Potential Role of Nanotechnology for Agricultural Applications: A Review

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Introduction

The matter at the nanoscale (1-100 nm) dimensions is the focus of nanotechnology. As these materials are scaled down to the nanoscale, they exhibit some properties that are distinct from those they do at the macroscale, opening up new possibilities for applications. Nanotechnology has revolutionised a variety of industries by enabling the development of goods and processes that would be nearly impossible to build using more traditional techniques. The list below discusses a few of them. Devices for Nano-Delivery As a result of the extreme environmental risks associated with pesticides like DDT. The industry has moved its attention to the use of integrated pest management systems, which combine the more intelligent and targeted use of pesticides with monitoring of plant health, as a result of increased public and regulatory awareness of the use of chemicals in agriculture.. Nanotechnology has revolutionised a variety of industries by enabling the development of goods and processes that would be nearly impossible to build using more traditional techniques. The list below discusses a few of them. The principles of nanotechnology, its applications in agriculture, its extent, its status, and its overall significance are all covered in this review paper, which is titled Nanotechnology and its Applications in Agriculture.

Scope of Nanotechnology

Commercial pesticide formulations now contain Nano emulsions because to business initiatives. A quick-release microencapsulated product manufactured by Syngenta, a renowned agrochemical company, is sold under the trade name Karate® ZEON. Pesticides can be contained in nano emulsions and released in a regulated manner, ensuring that they reach their intended target and minimising environmental damage. U-M Nanotechnology Institute is the source of the image. Food and Nanotechnology Nanotechnologists are hopeful that by affecting improvements in food production, processing, packaging, transportation, and consumption, nanotechnology can completely overhaul the food sector. The use of nanotechnology in these procedures guarantees the security of food items, fosters the development of a wholesome food culture, and improves the nutritional value of foods. Nanotechnology can be used to create smart food packaging systems, extending the shelf life.

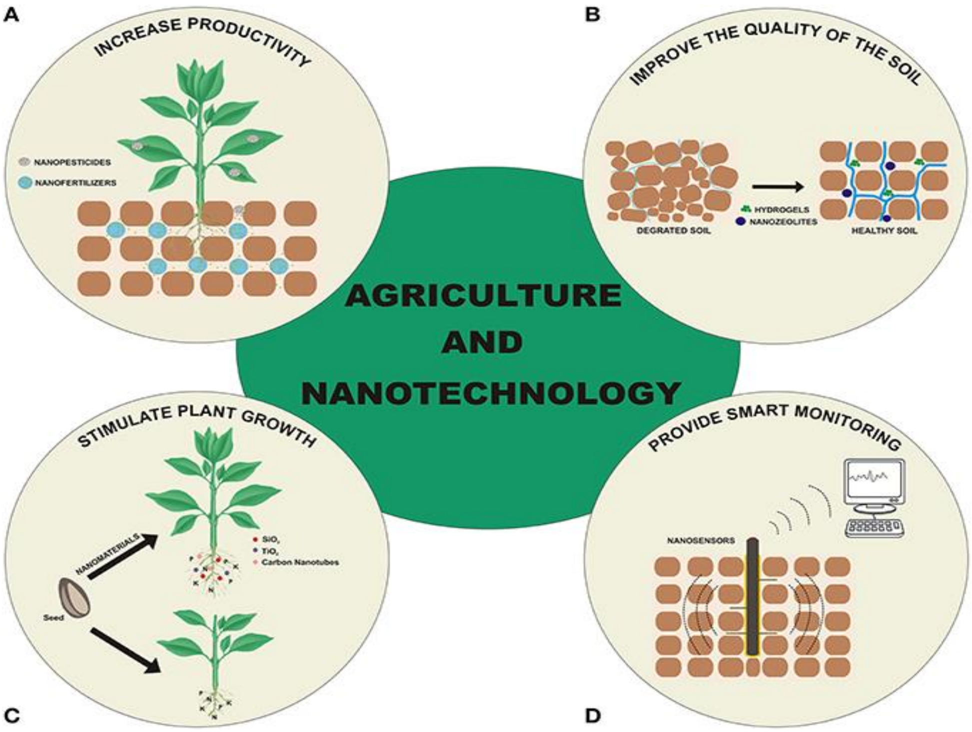
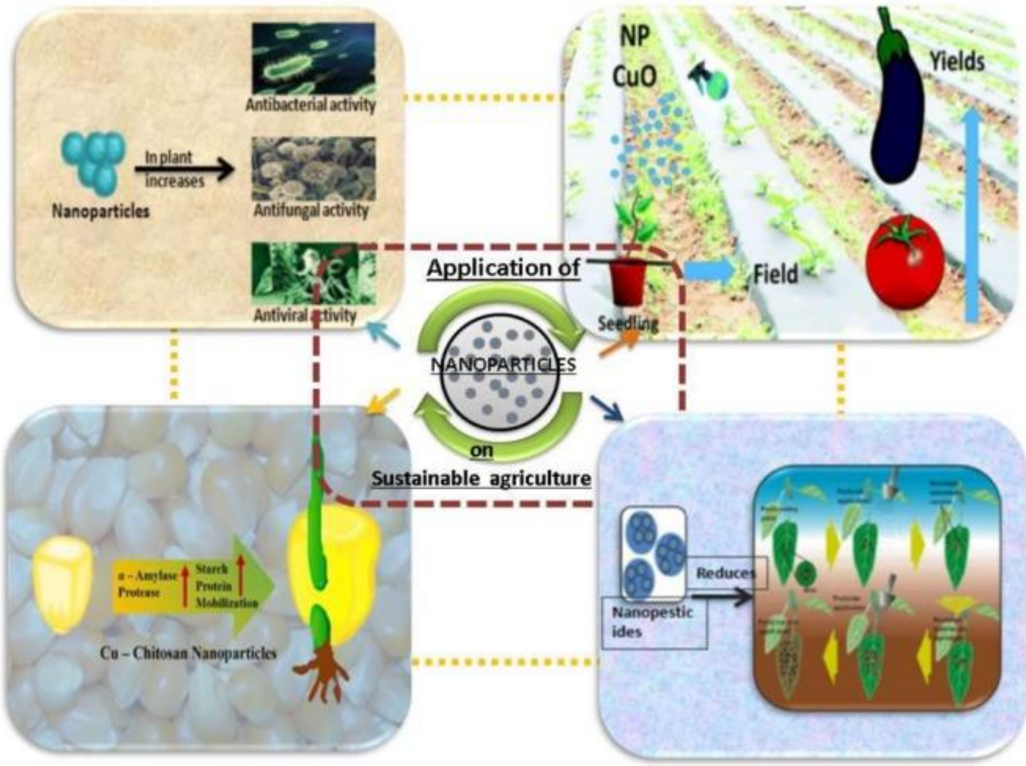


Figure 3 shows a schematic depiction of nanotechnology uses in agriculture. in Duhan et al (2017)



packaging film. Many silicate nanoparticles are used to create this packaging film. Nanoparticles are added to food products to boost nutrient absorption, and nanocapsules are used in food products to provide nutrients. A growing number of businesses are looking at food additives that can be quickly absorbed by the body and lengthen the shelf life of products. Nano cochleaes, coiled nanoparticles created by Biodelivery Sciences International, are able to carry nutrients and omega fatty acids to cells without altering the flavour or appearance of food. Micro- and nano-fertilizers for Optimal Crop Nutrition The efficiency of conventional fertilisers in using N, P, and K nutrients, which has been consistent over the past few decades, hardly exceeds 30–35%, 15-20%, and 50-60%. Nano-fertilizers aim to increase the efficiency of nutrient usage by taking advantage of special characteristics of nanoparticles. By adding nutrients individually or in combination to adsorbents with a nano-dimension, the nano fertilisers are created. When making nanomaterials using both physical (top-down) and chemical (bottom-up) techniques, the targeted nutrients are loaded both as they are for cationic nutrients (NH4 +, K+, Ca2+, Mg2+) and after surface modification for anionic nutrients (NO3, PO4 2, SO4 2). In order to maximise the efficiency with which nutrients are utilised while minimising any undesirable side effects, nano-fertilizers are known to give nutrients gradually and steadily for more than 30 days. As the nano-fertilizers are designed to release gradually over a long period of time, there is significantly less loss of nutrients in terms of environmental safety.

Identification of Gaps and Obstacles

Although tremendous progress has been made in finding potential uses for nanotechnology in agriculture, a number of difficulties must still be handled in the near future before this technology can significantly enhance the field. In order to maximise their effectiveness while adhering to the principles of green chemistry and environmental sustainability, some of the main aspects that need more attention include the design of processes easily up scalable at an industrial level. To demonstrate real-world benefits, comparing the effects of nano formulations and nanosystems with those of currently available commercial products for acquiring knowledge and developing methods for risk and life-cycle assessment of nanomaterials, nanopesticides, and nanofertilizers; and evaluating the impacts (such as phytotoxic effects) on non-target organisms, such as other plants, soil microbiota, and bees; (Amenta et al., 2015). The development in the use of nanopesticides (such atrazine) in this context serves as a good case study for identifying the key variables required to anticipate the behaviour of environmental nanomaterials (Grillo et al., 2012). Care was taken in the research of the atrazine-nanopesticide system to comprehend the processes of interaction with both target, mustard, and non-target species, maize, (Oliveira et al., 2015a), and risk-assessment assessments were also taken into consideration (Kah et al., 2014). Further case studies, however, are required to address the issue of workers' and customers' safety in relation to food made using nanomaterials and nanoparticles.

Current and Future Prospectus

Recently, a wide range of potential uses for nanotechnology in agriculture have been considered, sparking extensive research at the academic and industrial levels (Chen and Yada, 2011; Dasgupta et al., 2015; Parisi et al., 2015). In actuality, the special characteristics of nanoscale materials make them great candidates for the design and development of novel instruments supporting sustainable agriculture. The principal agricultural uses for some of these nanotools are described in the schematics and subsequent paragraphs.

These includes different major contribution which are given below

(A) Increase the productivity using nanopesticides and nanofertilizers;

(B) Improve the quality of the soil using nanozeolites and hydrogels;

(C) Stimulate plant growth using nanomaterials (SiO_2, TiO_2, and carbon nanotubes);

(D) Provide smart monitoring using nanosensors by wireless communication devices.

Potential applications of Nanotechnology for Sustainable Intensification in Agriculture Systems

Intensification refers to a production strategy that seeks to enhance yield while maintaining the same agricultural area without having a negative impact on the environment (The Royal Society, 2009). This paradigm offers a framework for assessing the optimum agricultural production strategy choices while taking into account the influence of the current biophysical, social, cultural, and economic conditions (Garnett and Godfray, 2012). In this context, innovative nanomaterials based on inorganic, polymeric, and lipid nanoparticles have been produced to boost productivity. These materials were created by utilising a variety of processes, such as emulsification, ionic gelation, polymerization, and oxydoreduction. For instance, they can be used to create intelligent nanosystems that immobilise nutrients and release them into the soil. These methods offer the advantage of minimising leaching while enhancing plant nutrient uptake and lowering eutrophication by limiting nitrogen transfer to groundwater (Liu and Lal, 2015). Furthermore, it is important to note that nanomaterials could be used to enhance the structure and performance of pesticides by making them more soluble, strengthening their resistance to hydrolysis and photodecomposition, and/or delivering a more targeted and controlled release towards the intended target organisms (Mishra and Singh, 2015; Grillo et al., 2016; Nuruzzaman et al., 2016).

Nanotechnology to improve quality of soil and fertilizer distribution

Crop management with nanotechnology is a crucial technology for increasing agricultural output. In agricultural research, nanomaterials and nanostructures including carbon nanotubes, nanofibers, and quantum dots are currently used as biosensors to assess soil quality and fertiliser distribution. Nanoparticles are used to reduce the quantity of chemical spread, limit nutrient loss during fertilisation, and boost quality and production by providing the right nutrients (Sangeetha et al., 2021). Vermiculite, nanoclay, and zeolite could be developed and used to increase crop productivity and fertiliser effectiveness in coarse-textured soil (Sivarethinamohan and Sujatha, 2021). In ecological agricultural systems, amending sandy loam soils with inorganic amendments decreases NH4-N passage and increases N fertiliser production (Mazloomi and Jalali, 2019). On the basis of chemical composition and nanoparticle form, nanoclay is systematised into a variety of modules, including montmorillonite, bentonite, kaolinite, hectorite, and halloysite (Sivarethinamohan and Sujatha, 2021). Use of fertiliser substantially influences how productive farming methods are. Research reveal that crop productivity is linearly controlled by exhaustive application of fertilisers to boost soil fertility (Rehmanullah et al., 2020).

Nanomaterials as Agents to Stimulate Plant Growth

Through improving nutrient uptake and use of elements, carbon nanotubes and nanoparticles of Au, SiO2, ZnO, and TiO2 can help improve plant growth (Figure 1C) (Khot et al., 2012). Nevertheless, in addition to the vulnerability of the plant species, the real effect of nanomaterials on plants depends on their composition, concentration, size, surface charge, and physical chemical properties (Ma et al., 2010; Lambreva et al., 2015). The creation of novel procedures and the application of various analytical methods (such as microscopy, magnetic resonance imaging, and fluorescence spectroscopy) could significantly advance our understanding of how plants interact with nanomaterials.

Nanotechnology in plant diseases control

Over the world, plant diseases and pests cause the loss of 20–40% of crops each year (Flood, 2010). Pest management techniques used in contemporary farming mainly rely on the use of insecticides, fungicides, and herbicides. It is essential to create insecticides that are effective, affordable, and less damaging to the environment. Pesticides may benefit from new ideas like nanotechnology by being less toxic, having a longer shelf life, and becoming more water-soluble, all of which may have favourable effects on the environment (Mali et al., 2020; Worrall et al., 2018). The importance of agricultural nanotechnology, particularly for preventing illness and ensuring safety, has been previously covered (Gogos et al., 2012; Rehmanullah et al., 2020; Sastry et al., 2010). The slow and continuous provision of nutrients and agricultural chemicals in a controlled amount to the plants is made possible by conventional herbicides and pesticides with nanotechnology-based formulations (Duhan et al., 2017). Moreover, nanoparticles might be crucial in the management of host infections and insect pests (Khota et al., 2012). For the manufacture of nano-insecticides, several polysaccharides including chitosan, alginates, starch, and polyesters have been taken into consideration (Mali et al., 2020). In general, there are two ways that nanoparticles can be used to protect plants: either they protect crops themselves or they act as carriers for pesticides already on the market and can be sprayed on the plants (Worrall et al., 2018). Unfortunately, there is little research on using nanoparticles to protect plants and provide food (Prasad et al., 2017a). Because of their small size, nanoscale fertilisers might enable more efficient nutrient delivery because they can reach plant surfaces and transport pathways (Mastronardi et al., 2015). Tomatoes, peppers, or flowers were grown with nano-fertilizer made from banana peels (Sivarethinamohan and Sujatha, 2021). Several crops have benefited from the usage of nano fertilisers. For example, ZnO nanoparticles were employed for chickpea growth, silicon dioxide and iron slag powder for maize, colloidal silica and NPK for tomatoes, TiO_2 for spinach, and gold and sulphur fertilisers for grape growth (Sivarethinamohan and Sujatha, 2021). Several crops have benefited from the usage of nano fertilisers. For example, ZnO nanoparticles were employed for chickpea growth, silicon dioxide and iron slag powder for maize, colloidal silica and NPK for tomatoes, TiO_2 for spinach, and gold and sulphur fertilisers for grape growth (Sivarethinamohan and Sujatha, 2021). Using fertilisers with nanoscale transporters may be done in such a way that the plant's roots are anchored to the soil's organic matter and other soil components, reducing chemical loss and environmental problems (Dasgupta et al., 2015). Nanoscale fertilisers can lessen soil toxicity, which reduces the likelihood of unfavourable effects from large dosages (Davari et al., 2017). These nano fertilisers slow down the release of nutrients and prolong the impact of fertiliser (Naderi and Danesh-Shahraki, 2013). The maize crop's growth has been significantly impacted by TiO_2 nanoparticles; in addition, SiO_2 with TiO_2 nanoparticles enhanced the action of nitrate and boosted plant absorption capability, with an effective result (Abobatta, 2018; Sekhon, 2014).

Nanotechnology and gene sequencing

The use of nanotechnology also facilitated gene sequencing, which increased the identification and application of plant trait means and altered the plants' capacity to adapt to environmental stresses and diseases. Quantum dots and nanoparticles have demonstrated to be an exceptionally accurate biological marker (Sharon et al., 2010). In the era of nanotechnology and nanoscopy, optical DNA mapping has also been observed (Levy-Sakin and Ebenstein, 2013). Access to genetic and epigenetic information on specific DNA molecules is made possible by optical DNA mapping. The limits of short-read data could be overcome by nanopore sequencing, which could enable sequencing of individual DNA molecules spanning tens of kbp (perhaps up to 100 kbp) (Levy-Sakin and Ebenstein, 2013). Nanotechnologies have generally been used in a range of applications, including as genome sequencing, targeted resequencing and the identification of transcription factor binding sites, noncoding RNA expression profiling, and molecular diagnostics (Elingarami et al., 2013)

Postharvest loss reduction

More than 40% of food (cereals, roots and tubers, pulses and oil crops, vegetables and fruit, fish meat, and dairy) is lost during the trade and consumer stages in wealthy countries, whereas more than 40% of food is lost during the post-harvest stage and processing stage in impoverished countries (FAO, 2019; Gustavsson et al., 2011). Unpreserved, freshly harvested, high-moisture yields may fast degrade as a result of microbial attack. Nanotechnology and other more recent, cutting-edge technologies can aid in reducing post-harvest losses. By creating functional packing elements with the least amount of bioactive ingredients, better gas and mechanical properties, and less impact on the sensing qualities of vegetables and fruits, nanotechnology application can reduce post-harvest losses (Flores-López et al., 2016) In general, edible coatings are applied on food as a liquid by dipping the item in a material that serves as a solution and is produced by the structural medium (carbohydrate, lipid, protein, or mixture). They prevent untreated foods from getting bad by preventing dehydration, reversing respiration, improving textural qualities, assisting in the preservation of volatile fragrance molecules, and limiting microbial development. A barrier to gas and moisture exchange is created by edible nanocoatings applied to various foods, which also supply flavours, colours, enzymes, antioxidants, and browning-resistant chemicals that may lengthen the shelf life of synthetic foods (Zambrano-Zaragoza et al., 2018) With this method, coatings with a thickness of up to five nanometers can be created (Sekhon, 2010). For horticultural products, edible coatings and thin films are frequently used. Cost, availability, functional qualities, mechanical properties (elasticity, tension), photosensitive properties (brilliance and opacity), the fencing effect against gas flow, structural barriers to water migration, the presence of microbes, and sensory suitability all play a role in how something is used (Zambrano-Zaragoza et al., 2018; Falguera et al., 2011). To regulate the post-harvest excellence of freshly harvested products, various edible coatings with nanoscale dimensions are applied to food. Due to their antibacterial qualities, which are important for food processing, silver nanoparticles are receiving more and more attention lately. When applied to asparagus, PVP-based silver nanoparticles significantly slowed down microbial development, weight loss, and skin colour changes (An et al., 2008). In a different study, edible gelatin-derived coverings with cellulose nanocrystals significantly extended strawberries' shelf lives (Fakhouri et al., 2014). Compared to other treatments, chitosan-assisted nano-silica coating successfully produced a remarkable semi-permeable layer, which significantly increased the physicochemical and physiological value of longan fruit at room temperature (Shi et al., 2013). Also, researchers looked into alginate or lysozyme-based nanolaminate coatings (Medeiros et al., 2014) and chitosan film-based nano-SiO_2 (Yu et al., 2012) to preserve the value of fresh diets throughout lengthy storage. Also, the nano-ZnO coating minimised microbial deterioration and preserved the post-harvest value of some fruits throughout storage (Sogvar et al., 2016). Using nanosensors, nanotechnology can also be used to monitor the quality of grains (Bouwmeester et al., 2009). The sensors can react to changes in the storage environment, such as temperature, oxygen exposure, and relative humidity, as well as to degradation products or microbial infection. They are additionally used to react to the presence of insects or fungi in grain that has been stored (Axelos and Van

De Voorde, 2017). Polymer nanoparticles have been used to create nanosensors for grain quality monitoring that react to volatile substances and other analytes in a setting of preserved foods and can therefore identify the type and cause of decomposition occurring (Neethirajan and Jayas, 2011).

Food processing

The largest food corporations worldwide are looking for different ways to alter the quality, value, safety, and nutritional aspects of food. For the food industry to increase productivity, market price, and quality, more modern technology are needed. Many applications of nanotechnology are being explored for the manufacturing and processing of food, including nano-based food additives, nanoencapsulation, nanosensors, smart distribution systems based on nanoparticles, nano-packing, as well as medications and health care (Rashidi and Khosravi-Darani, 2011). Moreover, biopolymer matrices, emulsions, simple solutions, and associated colloids provide efficient delivery mechanisms for its uses in the construction of encapsulations. Particularly for flavour encapsulation or odour enhancement, modifying food texture or improving food value, and novel gelation or viscosity raising agents, industrial food processing with nanotechnology is gaining traction (Duncan, 2011). Food nanotechnology focuses on the creation of nanometer-scale structures with unique properties that can be used for a variety of applications, including delivery systems, surfaces for food interaction with unique superficial properties, tools for food characterization, microfluidic instruments, sensor technology, and nanocomposite coatings, among many other things (Sadeghi et al., 2017).

The challenges of nanotechnology in food and agriculture system

As was previously discussed, nanotechnology has enormous benefits for food and agriculture. Nanomaterials, however, are linked to numerous safety concerns because of their possible risk values reaching the cells due to their tiny sizes and probable presence in the system (De Azeredo, 2009; Rajput et al., 2020; Sharma et al., 2017). ,, when you have the one that is for the one that is for the one that is for the one that is for the one that is the one that is the one that is the one that is the one that is the one that is the one that is the one that is the one that is (Baruah and Dutta, 2009). Although the characteristics and safety of the materials in bulk are typically obvious, nanoscale complements regularly show different characteristics as compared to those at the macroscale (De Azeredo, 2009). The risk posed by nanotechnology is mostly caused by the small size of nanoparticles with larger surface surfaces that are highly dispersible, penetrating cells to reach relatively remote locations of the body, and having the ability to cause toxicity (Dasgupta et al., 2015). Due to their size resemblance to DNA, nanomaterials have the potential to interact with biological samples (Baruah and Dutta, 2009).

Environmental factors may cause nanocomposites to degrade, releasing embedded nanoparticles from the polymeric texture into the environment (Moustafa et al., 2019). Certain food packaging materials, such as low-density polyethylene, lose strength after being exposed to environmental factors like UV light or ozone in humid environments (Han et al., 2018). Han et al. (2018) claim that low density polyethylene samples experienced oxidation under UV radiation or ozone, resulting in a significant change in structural, physical, and thermal properties. Pesticides and nano fertilisers used in agriculture are dispersed into the water, soil, or environment, posing a serious health risk to farmers (Roohinejad and Greiner, 2017). It is anticipated that the buildup of nanoparticles in soil may hinder plant growth and accumulate in edible tissues (Rajput et al., 2020). As the nanoparticles are released into the agro-environment, several changes start to happen right away. One of the biggest worries is how nanoparticles will interact with human tissue. Nanoparticles have the ability to produce toxicity and can injure cells through oxidative processes and provocative reactions (Han et al., 2018; Lewicka et al., 2013; Narei et al., 2017). The main way that nanotoxicity intervenes is by the massive creation of free radicals, which causes oxidative stress and renders cells incapable of supporting normal biological redox-regulated processes (Pathakoti et al., 2017). Human alveolar basal epithelial cell cancer may result from the breakdown of nano-clay found in low-density polyethylene clumps (Kumar et al., 2018). Many investigations have been done on Ag's antibacterial mechanism. Yet, because it is a heavy metal, it can cause toxicity when present in high concentrations by denaturing the proteins and enzymes in the body; its migratory threat may be calculated (Li et al., 2017). Research on Ag, TiO_2, and carbon nanotubes showed that these substances might enter the bloodstream, and because they are insoluble, they may accumulate in the organs (Ramachandraiah et al., 2015; Sharma et al., 2017). When TiO_2 is consumed as a food additive or in another form, it can enter the body and produce oxidative stress, which can lead to inflammation and chromosome instability (Baranowska-Wójcik et al., 2020). By cutaneous contact, ingestion, or inhalation, nanoparticles can enter the body. As their release from contaminated food or the environment raises concerns, there is a great deal of nanomaterial use in food packaging (Han et al., 2018). Unfortunately, there is little information on the migration of nanoparticles from packaging materials into food and their ultimate toxicological effects (De Azeredo, 2009; Pathakoti et al., 2017). For the protection of the environment, human health, and animal welfare, the selection of green nanofillers in nanocomposites research is of utmost importance. Moreover, factors like temperature, pH value, the concentration, molecular weight, particle size, diffusivity, stability of a specific chemical in a polymer blend, contact time, mechanical pressure, and food composition are crucial (Sharma et al., 2017). It's crucial to determine precisely how many nanoparticles have been discharged into the environment, how many have accumulated in plants, and how they affect human health (Rajput et al., 2020). Effective rules, regulations, and policies are generally needed for the safer application of nanoparticles in the food business. For instance, the European Union and United States' Food and Drug Administration (FDA) regulate nanotechnology-based food components and food packaging, respectively (Nile et al., 2020). Yet, the majority of nations that produce nanomaterials lack adequate legislation relevant to nanotechnology (Nile et al., 2020). Hence, comprehensive government regulations and laws as well as strict toxicological screening procedures are necessary for the legal applications of nanotechnology (Nile et al., 2020).

Conclusions

Nanotechnology is a relatively young invention that is rapidly increasing in several domains that are connected to human activities and advantages on a global scale. Many research findings have confirmed this remarkable phenomenon, which shows that nanoparticles and nanostructures improve a variety of attributes due to their small size, increased surface area, and highly catalytic nature. Food security cannot be achieved without nanotechnology, particularly in the agricultural sector. It can boost crop productivity via effective microbial, pest, and weed control with great economic value, security, and safety. Moreover, it is essential for food processing, modifying food, stability, sensing, extending shelf life, reducing food losses, and providing safe food. Nanotechnology also reduces post-harvest losses by improving packaging materials, stability, and safety. Nanoparticles including Ag, Au, Zn, TiO_2, ZnO, SiO_2, and MgO, which are frequently employed in the food processing industry, may also pose health problems because they may easily penetrate cells and cause unpleasant reactions in a variety of human organs, animal organs, and plant parts. Future study could reduce these risks from nanoparticles or composites by employing greener synthesis techniques and looking for quick, inexpensive methods for degrading and removing existing nanomaterial from potential attack areas.

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