Journal of Molecular Structure 1239 (2021) 130517

Contents lists available at ScienceDirect

Journal of Molecular Structure

journal homepage: www.elsevier.com/locate/molstr

A comprehensive review on regulatory invention of nano pesticides in Agricultural nano formulation and food system

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ARTICLE INFO

Article history:
Received 31 January 2021
Revised 15 March 2021
Accepted 15 April 2021
Available online 22 April 2021

Keywords:
Agriculture
Nanoagrochemicals
Nanoparticles
Nanofertilizer
Nanopesticides
Nanotechnology

ABSTRACT

In recent years, Nanotechnology gained a lot of attention due to its wide applications in various fields. As the surface area increases, the applicative efficiency of the nanostructure also increases. Now a days, the potential application of nanotechnology in the field of agriculture leads to an intensive researches. The combination of nanotechnology and agriculture acts a novel tool and result in the production of nano-fertilizers, nano-herbicides, nano-fungicides, nano-pesticides, and nano-insecticides, commonly termed as Nanoagrochemicals. These nano-agrochemicals have attained great interest in the research field due to the economically viable and eco-friendly nature. Beside, the enormous benefits of agrochemicals in agriculture, it helps to replace the synthetic fertilizers and pesticides which lead to the increase in the output. However, there is a vast research is going in this field, some difficulties are facing to reach among farmer, greater production cost, lack of awareness, impact on the environment, humans etc. In future we may expect nano-agrochemicals to upgrade the efficiency of inputs and providing a permanent solutions to problems faced for improving productivity and biosafety. In this chapter the authors will discuss about the economic importance and future trends of the nano-agrochemicals. enhancing the efficiency of agricultural inputs and providing solutions to agricultural problems for improving food productivity and security. This review covers the current influences of nanotechnology in agriculture, nanoagrochemicals, characterization of nanoparticles, and sustainable development.

1. Introduction

Currently, the world production and distribution are facing a huge stress due to the increase in population, climate change, environmental contamination, and higher demands of water and energy [1]. According to the current survey, world's population is increasing daily and at the same time the requirements also increases by 50%. Agriculture is considered as one of the most important and stable sector because it contributes food security to national economy [2]. But in this recent year, the agriculture field is affected by several issues such as decrease in farm profit, depletion of natural resources, diseases, global warming and climate change. At the same time, it's very difficult to meet the growing food demand as the population increases and also it is one of the unpredictable fields which depend on lot of variables such as weather, season, water, soil condition, etc. [3,4] Therefore the sensing, recording, manipulating and storing the reliable and precise data of all the biotic and a-biotic components is very much crucial to meet out the challenges of quality and quantity of food demand. Recent research has shown the promising potential of nanotechnology to improve the agriculture sector by increasing the efficiency of agricultural inputs and offering solutions to agricultural and environment problems for improving food productivity and security [5-7].

All though there were a lot of research data available in this field, this survey view centers around the significance of nanotechnology in agriculture, as nanoagrochemicals. The main aim is to maximize output (crop yields), minimize the input (fertilizers, pesticides, and herbicides) and monitoring environmental factors (sensors) and applying targeted action [2,8]. Currently there is a huge interest in this field due to their potential to improve seed germination, growth and plant protection through the controlled release of agrochemicals, with the reduction in the amounts of chemical products applied and the minimization of nutrient losses in fertilization [9]. Influence of nanotechnology helps to reduce the major challenges faced by the agriculture (Fig. 1).

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https://doi.org/10.1016/j.molstruc.2021.130517
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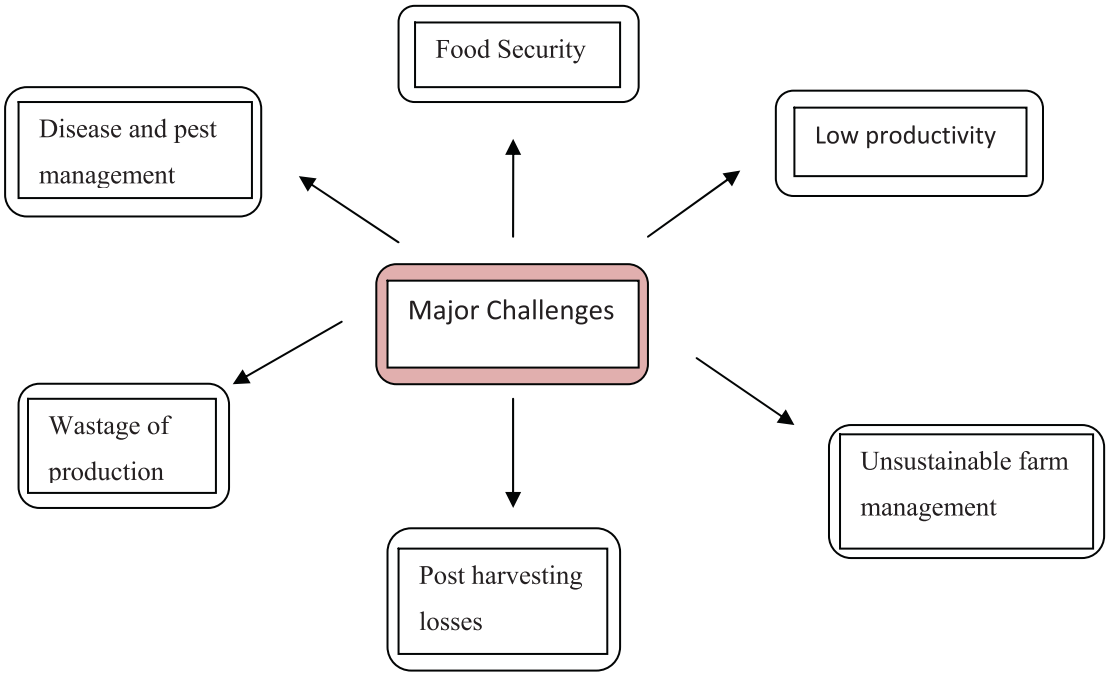

Fig. 1. Major challenges faced by the agriculture field.

The majority of the principle assets of agrochemicals are viably exploring nanotechnology for its valuable uses in agribusiness [10]. The vast majority of the organizations, have just given licenses decreasing a high scope of methods for the combination and working of nanopesticide arrangements [11]. The current European Food Safety Authority of "Stock of nanotechnology applications in the rural, feed and food area", suggested that, modest quantity of typified nano-pesticides is at present open available [12].In agriculture, nanotechnology is applied for all practices such as production, processing, storage, and distribution (Fig. 2).

For the development of agriculture, several forms of nanotechnology is applied in different area in financial system is unfold to expand techniques and procedures beneficial for human and health of the environment. When the nanoparticles are introduced in to the agriculture which has the capacity to carry the agriculture activities and which leads to the unintended health outcomes [13]. In the above mentioned case, the exposure of environment and human to residues of nanomaterial found in soil and plant species will induce bioaccumulation in food chain and its corresponding environment which can create new benefits and harmful effects in the health of environment and humans. In this approach a new concept is developed called green nano technology for the enhancement of agriculture this new concept that will provide protection in the environment safety risks and health provided by nanomaterials [14]. Also the problems caused by the use of exposure of nanomaterials can be identified by the help of perspective of tailored life cycle. This should have many functions in the specific area which including the removal and reuse of the products food serving which influenced in agro-system conditions that causes risk characterization and nanoparticles harmful properties [15].

During the time of working nanoparticles that occurs in the agriculture that badly and harmfully affect the workers that will cause many health problems when they contact with these still not –completely explored xenobiotic [16-18]. According to this content, the high usage of nanotechnology in the environment increases occupational risks, this type of nanomaterials that would control the problems for regulative needs. The potential different types of nanoparticles evolved, that do not completely clarified toxicologically once dispersed into physiological and chemical altering environments, also their specific advantages in the agriculture sector did not needed a “nano-focused” attention, specifically agriculture nanotechnology which used as strategies for management process and risk assessment in occupation. According to this topic, the evolving risks in occupation in this area have been explained and the majority of the functions including science in nano scale and engineering are identified and agriculture nanotechnology also subjected to conservation of productivity of the plant species [19,20].

Toxicological research priorities which based on the topics according to nanomaterials harmful effect presentation assessment, portion reaction connections and natural destiny have been found and these might be exceptionally essential to build future information concerning conceivable human and, all the more explicitly, word related wellbeing ramifications of nano-developments and to characterize reasonable methodologies for nano-hazard appraisal, considering likewise the expected transformation of existing word related danger evaluation models and strategies for use with farming nanotechnology [21-23]. This research means to feature some pivotal issues that would be contemplated when performing to characterize satisfactory word related danger the board techniques, wellbeing practices and arrangements. Generally speaking, these significant themes should be routed to expand a moral and mindful administrative agreement on nanotechnology in agribusiness [24-25].

1.1. A new frontier in agricultural development: nano-farming

Specific functions with elevated strength were identified by the help of present technology called nanoparticle engineering. The term Nanotechnology was preliminarily quoted in 1974. The name invented by Norio. In spite of the fact that, nanotechnology that should be included in different areas, the nanotechnology that deals with the production of nanoparticles, which helps to enhance the productivity in agriculture, which developed in the recent years and the study on this topic under development [26,27]. In recent years studies prove that the nanoparticles have different

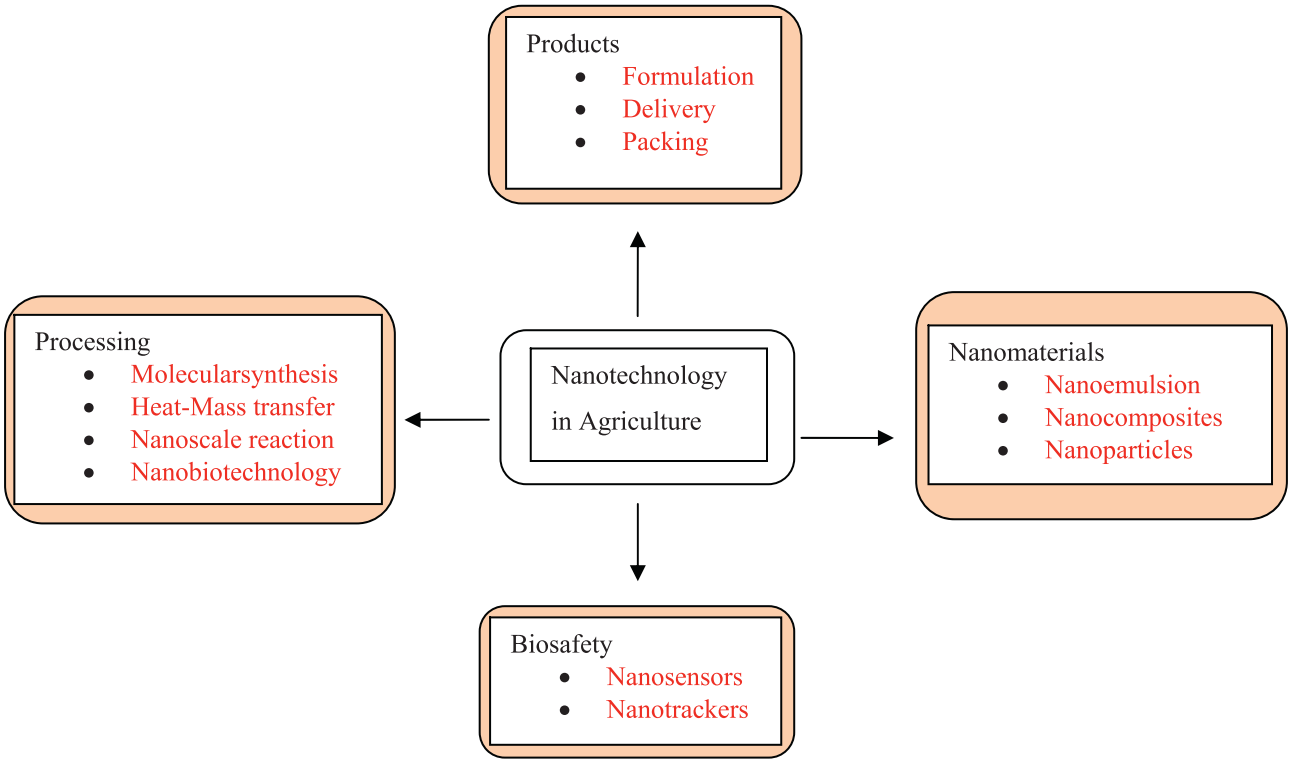

Fig. 2. Applicative phase of Nanotechnology in Agriculture.

size and shape they also have verity of clinical features. All the benefits of study on the nanoparticles subject that created for agriculture [28]. In our environment plants faces many problems due to biotic and abiotic stress such as reduced crop yield unavailability of nutrients and environmental pollution, the specific applications are obtained by the introduction of nanotechnology. In the current days, different methods for farming in agriculture are proposed, which involves the building up of wireless networking and sensors for observing which involves the miniaturization of the sensors to assess and control the agricultural processes.

For the crop conservation, particularly the on-site crop conservation, a large rang of manufacturing components used before and after plantation, starting from horticultural plant species to field plant species are used [29,30]. For the development of GM crops, technology for the nanoparticle synthesis has a vital role, the development of the area like tissue engineering and the development of nanoparticles which involved in the targeted transfer of Clustered Regularly Interspaced Short Palindromic Repeats mRNA and sgRNA which results in the development of genetically modified crops [31,32]. Further, nanotechnology offers brilliant answering for increasingly environmental demanding situations. For instance, the nanosensors has evolved for the remark of environmental pressure and improving the fighting potentials of crops against illness [33,34]. Therefore, such nonstop upgrades in nanotechnology with unique desire at recognition of issue or an improvement of cooperative procedure for agricultural field development has an important capacity to offer large satisfaction in society.

1.2. Nanopesticide and nanofertilizer

The nanopesticides and nanofertilizers are the two words widely used they have verity of meaning based on the topics. The Federal agency, US, the development of nanoagrochemicals can act as a promising agent for plant growth and pest control. Generally, fertilizers are very important for plant growth and nanomaterials can be used as fertilizers which help in crop improvement with low ecotoxicity [35]. In most of the countries, Fusarium wilt is a considered as a disease of tomato and lettuce due to its huge production loss, prolonged survival of fungus in soil and generation of resistant races. This disease can be reduced to some extent with the help of chemicals. But the use of chemicals is expensive and not always effective. The use of nanomaterials has been considered as an alternative solution to control plant pathogens. The synthesis of nanomaterials of magnesium oxide (MgO), copper oxide (CuO), zinc oxide (ZnO), magnesium hydroxide (MgOH) and magnesium oxide (MgO) has been carried out successfully by using aqueous extracts of Punica granatum peels, Olea europaea leaves, green peach aphid (GPA) and Chamaemelum nobile flowers [36,37].

1.3. Nanomaterials in plant protection

One of the commonly used techniques by the planters for the conservation of plant and to increase the yield of plant products is nanotechnology. The real impact of nanomaterials on plant depends on their size, composition, surface charge, concentration and physical and chemical changes. The different analytical techniques (such as microscopy, magnetic resonance imaging, and fluorescence spectroscopy) help to understand better about the interactions between plants and nanomaterials [38].

Nanoparticles have many advantages, conventional crop conservation activities also the functions of large-scale [39,40]. Almost most of the pesticides they do not work properly, approximately greater than 90% of the pesticides are misused and that will be lost in the environment and do not reach the target site and which do not efficiently reduce the weeds in the crops [41,42]. This now no longer more effective only enhances the value of plant species synthesis, also destroys the agriculture system. The pest control and crop productivity can be enhanced by the introduction of specific active substances in minimum specific concentrations of nanomaterials at the specific targeted site. According to this, the new technology was created for the conservation of plant which was important in the area of agriculture research. The technology were de-

Table 1
List of studies involved in nanoagrochemicals and its preparation method.

Sl.No	Vector used	Active ingredients	Process involved
1.	Chitosan	Imazapic and Imazapyr	Encapsulation [75]
2.	Silica	Piracetam, pentoxifylline, and pyridoxine	Suspension [76]
3.	Alginate	Imidacloprid	Emulsion [77]
4.	Polyacetic acid-polyethylene glycol-polyacetic acid	Imidacloprid	Encapsulation [78]
5.	Carboxymethyl chitosan	Methomyl	Encapsulation [79]
6.	Chitosan/tripolyphosphate	Paraquat	Encapsulation [80]
7.	Alginate	Azadirachtin	Encapsulation [81]
8.	Wheat gluten	Ethofumesate	entrapment/extrusion [82]
9.	Polyhydroxybutyrate-co-hydroxyvalerate	Atrazine	Encapsulation [83]
10.	Chitosan/tripolyphosphate	Chitosan, saponin, $CuSO_4$	Crosslinking [84]

veloped called nanoformulation or nanoencapsulation of pesticides which has an important role in the conservation of plants. Pesticides were subjected to encapsulation and which should contain less amount of that functions as a vibrant substance of pesticides. [43].

A developed technology called nano-encapsulation of pesticides which is active ingredient is covered with various materials of different size in nano range, would be encapsulated material are called internal phase of the core material (pesticide) and the material used for encapsulation called external phase [42]. In other ways, gradual enhancing in the pesticides or herbicides not only reduce the pesticide solubility in water and also cause bad effects on organisms, leads to the increase the inhibition of target microorganisms.

The development of nanoformulation technique that would helps to reduce the drawbacks pointed early. [29]. For instance, Petosa et al. [44] represent that the regulation of transport potential of pesticides which enhances the yield of the crop. Polymeric nanocapsules and the pyrethroidbifenthrin (nCAP4-BIF) mixed together to form a nano-formulation which shows high elution with time. Which explains that nCAP4 could be acting as a transfer vector of pesticides like pyrethroid in crop conservation. The nanomaterials used in the pesticide formulation have verity of useful characters like deep rigidity, permeability, thermal steadiness and also biodegradability [43] Table 1.

According to the features of integrated pest management (IPM), the controlled production of active ingredients decreases the whole content of pesticides essential for pest and disease control. The environment requires natural and eco- friendly pesticides and minimum use of chemical pesticides that will protect our environment from harmful effects and protect the non-target species [45,46]. In such circumstances the usage of nanoparticle which efficient in the control of pests and inhibit the harmful effects caused by the organisms [47]. The nanoparticles release the active substances (Al) which provide assurance of efficient contact with minimal agricultural impacts [29]. De Jorge provided an example for this which was nanosilica which was not soluble in water that can enter through the cuticle layer of the pest, and destroying the pest [48]. De Jorge et al. [49] discovered that, one of the main features of nanoformulation is its restricted aluminum delivery. The research proved that the nanoparticles formulation of Grapholitamolesta (Lepidoptera:Tortricidae) (Busck) pheromone do not have any impact on death rate over time, recommending a managed delivery of Aluminium and lengthy –time period attract-and-killing capacity of pesticide.

The further studies on nanoformulation of pesticides gives the information about the development of crop based systemic acquired resistance (SAR) against weeds. Li given the most probable example for this, nanosphere of silica formulation that have capacity to promote the efficiency of bactericide to transport into the plant, then enter in to the plant cell sap and inhibiting the growth of pests like aphids [50]. When the pesticicdes exposed to sunlight the hollow formulation escape this from photo degradation [51]. Another study indicates that the nano formulations change the non systemic characteristics of insecticides [52]. When tea leaves were treated with metallic nanoparticles (AuNPs) the non systemic activities of the ferbam can change and enhance the capacity to penetrate. These investigations will offer a new boundary of enhancement insecticide formulations to be able to collect plant – based systemic resistance. The research on this topic requires to get more details about the specific characters and action of insecticides and their reaction with biological macromolecules occurs in environment or in the plant crops. Meanwhile, Patil et al. [53] explained that the bioactive silver nanoparticles that would reduce the catalytic activity of trypsin, and there by destroying the pest.

The gold nanoparticles with help of proteins enhance the catalytic inhibition via covalent binding, electrostatic force of attraction or binding with –SH group of amino acids [53]. The synthesized nanoparticles have many applications in environment and it also plays a vital role in the pest control [47,54]. For example, zinc oxide NPs have been discovered as one of the versatile pesticide that has ability to block *Fusarium graminearum, Penicillium expansum, Alternaria* alternate, *F.oxysporum, Rhizopus stolonifer, Mucorplumbeus* and *Aspergillus flavus* as well as disease causing organism *Pseudomonas aeruginosa* [29,47,55]. Copper nanoparticle functions more effective towards *Phytophthora infestans* related to currently available on nano copper contents in tomato [56]. MO nanoparticles restrict the growth of fungal conidiophores and conidia which destroys the vegetative structure of fungi. The high quantity of pests in the agriculture that cause the reduction in the productivity of crops in the universe, crops were fight for essential elements, light and water [57]. Similarly, Kumar et al. [58] represents that pesticide (metsulfuron methyl)-loaded pectin (polysaccharide) NPs are extra cytotoxic to *C. album* crop species, each in labs or in-field situations and only a very low quantity of Aluminium is needed in comparison to the commercially produced herbicide [29]. Patile explained that, for the development of amino acids in the environment, the nanoparticles incorporated with insecticides like herbicides, bactericides and fungicides have crucial role [53]. Magnesium oxide (MgO) is important inorganic materials with many uses such as adsorbents, fire retardants, advanced ceramics, toxic waste remediation, and photo electronic materials. Therefore, various techniques and routes for synthesis of MgONPs have been reported such as green methods using nontoxic neem leaves extract [59], Citrus limon leaves extract, acacia gum [60]. Zinc has been considered as an essential micronutrient for metabolic activities in plants although it is required in trace amounts in plants. It was found that zinc has an important role in management of reactive oxygen species and protection of plant cells against oxidative stresses [61]. Zinc has important functions in the synthesis of auxin or indoleacetic acid (IAA) from tryptophan as well as in biochemical reactions required for formation of chlorophyll and carbohydrates. The crop yield and quality of produce can be affected by deficiency of Zn [38]. Carbon nanotubes can contribute to ameliorate development of plants, by enhancing elemental uptake and use of nutrients [62-68].

Plant virus, spherical in shape, which is considered to be naturally occurring nanomaterials. The smallest plant viruses known is satellite tobacco necrosis virus, which measures only 18 nm in diameter with single or double stranded RNA/DNA as genome. Their ability to infect, deliver nucleic acid genome to a specific site in host cell, replicate, package nucleic acid and come out of host cell precisely in an orderly manner have necessitated them to be used in nanotechnology. A complete review on use of plant viruses as bio templates for nanomaterials and their uses has been done recently by Young et al. [69,70].

Nanobiosensor is one of the tehnology which help in early detection to enhance crop yields by suitable management of water, land, fertilizers and pesticides. High surface to volume ratio, rapid electron-transfer kinetics, high sensitivity and stability with longer life is the main advantage over conventional sensor [69,68]. Fluorescent and surface enhanced Raman scattering (SERS) are two common optical sensors using biological macromolecules/ reduced metaloxide which helps in identification of metal ions in river water or soil bodies. Among the pesiticides, organo-phosphates, neonicotinoids, carbamatesand atrazines are considered as dominant classes and their residues were found at lower concentration for a longer time in soil due to low homogeneity [71]. The presences of pesticides using nanosensor that employ with the help of antigen-antibody interaction. Urea is most widely used fertilizer for crop production and contaminants in both water and soil is identified using microfludic impedimetric and colorimetric assay [72-74].

1.4. Characterization of nanoparticles / nanomaterials

It's very difficult to detect and quantify the nanoparticles / nanomaterials present in the environment due to their small size and low concentration and also due to the naturally occurring nanoparticulate which is similar with similar elemental composition [85]. Generally agricultural samples are heterogeneous in nature, which contain a mixture of natural and engineered nanoparticle in different composition. In some cases samples are required to be separated before characterization, which helps to reduce the complexity of the sample matrices. Several separation and characterization techniques can be used for the detection of nanomaterials or nanoparticles in agricultural samples (Fig. 3) [86-88]

Normally chromatography helps to separate the compounds based on different parameters such as charge (weak/strong cation or anion exchange chromatography; [IEC]); molecular mass (size exclusion chromatography [SEC]); hydrophobicity/polarity (reversed-phase HPLC, hydrophobic interaction chromatography), and specific characteristics (affinity chromatography), depending on the type of materials in the stationary phase [89]. Hydrodynamic chromatography (HDC) is also a very efficient technique to separate nanoparticles or nanomaterials from the agricultural samples based on their hydrodynamic radius [90].

The most widely used detection techniques for nanoparticles/ nanomaterials in agricultural samples include: dynamic light scattering (DLS), microscopic and spectroscopic techniques, surface plasmon resonance (SPR), and autofluorescence. The one of the method used to provide structural information is classical light scattering technique [91]. DLS is also known as photon correlation spectroscopy, which uses the scattered light to measure the rate of diffusion of nanoparticles/ nanomaterials and gives a size distribution. In some of the previous studies this technique is used for sensing the aggregated proteins, size characterization of lipid nanocapsules, size measurement of natural particles (*1–3 lm) present in milk [92]But it's very difficult to quantify the presence of any aggregates using DLS. This problem can be solved using the phase analysis light scattering (PALS) technique, which helps to determine the isoelectric point and electrophoretic mobility solution [93]. Static light scattering is also considered as another rapid, reproducible and widely used light scattering technique in dairy product.

Among all the microscopic techniques, Electron microscopy (EM) techniques are widely used to determine the size, shape, and other elemental properties of nanoparticles/ nanomaterials. Transmission EM (TEM) is one of the indispensable nanoscale imaging techniques for the characterization of NMs $<$ 200 nm in agricultural samples. In TEM, electrons are transmitted through the sample to acquire an image with a resolution of 0.5 nm [94-97]. TEM, coupled with an energy dispersive Xray spectroscopy (EDS or EDX) detector is used to get the elemental compositions of nanoparticles/ nanomaterials, and also it can provide the size, morphology, and size distribution of NMs with accuracy of – 5% [98]. This technique can be used to localize and identify inorganic particles. Atomic force microscopy (AFM) is also considered a powerful tool to investigate the fine structural information. AFM can detect irregularities in the polymer structure that usually hindered the detection in whole sample-based analyses [99]. Thus, AFM imaging provides the potential to characterize the integral heterogeneous assemblies of food macromolecules [100]. Cryo-TEM/Cryo-SEM can be used to acquire high-resolution images of biological samples under high vacuum and below ambient temperature (between - 100C and - 175C).

Confocal microscope images showed NP aggregates in root epidermis, cortex, and some NP aggregates in the xylem vessels [101]. SPR or surface-enhanced Raman spectrometry-based approaches are also being employed to measure NPs [102]. Autofluorescence can also be used to analyze agricultural samples. NMs can be detected with this technique: glutaraldehyde-fixed plant samples.

1.5. Nanotechnology and agricultural sustainable development

The nanotechnology has crictical position in development of agriculture by the control of the production of nutrients and which is the crucial step to enhance the crop productivity [103,104]. The observations of water quality and use of pesticides in proper way play a major role in the conservation and management of agriculture (Prasad et al., 2014). The study on nanoparticles explains that the nanoparticles having same chemical composition that will show variable shape or size and also shows various toxicity. The study on nanopesticides in agriculture concluded that the environment sectors were important for the sustainable development. The emergence of nanotechnology that would helpful in resource management, maintenance of fertility of the soil, and drug transfer technique. It is also helpful to investigate steadiness with the help of natural wastes and food mass as impact identification. Ion proposed that the nanosensors are widely used in the environment because of their strength and fast monitoring capacity for presence of microorganisms in the water or in the soil [105]. So many equipment are used for nano detection process like viz. biosensors, optical sensors, electrochemical sensors, and this equipment should be important for the identification of trance range of metals [105].

Nanoparticles have endless applications in horticulture it improve the catalysis of debasement of waste and poisonous materials that cause hurt and furthermore enact the corruption squander and harmful materials by microorganisms. For the evacuation of poisons and hazardous substances from the horticulture soil and water should be possible by bioremediation by microorganisms. In specific, some different terms are additionally commonly utilized such as bioremediation (gainful organisms), phytoremediation, and myco-remediation [106–109]. Consequently, with the treat of contaminated media with substantial compounds can be dispose natural sources and proficiently by microbes [110]. Thus, the rural treatment process of contaminated media helps in supportable revival of innovations to separate and re-establish the characteristic state of the dirt. The nano to nano collaboration to

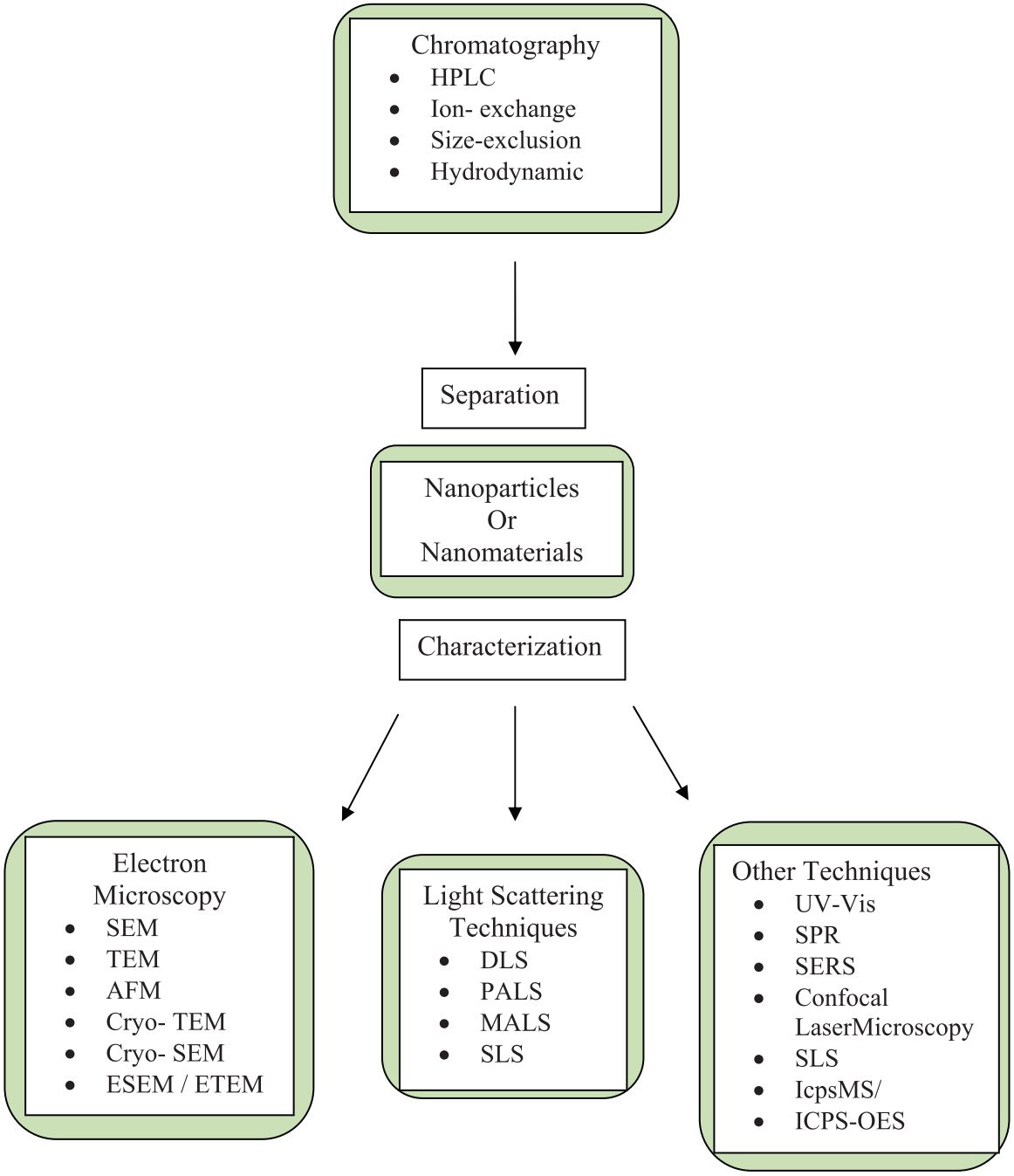

Fig. 3. An overview of separation and characterization method used for the identification of Nanoparticle/Nanomaterials in agricultural industry. HPLC/UPLC, high- or ultra-performance liquid chromatography; AFM, atomic force microscopy; TEM, transmission electron microscopy; SEM, scanning electron microscopy; ETEM/ESEM, environmental TEM or SEM; DLS, dynamic light scattering; MALS, multiangle light scattering; PALS, phase analysis light scattering; SLS, static light scattering; UV–vis, ultraviolet-visible; SERS, surface enhanced Raman scattering; SPR, surface plasmon resonance; ICP, inductively coupled plasma; MS, mass spectrometry; OES, optical emission spectrometry.

eliminate the toxic components of the farming soil and make it economical is really interesting [110,111]

Manures combined nanotechnology by can be brought from the market yet the farming composts are not created by the substance organizations (Table 2). Nanofertilizers may contain nano zinc, silica, iron and titanium di oxide, ZnCdSe/ZnS center shell QDs, InP/ZnS center shell QDs, Mn/ZnSe QDs, gold nanorods, center shell QDs, and so on just as ought to support control delivery and improve its quality. The examination on the take-up, organic destiny and harmfulness of a few metal oxide nanoparticles. aluminum oxide, Titanium dioxide, Cerium oxide, Iron oxide and Zinc Oxide nanoparticles were completed seriously in the current decade for agrarian creation [111]. The lack of Zn would be reported as one of the fundamental issues in restricting horticultural efficiency in the basic idea of soils. Crystalline solid nanoparticles are isotopic labeling by atomic particle barrage or advanced during union. Dimension, level of conglomeration and zeta capability of the metal oxide nanoparticles [111,112]. Additionally, nanoparticles take-up and intracellular destiny are followed by ion bar microscope analysis, TEM, Raman analysis and confocal laser scanning microscopy. Studies in the area of science, material science, biotechnology, biodiversity, biology, and designing provide opportunities to expand biomass advancement just as to use biomass and natural squanders at an exceptionally productive. During this

Table 2
A few marketable products of nano-fertilizers.

Marketable trade	Usage/Formation	Agency
Nano-Gro ™	Support the development and boost the immunity of plants	Agro Nanotechnology Corp., US
Nano green	Fraction of corn, grain, soybeans, coconut, and palm	Nano Green Sciences, Inc., India
Nano-AgAnswer®	Microbes, seaweeds, and nutrient supplement substances	Urth Agriculture, US
BiozarNano-fertilizer	Mixture of natural compounds, nutrient supplements, and nano particles	FanavarNano-PazhooheshMarkazi Company, Iran
Nano Max NPK Fertilizer	Multiple organic acid schelated with major nutrients, aminoacids, organic carbon, organic micronutrients/traceelements, vitamins, and probiotic	JU agri sciences Pvt. Ltd, India
Master NanoChitosan Organic Fertilizer	Water soluble liquid chitosan, organic acid and salicylic acids, phenolic compounds	PannarajIntertrade, Thailand
TAG NANO (NPK, PhoS, Zinc, Cal, etc.) fertilizers	Proteino-lacto-gluconatechelated	Tropical Agrosystem India (P) Ltd, India

century, the shrewd agribusiness is an approach to accomplish need of short and long haul improvement in the face of environmental change and fills in as a connection to other people [113]. It looks to help nations and other useful viewpoints in making sure about the important agrarian applications [114]. In the previous few years, investigates identified with the development of assets in an anometric degree and their characteristic properties are seriously led and centered. Two distinctive cycle would be happens during the transformation of crystallite size molecule to nanaoscale. In the first (quantum size effect), radical changes in the material causes modification in the physical–compound properties of material. For this situation, the exhibition is absolutely reliant on the semiconductors-NPs. Then again, because of the gigantic proportion of surface region to volume, for scientific motivation behind horticultural items NPs shows excellent transduction properties [114]. Nanostructures materials uncovered a few points of interest in consistent sciences when utilized as transducers or as a piece of the thankfulness in a full scale estimated detecting gadget. In this realities the gold NPs (AuNPs) has its inborn capacities, and may use as transducers for advancement of farming items. The Au NPs have notable surface plasma on band that is obvious around 520 nm. For the improvement of biosensing gadgets Au NPs can be utilized on the grounds that it has numerous properties like high surface region and physicochemical properties. Also, these NPs have stood out in organic examinations due to their small poisonousness, biocompatibility and extraordinary optical features [114-116]). In this manner, use of nanoscale particles results various points of interest over conventional systems.

The nanomaterials play an important role in crop conservation; also manufacturing of food is which important in later years. NPs have so many functions one of the major functions was the controlling of insect pest which reduces the yield in the agriculture there by increasing the productivity [115]. These properties maintained by conserving the encapsulated active substances from early degradation or by enhancing their pest control capacity for a long time [117,118]. The synthesized nanopesticides which were eco-friendly, less harmful and effectively protect the crops in the environment [42,116]. The synthesis of toxin free, eco-friendly nanopesticides which enhance the global productivity of food without causing any harmful effects to the environment [119,120].

2. Conclusion

Nanotechnology applications are currently being researched, tested and already applied in different the spectrum of food technology, from agriculture to food processing, packaging and food supplements. The wide range of application is due to the unique chemical, physical, and mechanical properties. In recent years, application of nanotechnology in the agricultural field has attained attention due to its large surface area which helps to increase the reactivity. Nanomaterials prepared by green precursors and eco-friendly nature helps to increases its agriculture potential, which improves fertilization process, plant growth regulators, pesticides delivery of active component to the target sites, treatment of wastewater and also enhancing the absorption of nutrients in plant. Moreover, they help to minimize the amount of harmful chemicals that pollutes the environment. As a part of biosafety, nanobiosensors are developed and have great demand due to its rapid, sensitive and cost-effective systems with a wide application in different human activity such as health care, agriculture, genome analysis, food and drink, the process industries, environmental monitoring, defense, and security. The editors of *Nature* estimated that any technology takes some 20 years to emerge from the laboratory and be commercialized [71]. Nanotechnology in agriculture might take a few decades to move from laboratory to land. Sustained funding and understanding on the part of policy planners and science administrators, along with reasonable expectations is needed to achieve it.

Funding

None.

Declaration of Competing Interest

The author declared that they have no conflicts of interests.

References

[1] R. Prasad, A. Bhattacharyya, Q.D. Nguyen, Nanotechnology in sustainable agriculture: recent developments, challenges, and perspectives, Front. Microbiol. 8 (2017) 1014.
[2] L.F. Fraceto, R. Grillo, G.A. de Medeiros, V. Scognamiglio, G. Rea, C. Bartolucci, Nanotechnology in agriculture: which innovation potential does it have? Front. Environ. Sci. 4 (2016) 20.
[3] M. Usman, M. Farooq, A. Wakeel, A. Nawaz, S.A. Cheema, H. ur Rehman, M. Sanaullah, Nanotechnology in agriculture: current status, challenges and future opportunities, Sci. Total Environ. 721 (2020) 137778.
[4] A.D. Servin, J.C. White, Nanotechnology in agriculture: next steps for understanding engineered nanoparticle exposure and risk, NanoImpact 1 (2016) 9–12.
[5] T. Dhewa, Nanotechnology applications in agriculture: an update, Octa J. Environ. Res. 3 (2) (2015).
[6] G. Pandey, Agri-Nanotechnology for sustainable agriculture, in: Ecological and Practical Applications For Sustainable Agriculture, Springer, Singapore, 2020, pp. 229–249. 2020.

[7] T. Hofmann, G.V. Lowry, S. Ghoshal, N. Tufenkji, D. Brambilla, J.R. Dutcher, K.J. Wilkinson, Technology readiness and overcoming barriers to sustainably implement nanotechnology-enabled plant agriculture, Nature Food 1 (7) (2020) 416–425.
[8] A. Acharya, P.K. Pal, Agriculture nanotechnology: translating research outcome to field applications by influencing environmental sustainability, NanoImpact (2020) 100232.
[9] I. Iavicoli, V. Leso, D.H. Beezhold, A.A. Shvedova, Nanotechnology in agriculture: opportunities, toxicological implications, and occupational risks, Toxicol. Appl. Pharmacol. 329 (2017) 96–111 2017.
[10] M.C. De Rosa, C. Monreal, M. Schnitzer, R. Walsh, Y. Sultan, Nanotechnology in fertilizers, Nat. Nanotechnol 5 (2010) 91: 10.
[11] R.J.B. Peters, H. Bouwmeester, S. Gottardo, V. Amenta, M. Arena, P. Brandhoff, H.J.P. Marvin, A. Mech, F. Botelho Moniz, L. QuirosPesudo, H. Rauscher, R. Schoonjans, A.K. Undas, M.V. Vettori, S. Weigel, K. Aschberger, Nanomaterials for products and application in agriculture, feed and food, Trends Food Sci. Technol. 54 (2016) 155–164.
[12] R.J.B. Peters, P. Brandhoff, S. Weigel, H. Marvin, H. Bouwmeester, K. Aschberger, H. Rauscher, V. Amenta, M. Arena, F. Botelho Moniz, S. Gottardo, A. Mech, Inventory of Nanotechnology Applications in the Agricultural, Feed and Food Sector, EFSA supporting publication, 2014 2014:EN-621.
[13] P. Pramanik, P. Krishnan, A. Maity, N. Mridha, A. Mukherjee, V. Rai, Application of nanotechnology in agriculture, in: Environmental Nanotechnology, 4, Springer, Cham, 2020, pp. 317–348.
[14] N. Ndlovu, T. Mayaya, C. Muitire, N. Munyengwa, Nanotechnology applications in crop production and food systems, Int. J. Plant Breed. Crop Sci. 7 (1) (2020) 624–634.
[15] R. Saxena, M. Kumar, R.S. Tomar, Implementation of nanotechnology in agriculture system: a current perspective, in: Nanobiotechnology: Concepts and Applications in Health, Agriculture, and Environment, 2020, p. 121.
[16] M.Z. Ghouri, Z. Khan, S.H. Khan, M. Ismail, S.O. Aftab, Q. Sultan, A. Ahmad, Nanotechnology: transformation of agriculture and food security, Bioscience 3 (2020) 19.
[17] R. Sabzali Parikhani, H. Sadighi, M. Bijani, Ecological consequences of nanotechnology in agriculture: researchers' perspective, J. Agric. Sci. Technol. 20 (2) (2018) 205–219.
[18] S. Ali, O. Shafique, T. Mahmood, M.A. Hanif, I. Ahmed, B.A. Khan, A review about perspectives of nanotechnology in agriculture, Pak. J. Agric. Res. 30 (2) (2018) 116–121 2018.
[19] M.A. Axelos, M. Van de Voorde, Nanotechnology in Agriculture and Food Science, John Wiley & Sons, 2017.
[20] J.S. Duhan, R. Kumar, N. Kumar, P. Kaur, K. Nehra, S. Duhan, Nanotechnology: the new perspective in precision agriculture, Biotechnol. Rep. 15 (2017) 11–23 2017.
[21] N. Mitter, K. Hussey, Moving policy and regulation forward for nanotechnology applications in agriculture, Nat. Nanotechnol. 14 (6) (2019) 508–510 2019.
[22] K. Jabeen, F. Anum, Myco-nanotechnology in agriculture, in: Nanoagronomy, Springer, Cham, 2020, pp. 53–68.
[23] A. Acharya, P.K. Pal, Agriculture nanotechnology: translating research outcome to field applications by influencing environmental sustainability, NanoImpact (2020) 100232.
[24] A. Rani, R. Singh, G. Shukla, Nanotechnology in agriculture and food sector, Appl. Nanotechnol. Introd. (2017) 11.
[25] S.O. Pathak, B.K. Pandey, S. Singh, M. Hasanain, G. Shukla, D.K. Maurya. Nanotechnol. Environ. Eng. Nanotechnol. Agric. benefits, risks and challenges, 2020.
[26] A. Gogos, K. Knauer, T.D. Bucheli, Nanomaterials in plant protection and fertilization: current state, foreseen applications, and research priorities, J. Agric. Food Chem. 60 (2012) 9781–9792.
[27] R.S. Kookana, A.B. Boxall, P.T. Reeves, R. Ashauer, S. Beulke, Q. Chaudhry, G. Cornelis, T.F. Fernandes, J. Gan, M. Kah, I. Lynch, J. Ranville, C. Sinclair, D. Spurgeon, K. Tiede, PJ. Van den Brink, Nanopesticides: guiding principles for regulatory evaluation of environmental risks, J. Agric. Food Chem. 62 (2014) 4227–4240.
[28] Y.W. Chen, H.V. Lee, J.C. Juan, S.M. Phang, Production of new cellulose nanomaterial from red algae marine biomass Gelidiumelegans, Carbohydr. Polym. 151 (2016) 1210–1219.
[29] S. Dwivedi, Q. Saquib, A.A. Al-Khedhairy, J. Musarrat, Understanding the role of nanomaterials in agriculture, in: D.P. Singh, H.B. Singh, R. Prabha (Eds.), Microbial Inoculants in Sustainable Agricultural Productivity, Springer, New Delhi, India, 2016, pp. 271–288. Eds..
[30] Y. Ran, Z. Liang, C. Gao, Current and future editing reagent delivery systems for plant genome editing, Sci. China Life Sci. 60 (2017) 490–505.
[31] J.B. Miller, S. Zhang, P. Kos, H. Xiong, K. Zhou, S.S. Perelman, H. Zhu, D.J. Siegwart, Non-viral CRISPR/Cas gene editing in vitro and in vivo enabled by synthetic nanoparticle co-delivery of Cas9 mRNA and sgRNA, Angew. Chem. Int. Ed. 56 (2017) 1059–1063.
[32] D.H. Kim, J. Gopal, I. Sivanesan, Nanomaterials in plant tissue culture: the disclosed and undisclosed, RSC Adv. 7 (2017) 36492–36505.
[33] A. Afsharinejad, A. Davy, B. Jennings, C. Brennan, Performance analysis of plant monitoring nanosensor networks at THz frequencies, IEEE Internet Things J. 3 (2016) 59–69.
[34] S.-Y. Kwak, M.H. Wong, T.T.S. Lew, G. Bisker, M.A. Lee, A. Kaplan, J. Dong, A.T. Liu, V.B. Koman, R. Sinclair, Nanosensor technology applied to living plant systems, Annu. Rev. Anal. Chem. 10 (2017) 113–140.
[35] R.T. Gahukar, R.K. Das, Plant-derived nanopesticides for agricultural pest control: challenges and prospects, Nanotechnol. Environ. Eng. 5 (1) (2020) 1–9.
[36] N. Konappa, S. Krishnamurthy, U.C. Arakere, S. Chowdappa, R. Akbarbasha, N.S. Ramachandrappa, Nanofertilizers and nanopesticides: recent trends, future prospects in agriculture, Adv. Nano-Fertil. Nano-Pestic. Agric. (2021) 281–330.
[37] R. Grillo, L.F. Fraceto, M.J. Amorim, J.J. Scott-Fordsmand, R. Schoonjans, Q. Chaudhry, Ecotoxicological and regulatory aspects of environmental sustainability of nanopesticides, J. Hazard. Mater. (2020) 124148.
[38] H. Chhipa, Applications of nanotechnology in agriculture, Methods Microbiol. 46 (2019) 115–142.
[39] E. Worrall, A. Hamid, K. Mody, N. Mitter, H. Pappu, Nanotechnology for plant disease management, Agronomy 8 (2018) 285.
[40] S.K. Verma, A.K. Das, M.K. Patel, A. Shah, V. Kumar, S. Gantait, Engineered nanomaterials for plant growth and development: a perspective analysis, Sci. Total Environ. 630 (2018) 1413–1435.
[41] O. Zaytseva, G. Neumann, Carbon nanomaterials: production, impact on plant development, agricultural and environmental applications, Chem. Biol. Technol. Agric. 3 (2016) 17.
[42] M. Nuruzzaman, M.M. Rahman, Y.J. Liu, R. Naidu, Nanoencapsulation, nano–guard for pesticides: a new window for safe application, J. Agric. Food Chem. 64 (2016) 1447–1483.
[43] I.U. Haq, S. Ijaz, R. Prasad, V. Kumar, M. Kumar, D. Choudhary, Use of metallic nanoparticles and nanoformulations as nanofungicides for sustainable disease management in plants, in: Nanobiotechnology in Bioformulations, Springer, Cham, Switzerland, 2019, pp. 289–316. Eds..
[44] A.R. Petosa, F. Rajput, O. Selvam, C. Ohl, N. Tufenkji, Assessing the transport potential of polymeric nanocapsules developed for crop protection, Water Res. 111 (2017) 10–17.
[45] R. Gonzalez-Fernandez, E. Prats, J.V. Jorrin-Novo, Proteomics of plant pathogenic fungi, J. Biomed. Biotechnol. (2010) 932527.
[46] M. Rai, A. Ingle, Role of nanotechnology in agriculture with special reference to management of insect pests, Appl. Microbiol. Biotechnol. 94 (2012) 287–293.
[47] A. Servin, W. Elmer, A. Mukherjee, R. De la Torre-Roche, H. Hamdi, J.C. White, P. Bindraban, C. Dimkpa, A review of the use of engineered nanomaterials to suppress plant disease and enhance crop yield, J. Nanopart. Res. 17 (2015) 92.
[48] R. Nair, S.H. Varghese, B.G. Nair, T. Maekawa, Y. Yoshida, D.S. Kumar, Nanoparticulate material delivery to plants, Plant Sci. 179 (2010) 154–163.
[49] B.C. De Jorge, R. Bisotto-de-Oliveira, C.N. Pereira, J. Sant'Ana, Novel nanoscale pheromone dispenser for more accurate evaluation of Grapholitamolesta (Lepidoptera: tortricidae) attract-and-kill strategies in the laboratory, Pest Manag. Sci. 73 (2017) 1921–1926.
[50] E.F. Santiago, M.S. Pontes, G.J. Arruda, A.R. Caires, I. Colbeck, R. Maldonado-Rodriguez, R. Grillo, Understanding the interaction of nanopesticides with plants, in: Nanopesticides, Springer, Cham, 2020, pp. 69–109. 2020.
[51] D.G. Panpatte, Y.K. Jhala, H.N. Shelat, R.V. Vyas, Nanoparticles: the next generation technology for sustainable agriculture, in: Microbial Inoculants in Sustainable Agricultural Productivity, Springer, New Delhi, India, 2016, pp. 289–300.
[52] R.Y. Hou, Z.Y. Zhang, S. Pang, T.X. Yang, J.M. Clark, L.L. He, Alteration of the nonsystemic behavior of the pesticide ferbam on tea leaves by engineered gold nanoparticles, Environ. Sci. Technol. 50 (2016) 6216–6223.
[53] C.D. Patil, H.P. Borase, R.K. Suryawanshi, S.V. Patil, Trypsin inactivation by latex fabricated gold nanoparticles: a new strategy towards insect control, Enzym. Microb. Technol. 92 (2016) 18–25.
[54] W.H. Elmer, J.C. White, The use of metallic oxide nanoparticles to enhance growth of tomatoes and eggplants in disease infested soil or soilless medium, Environ. Sci. Nano 3 (2016) 1072–1079.
[55] P. Vanathi, P. Rajiv, R. Sivaraj, Synthesis and characterization of Eichhornia–mediated copper oxide nanoparticles and assessing their antifungal activity against plant pathogens, Bull. Mater. Sci. 39 (2016) 1165–1170.
[56] K. Giannousi, I. Avramidis, C. Dendrinou-Samara, Synthesis, characterization and evaluation of copper based nanoparticles as agrochemicals against Phytophthorainfestans, RCS Adv. 3 (2013) 21743–21752.
[57] J. Sharifi-Rad, M. Sharifi-Rad, J.A.T. da Silva, Morphological, physiological and biochemical responses of crops (Zeamays L., Phaseolusvulgaris L.), medicinal plants (Hyssopuso_cinalis L., Nigella sativa L.), and weeds (Amaranthusretroflexus L., Taraxacumo_cinale F. H.Wigg) exposed to SiO_2 nanoparticles, J. Agric. Sci. Technol. 18 (2016) 1027–1040.
[58] S. Kumar, G. Bhanjana, A. Sharma, N. Dilbaghi, M.C. Sidhu, K.H. Kim, Development of nanoformulation approaches for the control of weeds, Sci. Total Environ. 586 (2017) 1272–1278.
[59] S.K. Moorthy, C.H. Ashok, K.V. Rao, C. Viswanathan, Synthesis and characterization of MgO nanoparticles by Neem leaves through green method, Mater. Today: Proc. 2 (9) (2015) 4360–4368.
[60] A.M. Awwad, A.L. Ahmad, Biosynthesis, characterization, and optical properties of magnesium hydroxide and oxide nanoflakes using Citrus limon leaf extract, Arab J. Phys. Chem. 1 (2) (2014) 66 2014.
[61] A.Y. Ghidan, T.M. Al-Antary, A.M. Awwad, O.Y. Ghidan, S.E.A. Araj, M.A. Ateyyat, Comparison of different green synthesized nanomaterials on green peach aphid as aphicidal potential, Fresenius Environ. Bull. 27 (10) (2018) 7009–7016 2018.
[62] S. Anandhi, V.R. Saminathan, P. Yasotha, P.T. Saravanan, V. Rajanbabu, Nano-pesticides in Pest Management, 2020.

[63] R.K. Saini, S. Patel, J. Bajpai, A.K. Bajpai, Advanced controlled nanopesticide delivery systems for managing insect pests, in: Controlled Release of Pesticides for Sustainable Agriculture, Springer, Cham, 2020, pp. 155–184.
[64] T.A. Wani, G.A. Rather, M. Ahmad, Z.A. Kaloo, Embodiment of nanobiotechnology in agriculture: an overview, Nanobiotechnol. Agric. (2020) 113–128.
[65] F.S. de Oliveira Pereira, D.A. Agarrayua, C.B. Quines, D. Ávila, Risk assessment of nanofertilizers and nanopesticides, in: Nanopesticides, Springer, Cham, 2020, pp. 299–316.
[66] X. Xin, J.D. Judy, B.B. Sumerlin, Z. He, Nano-enabled agriculture: from nanoparticles to smart nanodelivery systems, Environ. Chem. 17 (6) (2020) 413–425.
[67] S. Pradhan, D.R. Mailapalli, Nanopesticides for pest control, in: Sustainable Agriculture Reviews, 40, Springer, Cham, 2020, pp. 43–74.
[68] H.S. Bindra, B. Singh, Nanofertilizers and nanopesticides: future of plant protection, in: Advances in Nano-Fertilizers and Nano-Pesticides in Agriculture, 2021, pp. 57–84.
[69] M. Usman, M. Farooq, A. Wakeel, A. Nawaz, S.A. Cheema, H. ur Rehman, M. Sanaullah, Nanotechnology in agriculture: current status, challenges and future opportunities, Sci. Total Environ. 721 (2021) 137778.
[70] M. Young, W. Debbie, M. Uchida, T. Douglas, Plant viruses as biotemplates for materials and their use in nanotechnology, Annu. Rev. Phytopathol. 46 (2008) 361–384.
[71] O. Delgadillo-Vargas, R. Garcia-Ruiz, J. Forero-Álvarez, Fertilising techniques and nutrient balances in the agriculture industrialization transition: the case of sugarcane in the Cauca river valley (Colombia), Agric. Ecosyst. Environ. 218 (2016) 150–162.
[72] A.K. Srivastava, A. Dev, S. Karmakar, Nanosensors and nanobiosensors in food and agriculture, Environ. Chem. Lett. 16 (1) (2018) 161–182 2018.
[73] M. Kaushal, S.P. Wani, Nanosensors: frontiers in precision agriculture, Nanotechnology (2017) 279–291 2017Springer, Singapore.
[74] H. Chhipa, "Nanofertilizers and nanopesticides for agriculture", Environ. Chem. Lett. 15 (1) (2017) 15–22.
[75] C.R. Maruyama, M. Guilger, M. Pascoli, N. Bileshy-José, P.C. Abhilash, L.F. Fraceto, R. De Lima, Nanoparticles based on chitosan as carriers for the combined herbicides imazapic and imazapyr, Sci. Rep. 6 (1) (2016) 1–15.
[76] J. Jampilek, K. Zaruba, M. Oravec, M. Kunes, P. Babula, P. Ulbrich, P. Suchy, Preparation of Silica Nanoparticles Loaded With Nootropics and Their in Vivo Permeation Through Blood-Brain Barrier, BioMed research international, 2015.
[77] S. Kumar, G. Bhanjana, A. Sharma, M.C. Sidhu, N. Dilbaghi, Synthesis, characterization and on field evaluation of pesticide loaded sodium alginate nanoparticles, Carbohydr. Polym. 101 (2014) 1061–1067.
[78] N. Memarizadeh, M. Ghadamyari, M. Adeli, K. Talebi, Preparation, characterization and efficiency of nanoencapsulated imidacloprid under laboratory conditions, Ecotoxicol. Environ. Saf. 107 (2014) 77–83 2014.
[79] C. Sun, K. Shu, W. Wang, Z. Ye, T. Liu, Y. Gao, Y. Yin, Encapsulation and controlled release of hydrophilic pesticide in shell cross-linked nanocapsules containing aqueous core, Int. J. Pharm. 463 (1) (2014) 108–114.
[80] R. Grillo, A.E. Pereira, C.S. Nishisaka, R. De Lima, K. Oehlke, R. Greiner, L.F. Fraceto, Chitosan/tripolyphosphate nanoparticles loaded with paraquat herbicide: an environmentally safer alternative for weed control, J. Hazard. Mater. 278 (2014) 163–171.
[81] J. Jerobin, R.S. Sureshkumar, C.H. Anjali, A. Mukherjee, N. Chandrasekaran, Biodegradable polymer based encapsulation of neem oil nanoemulsion for controlled release of Aza-A, Carbohydr. Polym. 90 (4) (2012) 1750–1756.
[82] A. Chevillard, H. Angellier-Coussy, V. Guillard, N. Gontard, E. Gastaldi, Controlling pesticide release via structuring agropolymer and nanoclays based materials, J. Hazard. Mater. 205 (2012) 32–39.
[83] V. Saharan, A. Mehrotra, R. Khatik, P. Rawal, S.S. Sharma, A. Pal, Synthesis of chitosan based nanoparticles and their in vitro evaluation against phytopathogenic fungi, Int. J. Biol. Macromol. 62 (2013) 677–683.
[84] R. Grillo, N.F. de Melo, R. de Lima, R.W. Lourenço, A.H. Rosa, L.F. Fraceto, Characterization of atrazine-loaded biodegradable poly (hydroxybutyrate-co-hydroxyvalerate) microspheres, J. Polym. Environ. 18 (1) (2010) 26–32.
[85] T.A. Saleh, Trends in the sample preparation and analysis of nanomaterials as environmental contaminants, Trends Environ. Anal. Chem. (2021) e00101.
[86] R.P. Singh, R. Handa, G. Manchanda, Nanoparticles in sustainable agriculture: an emerging opportunity, J. Control. Release (2020).
[87] B. Bocca, F. Barone, F. Petrucci, F. Benetti, V. Picardo, V. Prota, G. Amendola, Nanopesticides: physico-chemical characterization by a combination of advanced analytical techniques, Food Chem. Toxicol. 146 (2020) 111816.
[88] I. Hagarová, Magnetic solid phase extraction as a promising technique for fast separation of metallic nanoparticles and their ionic species: a review of recent advances, J. Anal. Methods Chem. (2020).
[89] W. Fu, J. Min, W. Jiang, Y. Li, W. Zhang, Separation, characterization and identification of microplastics and nanoplastics in the environment, Sci. Total Environ. 721 (2020) 137561.
[90] A.S. Tsagkaris, S.G. Tzegkas, G.P. Danezis, Nanomaterials in food packaging: state of the art and analysis, J. Food Sci. Technol. 55 (8) (2018) 2862–2870.
[91] R. Singh, N. Kumar, R. Mehra, H. Kumar, V.P. Singh, Progress and challenges in the detection of residual pesticides using nanotechnology based colorimetric techniques, Trends Environ. Anal. Chem. 26 (2020) e00086.
[92] M. Sajid, J. Płotka-Wasylka, Nanoparticles: synthesis, characteristics, and applications in analytical and other sciences, Microchem. J. 154 (2020) 104623.
[93] H. Cai, E.G. Xu, F. Du, R. Li, J. Liu, H. Shi, Analysis of environmental nanoplastics: progress and challenges, Chem. Eng. J. 410 (2021) 128208.
[94] S. Shakiba, C.E. Astete, S. Paudel, C.M. Sabliov, D.F. Rodrigues, S.M. Louie, Emerging investigator series: polymeric nanocarriers for agricultural applications: synthesis, characterization, and environmental and biological interactions, Environ. Sci. Nano 7 (1) (2021) 37–67.
[95] A. Baysal, H. Saygin, Smart nanosensors and methods for detection of nanoparticles and their potential toxicity in air, in: Nanomaterials For Air Remediation, Elsevier, 2020, pp. 33–59.
[96] A. Jain, S. Ranjan, N. Dasgupta, C. Ramalingam, Nanomaterials in food and agriculture: an overview on their safety concerns and regulatory issues, Crit. Rev. Food Sci. Nutr. 58 (2) (2018) 297–317.
[97] N. Dasgupta, S. Ranjan, C. Ramalingam, Applications of nanotechnology in agriculture and water quality management, Environ. Chem. Lett. 15 (4) (2017) 591–605.
[98] Y. Picó, Challenges in the determination of engineered nanomaterials in foods, TrAC Trends Anal. Chem. 84 (2016) 149–159.
[99] E. de Almeida, N.M. Duran, M.H. Gomes, S.M. Savassa, T.N. da Cruz, R.A. Migliavacca, H.W. Pereira de Carvalho. 2016.
[100] A. Samsidar, S. Siddiquee, S.M. Shaarani, A review of extraction, analytical and advanced methods for determination of pesticides in environment and foodstuffs, Trends Food Sci. Technol. 71 (2018) 188–201.
[101] T. Rasheed, M. Bilal, F. Nabeel, M. Adeel, H.M. Iqbal, Environmentally-related contaminants of high concern: potential sources and analytical modalities for detection, quantification, and treatment, Environ. Int. 122 (2019) 52–66.
[102] R. Jackson, B.A. Logue, A review of rapid and field-portable analytical techniques for the diagnosis of cyanide exposure, Anal. Chim. Acta 960 (2017) 18–39.
[103] N. Dasgupta, S. Ranjan, C. Ramalingam, Applications of nanotechnology in agriculture and water quality management, Environ. Chem. Lett. 15 (4) (2017) 591–605.
[104] R. Prasad, A. Bhattacharyya, Q.D. Nguyen, Nanotechnology in sustainable agriculture: recent developments, challenges, and perspectives, Front. Microbiol. 8 (2017) 1014.
[105] F. Salamanca-Buentello, D.L. Persad, D.K. Martin, A.S. Daar, P.A. Singer, Nanotechnology and the developing world, PLoS Med. 2 (5) (2005) e97.
[106] A. Shafi, J. Qadir, S. Sabir, M. Zain Khan, M.M. Rahman, Nanoagriculture: a holistic approach for sustainable development of agriculture, in: Handbook of Nanomaterials and Nanocomposites for Energy and Environmental Applications, 2020, pp. 1–16.
[107] S.C. Mali, S. Raj, R. Trivedi, Nanotechnology a novel approach to enhance crop productivity, Biochem. Biophys. Rep. 24 (2020) 100821.
[108] S.A. Ashraf, A.J. Siddiqui, O.E. Abd Elmoneim, M.I. Khan, M. Patel, M. Alreshidi, M. Adnan, Innovations in nanoscience for the sustainable development of food and agriculture with implications on health and environment, Sci. Total Environ. (2020) 144990.
[109] D.J. McClements, Nanotechnology approaches for improving the healthiness and sustainability of the modern food supply, ACS Omega 5 (46) (2020) 29623–29630.
[110] R. Dixit, D. Wasiullah Malaviya, K. Pandiyan, U.B. Singh, A. Sahu, Bioremediation of heavy metals from soil and aquatic environment: an overview of principles and criteria of fundamental processes, Sustainability 7 (2015) 2189–2212.
[111] Q. Zhang, L. Han, H. Jing, D.A. Blom, Y. Lin, H.L. Xin, The effect of nano-zinc oxide on particleboard decay resistance, MaderasCienc. Tecnol. 17 (2016) 63–68.
[112] G. Helar, A. Chavan, Synthesis, characterization and stability of gold nanoparticles using the fungus Fusariumoxysporum and its impact on seed, Int. J. Recent Sci. Res. 6 (2015) 3181–3318.
[113] S. Kandasamy, R.S. Prema, Methods of synthesis of nanoparticles and its applications, J. Chem. Pharm. Res. 7 (2015) 278–285.
[114] A. Bhattacharyya, P. Duraisamy, M. Govindarajan, A.A. Buhroo, R. Prasad, Nano-biofungicides: emerging trend in insect pest control, in: R. Prasad (Ed.), Advances and Applications through Fungal Nanobiotechnology, Cham: Springer International Publishing, 2016, pp. 307–319.
[115] J.L. De Oliveira, E.V. Campos, M. Bakshi, P.C. Abhilash, L.F. Fraceto, Application of nanotechnology for the encapsulation of botanical insecticides for sustainable agriculture: prospects and promises, Biotechnol. Adv. 32 (2014) 1550–1561.
[116] S. Gottardo, A. Mech, J. Drbohlavova, A. Malyska, S. Bøwadt, J.R. Sintes, H. Rauscher, Towards safe and sustainable innovation in nanotechnology: state-of-play for smart nanomaterials, NanoImpact (2021) 100297.
[117] W.K.A. Nilmini, Nanofertilizers: a novel approach towards a sustainable agriculture, 2020.
[118] M. Kamle, D.K. Mahato, S. Devi, R. Soni, V. Tripathi, A.K. Mishra, P. Kumar, Nanotechnological interventions for plant health improvement and sustainable agriculture, 3 Biotech 10 (4) (2020) 1–11.
[119] A. Hossain, R.G. Kerry, M. Farooq, N. Abdullah, M.T. Islam, Application of Nanotechnology for Sustainable Crop Production Systems, in: Nanotechnology for Food, Agriculture, and Environment, Springer, Cham, 2020, pp. 135–159.
[120] C. Bartolucci, A. Antonacci, F. Arduini, D. Moscone, L. Fraceto, E. Campos, V. Scognamiglio. (2020). Green nanomaterials fostering agrifood sustainability. TrAC Trends in Analytical C.