

Amalgamation of Nanotechnology with Plant Sciences

Abstract This review paper deals with the basic aspects and advancement of plant Nanotechnology and its varied applications in every possible field starting from biotechnology, drug science, energy related sectors, pharmaceutical sector and so on. They show some explicit properties like strength, electrical, and optical and chemical properties. NPs show increment in plant productivity by showing direct interactions with plants or indirectly with soil. Nanoparticles can easily be synthesized utilizing microbes and plants, so they are organically-protected, savvy, and climate-amicable. Nanoparticles are termed as “magic bullets” because of their extraordinary properties, and for this very reason they are employed in production of nano herbicides, nano pesticides. Nanotechnology does the job of addressing distinctive natural and medical problems which occurs to happen with the unreasonable utilization of pesticides and fertilizers in horticultural practices. When used in an appropriate amount and concentration they cause positive effects on the respective plants. Some of these include increment in crop production, better quality, increased photosynthetic activity, biomass, chlorophyll content and the list goes on. With every positive effect comes the detrimental ones also. Inhibition of root and shoot length, reduced seed germination, inefficiency in photosynthetic activity.

Comment [r1]: Only plant-based nanoparticles?

Keywords: Nanoparticles; Agri business; Nano applications; Plant protection; Plant growth and development; Nano-herbicides.

1. Introduction

Nanotechnology is one of the rising and captivating field of science, that grants progressed research in numerous fields and revelations in this field has the potential to unfold many biotechnological applications, life sciences, medicine, and farming [1]. Nanoparticles (NPs) generally possess size around 100 nm and huge surface region facilitating binding with functional ligands [7][21]. They show some explicit properties like strength, electrical, and optical and chemical properties [3][10]. Because of their wide applications in agri-business, they are rightly called as “magic bullets” [23]. NPs can be derived either from normal resources or from human-centered ones, for example, designed or undesirable NPs [7].

Nano-fertilizers or Nano-typified supplements exhibit properties that are successful to crops, such as controlled release of compounds regulating plant growth and development, release of nutrients on demand with upgraded target activity and providing phytopathogen resistance to plants [1][10]. It is sensible to contend that the possibility and the advantages of the utilization of NPs in plant sciences and agribusiness are yet not completely utilized, because of certain hindrances, which can be momentarily summed up as follows: (i) the methods of extraction of NPs and their uptake are still under study (ii) the manufacturing of NPs that are sustainable and do not meddle adversely with plant development and improvement [6].

Nanotechnology is certifiably not a solitary innovation, yet it is a combination of a few innovative discoveries, which works at the nano-level. In the field of horticulture, nanotechnology has varied applications, for example, recording data related to ecological stress by usage of nano sensors. resilience against biotic as well as abiotic factors resulting in improved crop quality [20]. Nanomaterials can be utilized as promising source in order to transport the genes or the synthetic substances to the objective site needed for plant working with high precision in a controlled way [8]. NPs show increment in plant productivity by interacting directly (plants) or indirectly (with soil). By chelation of salts existing in soil, NPs improve soil health by regulating soil pH and interacting with soil microbes [10]. They have high proficiency and thus lessen the bothersome natural impacts that outcome from the gigantic use of ordinary fertilizers. Effects of various nanofertilizers like nano-calcium carbonate, nano-phosphorus manure, iron, magnesium, molybdenum oxides, zinc, managanese were studied on plants and positive outcomes were recorded in accordance with their respective dosage [14].

Comment [r2]: How genes could be transported with nanomaterial?

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2. Synthesis

NP's synthesis can be achieved by mainly three ways: chemical, biological, and physical. Ordinarily, physical, and chemical methods are popularly used [23]. Physical and chemical techniques employ usage of hazardous substances like organic solvents, reducing agents etc, that can prove to be toxic [27]. Nanoparticle production utilize various algae, plants, bacteria, waste from agricultural activities [23]. By Green Synthesis, Nanoparticles can easily be synthesized utilizing microbes and plants so they are organically protected, savvy, and climate amicable. Plants and microorganisms have inbuilt mechanisms to eat up and collect inorganic metal particles from their adjoining niche [27]. Agrarian waste like corn cob, sugarcane bagasse, rice husk, mang peels and extract from plants like *Citrus sinensis*, *Glycine max*, *Azadirachta indica*, *Mangifera indica* and Algae like *Chlorella*, *Euglena*, *Chlamydomonas spp* are employed for synthesis of various nanoparticles [23].

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Table 1 Synthesis of various NPs from plants and Agricultural waste

Plant name/Agricultural waste	Nanoparticles synthesized	Reference(s)
<i>Eclipta prostrata</i> <i>Citrus sinensis</i> Tea leaf extract Orange peel Coconut shell	Ag	[23][5]
<i>Aloe vera</i>	Ag, Au, ZnO, Cu	[28][29][23]

Comment [r8]: Formatting

<i>Mangifera indica</i> <i>Vitex negundo</i>	Au	[23][5]
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Banana peel extract Egg shell Grape waste		
<i>Glycine max</i>	Pd	[23]
<i>Azadirachta indica</i>	Au/Ag bimetallic	[23]
Sugarcane bagasse Cassava periderm Maize stalk	Si	[30][23]

3. Classification

On the basis of chemical nature, Nanoparticles can be classified into 4 categories namely; carbon, polymeric compounds, metal and ceramic (metal oxides). Ceramic based nanomaterials contain inorganic solids made of metal oxides (ZnO, FeO₂, and TiO₂). On the other hand, Carbon-based nanomaterials consist of graphene, fullerenes and carbon nanotubes. Metal-based nanomaterials include Cu, Ni, Au, and Ag which lead to plant growth and development [3].

Comment [r9]: Grammar mistakes

3.1 Zinc Oxide NPs

According to research by various scientists, ZnO NPs were beneficial in increasing plant growth in many crops like wheat, soybean, peanut etc [1]. ZnO NPs have been broadly utilized, as zinc is a fundamental micronutrient essential for various physiological reactions. According to few researchers, ZnO NPs are less harmful for crops in comparison to other nanoparticles like ZnO bulk particles or Zn²⁺ [10]. These NPs when supplemented with MS media lead to advancement in plantlets regeneration, shooting, somatic embryogenesis, and furthermore promoted synthesis of proline, action of dismutase, superoxide, catalase and peroxidase consequently developing resistance to any sort of biotic stress [1]. Nano manure like Nano-Ag Answer^R, Nano-GroTM, , TAG NANO (NPK,Zinc, PhoS etc) are quite in demand [10].

Comment [r10]: Spell mistake

3.2 SiO₂ NPs

Many researchers studied the effect of nano SiO₂ on variety of crop plants like maize, tomato, soybean and many more [1]. Lately, silicon has given a great deal of consideration by the agrarian researchers. It had been accounted that Si might assumed a basic part in expanding plant's resistance against biotic stresses in cucumber [12]. Improvement in seed germination was observed on treating tomato with low dosage of nano SiO₂. Likewise, the same was observed in maize which was aided by better availability of nutrients to the seeds. Exogenous utilization of nano-SiO₂ on seedlings of *Changbai larch* developed root collar diameter, mean height, fundamental root length, seedlings the induction of chlorophyll synthesis [1]. Subsequently, silicon influences plant development under conditions of stress by influencing an assortment of cycles which covers plant water relations, upregulation of phyto defence, changes in ultra-structure of leaf organelles. The leaf spray of SiO₂ on cucumber plant led to increment in number of fruits per plant, fruit diameter, plant height, number of leaves, etc [12].

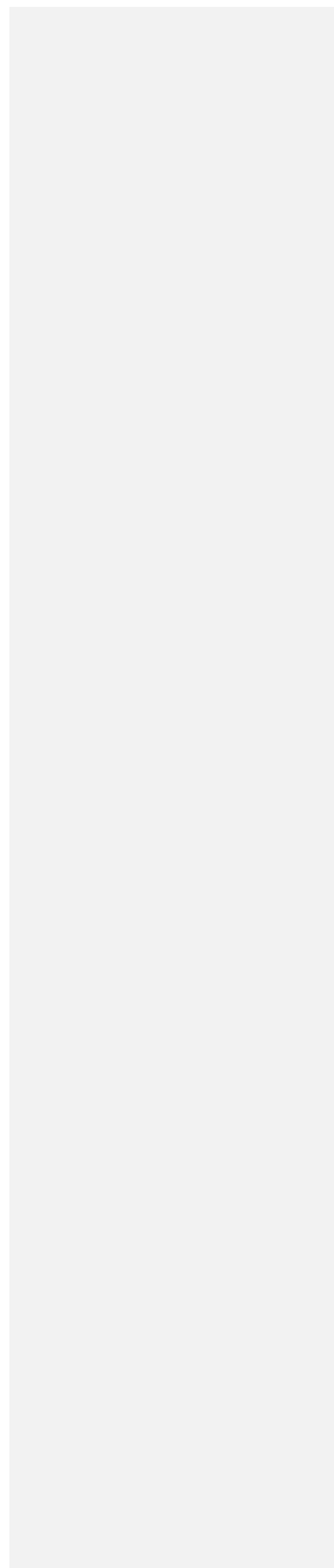
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3.3 Carbon based NPs

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Carbon is one of the few components which has the tendency to polymerize at the nuclear level, and therefore framing extremely long carbon chains. It is tetravalent in nature and non-metallic, forming covalent bonds [13]. Carbon based nanoparticles include Carbon nanotubes, fullerenes, graphene [3].

Comment [r13]: Check grammar and formatting mistakes

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Lately, CNTs have been the subject of broad examination due to their exceptional properties (chemical, mechanical, thermal) and wide scope of biotechnological applications [15]. Because of their extraordinary properties, they can infiltrate the cell wall and the plasma membrane and furthermore give an appropriate transport arrangement of chemicals to cells [1]. Because of these properties, they are widely used for pollution control, crop management, nutrient carriers, detection of pesticides and as Nanofertilizers [15]. Multi walled carbon nanotubes (MWCNTs) act as plant growth regulators and leads to increment in fresh weight of tomato plant [15]. The single-walled-CNTs (SWCNTs) help conveyance of various dyes and DNA into plants cells [1].

Comment [r14]: Define CNTS?

Comment [r15]: Spelling check

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Comment [r18]: From where these fullerenes come? Most provide little background to make sense.

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Fullerenes comprise of 20 hexagonal and 12 pentagonal rings forming a close caged structure [13]. The fullerene, C₆₀ and CNTs have been displayed to build the water holding capacity, fruit yield and biomass in plants up to ~118% which is a wonderful accomplishment of nanotechnology lately. When treated with the fullerene, the bitter tasting melon seeds led to increment in the phytomedicine constituents for example lycopene (82%), cucurbitacin-B (74%), insulin(91%),and charantin (20%).The fullerenes also acts as antioxidants, antiviral and anti cancerous agents[16].

Graphene is a 2D allotrope of Carbon made of single layer of carbon atoms having sp² hybridized C atom[13]. Graphene is the most acknowledged nanoparticle for manufacture of biomedical sensors for bio imaging, bio sensing and curative because of its invigorating characteristics like exceptional surface properties, fluid processability, surface-improved Raman scattering and cell development capacity[19].

Comment [r20]: Is Raman scattering a property of nanoparticles?

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3.4 TiO₂ NPs

Titanium dioxide (TiO₂) is considered as one of the useful components for plant development which finds its usage in agribusiness, consumer goods, and energy areas[20].According to various studies, TiO₂ NPs led to advancement in radical and plumule development on canola seedlings [1].By applying Titanium dioxide via means of roots or leaves at low dosage, reported to further develop crop performance through invigorating the action of specific catalysts, reinforcing pressure resilience,advancing supplement take up, improving chlorophyll content and photosynthesis thus developing harvest yield and its quality[20]. TiO₂ nanoparticles controls various catalytic activities associated with metabolism of Nitrogen, for instance, glutamate dehydrogenase ,glutamine synthase ,nitrate reductase, and glutamic-pyruvic transaminase help the plants to assimilate nitrate. It favours the transformation of inorganic nitrogen to organic one in the form of protein and chlorophyll Therefore,it leads to increment in dry and fresh weight of the plant.Also,these nano particles act as photocatalyst leading to redox reactions . TiO₂NPs perceptibly brings about vigour in mature seeds' life and chlorophyll development .Furthermore, these invigorates activity of RuBisCO enzyme and accelerates photosynthetic activity of plants leading to their development[1].

Comment [r22]: Grammar, spelling and formatting mistakes in whole text

3.5 Ag and Au NPs

Silver and gold nanoparticles (AgNPs and AuNPs, respectively), have been utilized progressively due to their potential benefits, like high stacking capacity and stability[21]. Gold and silver nanoparticles find their utilization as medication transporters, utilizations in biomedicine, enhancers as well as converters of the optical signal, and immunomarkers[22] .

AgNPs when administered on *Bacopa monnieri* led to protein and carbohydrate synthesis in the plant. Also,an increase in leaf area, shoot length,root length along with biochemical properties(antioxidant enzymes,protein and carbohydrate contents,chlorophyll) was observed in *Brassica juncea* [1].

The effects of AuNPs were studied on *Gloriosa superb* that advanced seed germination.Overall,these increased chlorophyll content, surface area of leaves,height of the plant resulting in high yield of crops[1].Viability of tissue infiltration of AuNPs depends on surface charge,

Comment [r23]: Formatting, spelling and grammar mistakes

particle size and plant species. AuNPs containing positive charge are taken up exclusively by plant roots. On the contrary, those containing negative charge move towards stems and leaves via roots [22].

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Check formatting mistakes

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4. Nanoparticles as -A Boon to Plants

Comment [r25]:

Nanotechnology does the job of addressing distinctive natural and medical problems which occurs to happen with the unreasonable utilization of pesticides and fertilizers in horticultural practices. When used in an appropriate amount and concentration NPs like titanium oxide, sulfur, gold, zinc, carbon nanotubes, iron, copper, silver, chitosan NPK NPs show further developed plant development and an increment in crop harvest [8].

4.1 Plant Growth and development

Lately, various examinations have been directed to investigate and portray the impact of NPs on crops [4]. Plants on interaction with NPs causing numerous physiological and morphological alterations which are entirely contingent upon the properties of nanoparticles. Adequacy of NPs is controlled by their size and shape, reactivity, surface covering and charge and in particular the dosage at which they are operative and effective. Concentrations of NPs determine its efficacy which differs from plant to plant [1]. On treating soybean (glycine max) with nano-TiO₂ and nano-SiO₂, nitrate reductase activity was hastened thereby amplifying water absorption and utilization by the crop plant[25]. Water-stressed plants treated with SiO₂NPs gave higher yield than those without the SiO₂ NPs application[11]. Graphene Oxide can be utilized to accelerate growth of the plant(root elongation,increases surface area of leaves), increase sugar content of and its ripening process[18]. The use of certain NPs can advance the movement of proteins like amylase,Carbonic anhydrase, phosphatase, nitrate reductase, and phytase which are associated with digestion and supplement procurement[24].

Comment [r26]: Grammar and formatting problems

4.2 In Photosynthesis

Photosynthesis is a vital process that converts light energy into chemical energy [1]. Ongoing advancements in science have started to exhibit that nanoparticles (NPs) can be manufactured and linked with photosynthesis resulting in increased crop yields [9]. Out of the total accessible energy, only 2-4% is converted by plants for their growth. Researchers are trying their hands in order to increase proficiency of vascular plants, by working on Rubisco (a photosynthetic enzyme)[1].

When treated with nano anatase,higher activity of Rubisco was observed in spinach plants which was an outcome of increased rates of photophorylation,electron transport and evolution of O₂[8].TiO₂ and ZnO NPs can invigorate biogenesis of chlorophyll and photosynthetic activity[24]. TiO₂ NPs have been proven beneficial in improving absorbance of light, in stimulation of CO₂ consolidation and acts as shield to inhibit ageing of chloroplasts from long brightening hours[1][26]. Titanium oxide NPs are useful in transfer of energy away from PSII, which enhances the proficiency in conversion of energy for PSII, in this way permitting more light to get absorbed [9].Nanoparticles such as SWCNTs increased the photosynthetic activity by three times by upgrading mechanism of electron transport which assisted in detecting NO –a signaling molecule[1]. Single-walled carbon nanotubes (SWCNTs)when conveyed into the chloroplast lipid bilayers enhanced photosynthesis and electron transport[18]. Analysts have recognized transportation of electron transport out from the photosystems can be useful in accelerating ATP synthesis and thereby photosynthetic activity.Studies suggest that QDs(quantum dots) behave as artificial light harvesting antennae distributing energy to LHCs.

Comment [r27]: Recheck and make sure to remove above said problems

4.3 In Agri industry

Nanoscience is a hot topic of research and discussion in the present century,especially in farming sector. Due to extraordinary properties of Nanoparticles (NPs) (pore size,surface area,reactivity,molecular morphology etc) these are termed as “magic bullets” in farming sector[23]. Metal, metal oxide,

composite and polymeric nanoparticles are applied to plants through different modes to

Comment [r28]:

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enhance the crop yield and shield from pathogenic assault[5]. NPs can be utilized to shield plants from natural effects, for example, salty or dry conditions and refrain settling of hazardous metals [24]. Utilization of NPs as nano pesticides,nano herbicides nanofertilizers, prove to be helpful in controlling over usage of synthetic manure, manage plant growth and development, their biological activity resulting in better crops efficiency, and furthermore increment survivability against biotic pressure[23]. NPs have come out as an excellent source of micronutrients (for example Fe,Mn based NPs, ZnO), consequently expanding wellness and assists plants to adapt to pressure conditions. TiO₂ and iron-based NPs can defer senescence and accelerate cell division by means of changes in phytohormonal levels.[24].NPs might affect the plant development on the basis of species and the dosage used.What may be beneficial for one,might be harmful for another species[23].

Comment [r29]: Grammar mistakes

The effects of AuNPs were studied on *Gloriosa superb* that advanced seed germination.Overall,these increased chlorophyll content, surface area of leaves,height of the plant resulting in high yield of crops[1].Viability of tissue infiltration of AuNPs depends on surface charge ,size of the particles and plant species.AuNPs containing positive charge are taken up exclusively by plant roots.On the contrary,those contain negative charge move towards stems and leaves via roots[22].

Comment [r30]: Already described same lines above. Avoid duplication.

Application of Nano-fertilizers boost the crop harvest by enhancing fatty acids,amino acids,reducing sugar content in a plant[23]. There are three different ways in which plant nutrients get distributed to their destination utilizing nanofertilizers, which are the supplements can be typified inside nanomaterials like nanotubes or Nano permeable materials, covered with a slightly protective polymer film ,or they are distributed as particles straightforwardly to the plants or as Emulsions of nanoscale measurements[5].ZnO NPs enhanced plant growth and helped to curb the zinc deficiency[3].

Nano-herbicides are used to kill weeds and stop their spread further [23]. Encapsulated Polymeric NPs are extensively used .Chitosan NPs proved to be beneficial and less hazardous when utilized in encapsulation of paraquat[3].Various nano pesticides like nano silica, are commonly used to control the spread of diseases in crops[23].

Comment [r31]: Grammar and spelling mistakes. Constantly repetition of same explanation.

Table 2 Nanoparticles and their positive effects on plants

Nanoparticles	Plant Species	Positive Effects	Reference(s)
TiO ₂ NPs	<i>Triticum aestivum</i> <i>Arabidopsis thaliana</i> <i>Foenticum vulgare</i> <i>Zea mays</i> <i>Avena sativa</i>	Increased Chlorophyll content Antifungal against wheat rust Increased plant growth seed germination Increased crop harvest Enhanced seed germination and root elongation	[1][3][23][20]
Multiwalled carbon nanotubes (MWCNTs)	<i>Nicotiana tabacum</i> <i>Lycopersicum esculentum</i>	Increment in flower number, plant height and growth.	[23]
Single walled carbon nanotube	<i>Allium cepa</i>	Root length elongation	[16]

Comment [r32]: Rewrite properly

AgNPs	<i>Cuscuta reflexa</i> <i>Lolium multifolium</i> <i>Sidacordifolia</i> <i>Saccharum officinarum</i>	Antibacterial	[21][23]
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SiO ₂	<i>Glycine max</i> <i>Lycopersicum</i> <i>esculentum</i>	Increased plant germination Enhanced germination of seed of tomato plant	[23]
ZnO Zn NPs	<i>Oryza sativa</i> <i>Arachis hypogea</i> <i>Cicer arietum</i> <i>Cucumis sativa</i>	Reduced Arsenic and Cadmium content At low concentration, enhanced seed germination Dry shoot weight increment Increase in micronutrient content	[3]

5. Nanoparticles as - A bane to Plants

Despite having wide range of applications, Nanoparticles caused severe detrimental effects on plant's function, quality, and yield [8]. Effects of Graphene were studied on plants that restrained the chlorophyll biogenesis and diminished content of chlorophyll in plants, prompting disabled photosynthetic activity and stunted growth [17]. Few reports revealed inhibition in seed germination caused by nano ZnO particles, decrease in photosynthetic activity of plants in *Elodea densa*, inhibition in growth of *Allium cepa* due to decrease in mitotic activity caused due to high concentration of NPs[8].

When used in bulk, TiO₂ NPs inhibits germination of the seeds [25]. TiO₂ NPs caused deleterious effects in *Nicotina tobacum* and *Allium cepa*. Nano TiO₂ caused DNA damage in leaf of *Nicotina tobacum* and peroxidation of lipids in root of *Allium cepa* [20].

After treating tomato with Ag NPs, decrease in biomass and root length of the crop was reported [25].

Comment [r33]:

Table 3 Negative impacts of Nanoparticles on Plants

Nanoparticles	Plant species	Negative Effects	Reference(s)
ZnO	<i>Triticum aestivum</i> <i>Cucumis sativa</i>	Reduced photosynthetic activity due to inhibition of Chlorophyll synthesis. Root growth inhibition.	[23]
FeO	<i>Arabidopsis thaliana</i>	Plant development is inhibited.	[23]

AgNPs	<i>Triticum aestivum</i> <i>Zea mays</i> <i>Baccopa monnieri</i>	Shoot weight is decreased, reduced growth. High concentration leads to decreased shoot & root length. Ruptured Epidermis and root cap.	[23]
Fullerenes	Soybean and Corn	Biomass is reduced.	[16]
Single walled carbon nanotubes(SWCNTs)	<i>Oryza sativa</i>	Decrease in yield and delayed flowering	[16]
Multi walled carbon	<i>Lactusa sativa</i>	Reduction in root length	[16] [13]

nanotubes(MWCNTs)	<i>Oryza sativa</i> <i>Amaranthus dubius</i>	Cell membrane detachment from cell wall, cell death shrinkage due to chromatin condensation inside cytoplasm. Inhibition in growth and cell death	
TiO2 NPs	<i>Glycine max</i> <i>Allium cepa</i> <i>Nicotiana tabacum</i>	Inhibition of plant growth DNA damage	[20]

6. Conclusion

Nevertheless, this branch of science has quite a lot of applications in every possible field ranging from electronics to life science. With the very positive effects come the negative ones also [1]. Examination of various nanoparticles and their detrimental effects on plants have been under the study since a decade, which appears to be too short a period for researchers to have the option to inspect all parts of the issue, as needed by the standards of biosafety[22]. As nanotechnology is a creative and logical development region with a remarkable creation, more data is required which is bothered by the effects of these nanomaterials in the climate and, especially, on the wellbeing of humankind [7]. Regardless, of all the pros and cons, few significant conclusions can be drawn. The undoubted variables that decide the entrance of nanoparticles inside the cell are their size, shape, chemical nature, surface charge, and the dosage of the nanoparticles. Suspension cell culture have turned out satisfactory in studying the effects of nanomaterials on plants[22]. Nonetheless, the information about the destiny, change, and their accumulation in the climate and life forms is required preceding their utilization in horticulture to keep away from negative ecological effects [24]. Agronomy is the spine of our economy, however presently agrarian area is dealing with numerous issues like urbanization, ecological stress, sustainable use of resources and finally climate change. Nanotechnology in farming is a clear cut resolution for a high food supply

Comment [r34]: About which branch talking about?

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Comment [r36]: Any link with nanotechnology?

demand due to ever increasing human population. Agriculture waste can be utilized to synthesize NPs thereby, acts as promising substitute for waste management [5]. NPs can be orchestrated through green innovation by utilizing extracts from plants, algae, and agrarian waste. It would be a financially savvy, ecofriendly and simple to deal with in comparison to chemical and physical techniques [23].

Comment [r37]: Grammar mistakes

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