhance nutrients, protect (Castro et al., 2018; Batista et al.,2018). Microorganism-based bio fertilizers proved economically viable for organic farming, leading to a 12% market expansion (Meticulous Market Research., 2017). Nanotechnology has gained prominence in precision agriculture, aiming to address challenges faced by microbial inoculants in the field. By utilizing nanoparticles (NPs) with unique properties and smaller sizes, it seeks to improve bio fertilizers' stability, storage, and overall effectiveness (Duhan et al., 2017). Utilizing a variety of nanoparticles, nanotechnology improves plant characteristics and increase PGPB potential (Zand et al.,2020). Nanomaterials are seen as humanity's future (Singla et al., 2020).

Nanotechnology for organic farming

Nanotechnology utilizes materials at the nanoscale, offering unique properties like quantum confinement and enhanced bioactivity, adhesion, and reactivity (Gutiérrez et al.,2011). Nanotech offers effective solutions for sustainable agriculture, addressing safety, security, disease, and climate (Prasad et al.,2017). Scientists are investigating nanomaterials as a means to boost agricultural efficiency. Nanotechnology finds applications in seed science, nanofertilizers, water management, biosensors, and more. Smart agricultural systems utilizing nanomaterials promote nutrient absorption, precise molecule delivery, disease detection and environmental protection (Koul., 2019, Bhattacharyya et al.,2016). Nanoencapsulated bacteria in smart seeds lower planting rates, ensure better seedling growth, and boost crop production. They sprout in ideal conditions. (El-Ramady et al., 2018). Nanomaterials aid crop genetic engineering, monitor plant responses, and improve crop productivity, adapting to climate change (Figure 1).

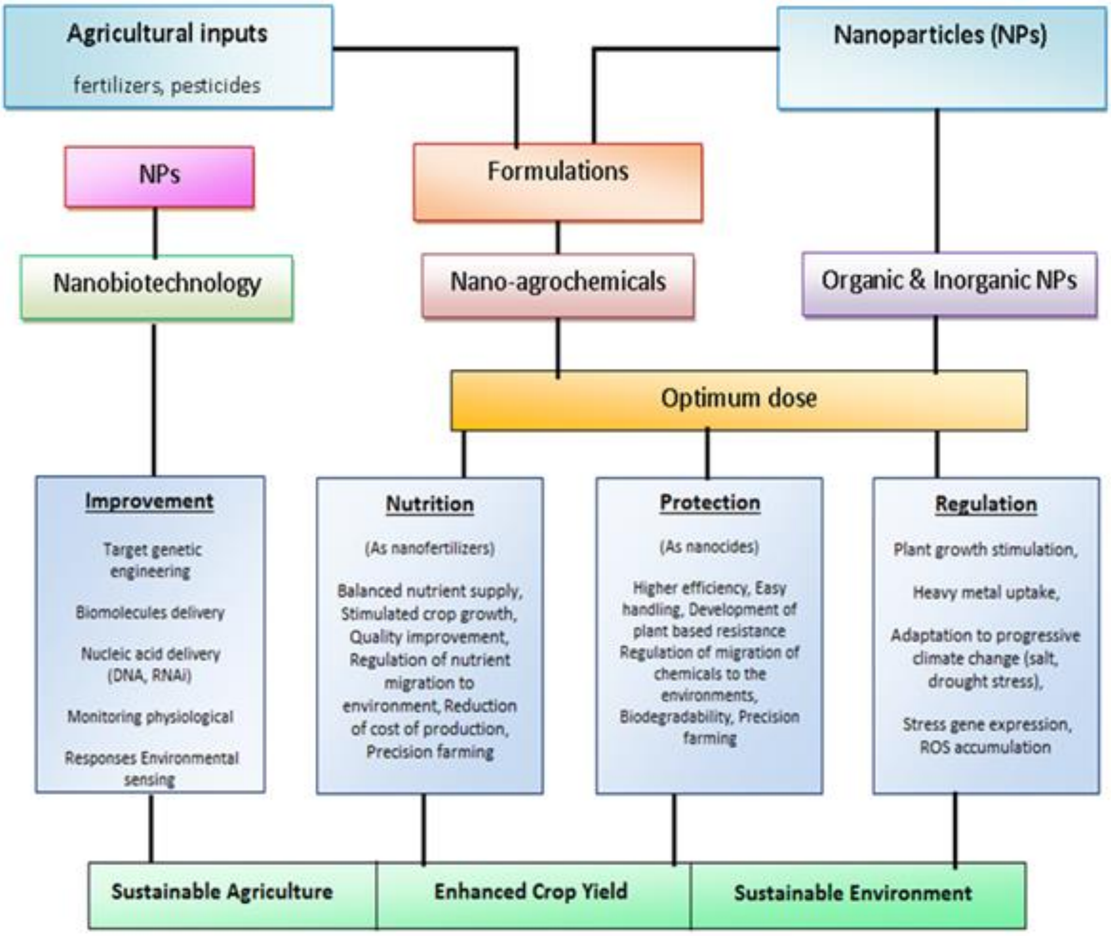

Fig: 1-Simplified overview of potential applications of nanomaterials in sustainable

Biofertilizer formulations using nanomaterials

PGPB support plant health by absorbing nutrients, regulating growth hormones, limiting pathogens and promote resistance in plants (Gond et al., 2015, Glick., 2020, Srivastava et al.,2016). Biofertilizers serve as carriers of beneficial microbes, enhancing nutrient availability in plants. These formulations, containing live microorganisms, are widely utilized in agriculture for nitrogen fixation, phosphorus and potassium solubilisation and biocontrol purposes (Sahu and Brahmaprakash., 2016, Kour et al.,2020). Biofertilizers are eco-friendly, sustainable, enhance soil fertility, and benefit farmers (Thomas and Singh., 2019). Frequent inoculants include Azospirillum, Acetobacter, Azotobacter, Pseudomonas - aiding plant growth (Kumar and Verma., 2018). NPs' surface area and negative charge influence microorganism-NP interactions, while positive charges on cells enhance adhesion (Kurdish., 2019). Particles and bacteria interact via electrostatic attraction and chemical changes on bacterial surfaces. Key biomolecules involved are LPS, LTA, proteins, and phospholipids, affecting NP transportation into cells without a defined model (Palmqvist et al., 2015, Shukla et al.,2015). NPs enhance PGPB's ability to inhibit phytopathogens. PGPB gain an advantage in habitats and resources, as NPs increase bacterial cell numbers. Nanomaterials boost beneficial bacterial traits like nitrogen fixation and secondary metabolite synthesis (Figure 2). For example, ZnO NPs enhance siderophore formation in Pseudomonas chlororaphis, CuO NPs increase IAA synthesis, and AgNPs improve Nitrosomonas europaea's nitrogen-fixing ability by upregulating amoA1 and amoC2 genes. Nanomaterials effects bacteria, influencing their metabolism through ion interactions, gene expression changes, and cell membrane modifications. Beneficial bacteria combat plant-harming microbes through competition or antimicrobial production (Quecine et al.,2014). Research gaps exist regarding molecular interactions between bacteria, NP and plants promoting development. Limited knowledge on PGPB-related nanomaterials' impact on plant molecular activity. Physiological studies reveal larger NPs concentrate in apoplastic space, while smaller NPs can move through plasmodesmata in the symplast (Jha and Pudake.,2016). Plant roots produce reactive oxygen to obtain nitrogen from symbiotic bacteria, engaging in microbivory. Bacteria enter the plant, providing nutrients that the host absorbs through an oxidative process. Some NPs may remain in plant tissues during this cycle (Quecine et al.,2014).

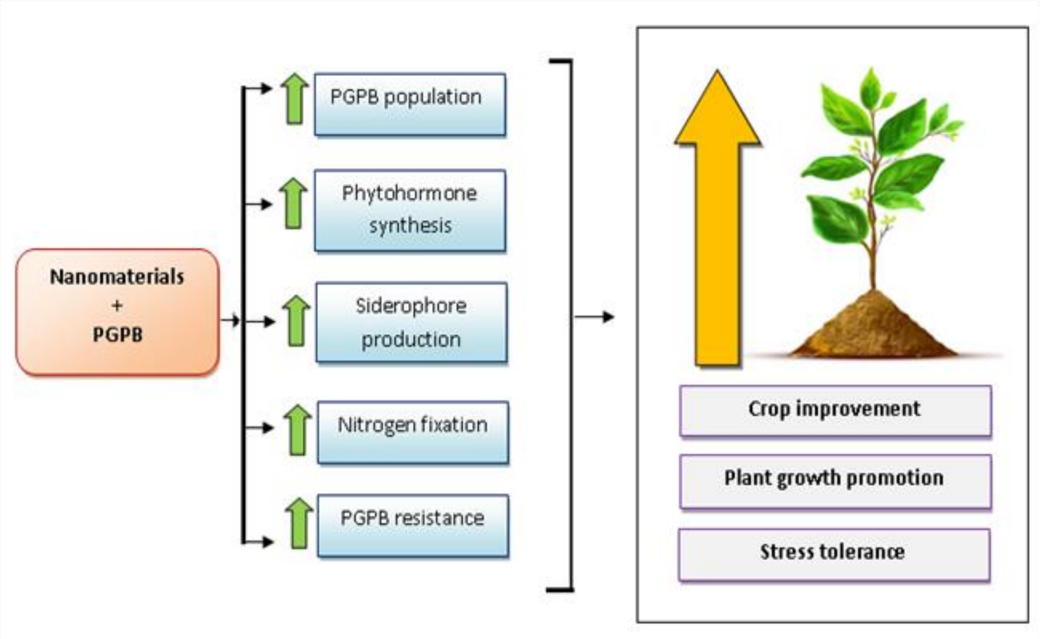

Fig: 2- Positive effects of NPs on beneficial bacteria and plant

In this process, NPs on bacteria may persist in plant materials, according to our hypotheses.

SiO_2nanoparticles

Silica NPs are widely used due to their inexpensive synthesis and versatile properties (Jeelani et al., 2020). Silica NPs facilitate controlled-release systems, enhancing molecule efficiency and specificity (Xu et al.,2019). Silica nanoparticles enhance bioremediation and maize seed viability (Liang et al.,2020). Nanosilica enhanced maize's PGPB effects. Nanosilica boosts tomato growth significantly (Siddiqui and Al-Whaibi.,2014). Encapsulated bacteria improved UCB-1 pistachio growth by enhancing root length and micropropagation in this study. Researchers found that using silica nanoparticles from Equisetum telmateia at 0.05 and 0.07 ppm doses enhanced the growth of Pseudomonasstutzeri and Mesorhizobium spp., resulting in significant improvement in land cress plant growth with increased soil nutrients. SiO2 NPs boost plant-bacteria interaction (Kurdish.,2019).

TiO_2 nanoparticles

Anatase, rutile, and brookite are the three different crystalline phases of TiO_2. The first two is the most typical and feature tetragonal formations. The popular techniques hydrothermal and sol-gel, regulate nanoparticle size and form. Altering pH, temperature, and solvent modifies material properties . TiO2 nanoparticles enhance PGPR attachment to roots, increasing wheat growth (Timmusk et al., 2017). Titanium nanoparticles shielded plants from the fungus *Alternariabrassicae* and assisted the plant-growth-promoting bacterium *Bacillusamyloliquefaciens* in attaching to the roots of oilseed rape (*Brassicanapus*). Titanium NPs improved broad beans in saline soil, aiding crops (Palmqvist et al., 2015).

ZnO nanoparticles

The n-type semiconductor zinc oxide has good chemical and photothermal stability, nontoxicity, biocompatibility in its nanoparticles. ZnO nanoparticles can be produced using physical and chemical methods. Two common physical techniques are laser ablation and physical vapor deposition (Laurenti et al., 2015). Zinc oxide nanoparticles hindered bacterial IAA production. Concentration affected results. Phosphate solubilization was also blocked. Siderophore production increased with NP concentration (Haris and Ahmad., 2017). $ZnSO_4$ NPs and Pseudomonas spp. PGPB enhanced rice yield and nutrients. Increased plant height, nodule count, and grain weight were caused by ZnO NPs injected into soybean plants using PGPR. According to (Seyed Sharif and Khoramdel., 2016), Higher zinc oxide, more pods, grains, and nodules.

Other nanoparticles

CuO NPs improved wheat's (*Triticumaestivum*) nitrogen fixation, gene expression. Gold nanoparticles exhibit chemical inertness, resist surface oxidation, and are nontoxic in nature. As the AuNP concentration increased, they enhanced the growth of beneficial bacteria, showing their potential in nanobiofertilizers (Shukla et al., 2015). Cowpea responded positively to growth factors and nodulation, Brassica to shoot parameters, wheat had a detrimental impact. Cowpea and wheat bacteria, 50 ppm impacted P solubilizers, but 75 ppm decreased N fixers and siderophore producers. Brassica's diversity was unaffected by either concentration (Shukla et al., 2015).

Nanoparticles' toxicological effects on microorganisms that promote plant growth

Nanomaterial toxicity linked to charge, shape, absorption, dissolution (Singh et al., 2019). NPs have good and detrimental effects on plants in terms of phytotoxicity. According to (Jha and Pudake, 2016), Plant species and NP content affect harm differently. Bacterial toxicity varies with metal type and NP concentration (Hayden et al., 2012). Nanomaterials pose challenges to organisms in the environment. Proof of agricultural progress with NPs and PGPB needed. In-depth case-by-case examinations necessary for safety.

Conclusion and future perspectives

PGPB offers a viable, environmentally beneficial substitute for pesticides used in agriculture. To succeed, studying plant-microbe interactions and novel strategies is essential. Nanotechnology can help overcome challenges in biofertilizers, with nanomaterials showing positive effects on PGPB and plant growth. However, potential harmful effects on the environment and human health must be explored. Field experiments are crucial to validate findings in natural conditions. Careful risk assessment is vital to harness the benefits safely.

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