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A Review of Nano Materials in Agriculture and Allied Sectors: Preparation, Characterization, Applications, Opportunities, and Challenges.

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Abstract: This review is objectively positioned and aimed at bringing to the fore the advances made in nanotechnology and present knowledge on the preparation (i.e., physicochemical, physicomechanical, and biological procedures), characterization (i.e., the use of several techniques to appraise the particle sizes, crystal geometry, and chemical composition,), claims in the agro-allied industries (i.e., construction of farm implements), electronics (i.e., glowing materials), medical (i.e., genetically modified plants), renewable energy(i.e., the harvesting of wind, solar and biomass energy in agriculture), oil/gas(i.e., the use of cracked oil in the production of fertilizers), textiles (i.e., weed control by landscape fabric)), environmental remediation (i.e., the production of eco-friendly materials using solid-state fermentation), and the military (i.e., the erection of the military post and farming structures), and public perception on nano-based technology. Also, the review has highlighted the positives and negatives in terms of challenges being faced by stakeholders in the nanotechnology sector. A good understanding of the strength (i.e., a steadily growing technology) and weaknesses (i.e., poor labeling and marketing strategy of products based on inadequate legislation) in these sectors as highlighted would provide a driving force for stakeholders to tackle the existing challenges herein.

Keywords: Luminescent materials; Nanomaterials; Nano environmental protection materials; Agriculture; Allied sector, Nanomaterials preparation; Nanomaterials characterization; Nanomaterials applications; Nanomaterials opportunities; Nanomaterials challenges.

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1. Introduction

Nano-sized particles (i.e., materials and systems at the scale of 10^{-9} meters) have gained considerable interest in all fields of science and technology because these particles are modulated and engineered into many forms of sizes, shapes to achieve desirable properties and functionalities [1]. These particles exist as aerosol (i.e., solid or liquid phase in the air), suspension (i.e., as solids in liquid), and emulsion (i.e., two liquid phases). There is this understanding that particles of matter in their unified macro-forms are less reactive and difficult to modulated when compared with the same material in the nanoscale unit [2]. Therefore, the discovery of the unusual new properties of

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nanoparticles has immense benefits in medicine, telecommunications, computers, aerospace, and security. However, the stability of these intrinsic properties when subjected to field conditions remains an unsolved problem [3]. Chemical processes with complex chemical changes are to be expected at the surfaces of nanoparticles, especially when in contact with adsorbates at differential temperatures and other environmental conditions. These complex changes could lead to aggregation and agglomeration of nanoparticles, thus changing the overall chemical and physical attitudes of these particles [4]. The presence of chemical agents (i.e., surfactants) and the use of electrochemical processes can stabilize nanoparticles and their charges against aggregation and agglomeration [5]. Therefore, failures recorded by nanoparticles in the building of a robust technological framework could be attributed to the changing conditions and parameters that control the stability of these nanoparticles in the bulk material.

Nanotechnology can be defined as the implementation of traditional or/and recent technologies to incorporate or/and produce materials at the nano-size scale [6].

Nanotechnology-based studies proposed new nanoparticles and operations to the industry. The countries that take the lead in this concern are the USA, Japan, China, South Korea, France, Germany, and Russia. However, the commercialization of nanoparticles in any country requires the support of the researchers with funds and facilities, assess the risks, implementation of standards, ethical issues and environmental limitation, the establishment of collaborations between research and industrial sectors, increase public acceptance and awareness [7].

2. Nanotechnology outlook

Nanomaterials improved the quality of many products and induced a new generation of products. The techno-economic network provides a useful method of structuring and interpreting the relationships in the technological system [8]. The difference in research and technology policies among countries arises from the difference in level and rates of economic development, level of culture and education, and strengths and weakness points in the industrial sectors [9]. The private sector contributes to research through funding and research and development centers. The majority of these companies are located in the Asian region and the European Union, also to some company presents in the USA [10]. Asian companies generate a lot of research papers like NTT, NEC, Samsung, Sony, Toshiba and Hitachi, Sumitomo, Toyota companies.

Nanotechnology encompasses the production, development of nanoparticles and nanosystems, and nano-devices at scales ranging from a small number of atoms/molecules to hundreds of nanometers. Nanotechnology makes the revolution in various industrial sectors, including manufacturing, communication, energy, agriculture, transportation, medicine, etc. in the following sections, the implementation of nanotechnology in different industrial and commercial sectors.

3. Preparation of nano-sized particles for nanotechnology

The preparation of nano-sized particles, especially of metals and metal oxides, stem from physical (i.e., mechanical), chemical, and biological processes [11]. The physical process involves the synthesis of the nanoparticles by lithographic, ball milling, etching, and sputtering techniques. This process entails the breakdown of larger molecules of materials to achieve a non-size fraction with suitable morphological and functional characteristics. The chemical processes involved in the synthesis of nanoparticles involves the buildup of nanoparticles from non-complex molecular structures. These methods include deposition by chemical vaporization, condensation of atomic and molecular structures, spray and laser heating at controlled temperature conditions, and aerosol formation [12].

The sizes and shapes of these nanoparticles (NPs) and other morphological characteristics are essentially controlled by physical activities, chemical conditions, and reaction states of the processes. For these reasons, the technologies derived from these nanoparticles have some setbacks in field conditions [1]. The stability of these NPs and the associated technologies fail due to dramatic changes in the environmental conditions. There is a limited scientific understanding of reaction mechanisms and modeling characteristics associated with these methods [13]. Also, these methods have left trails of bioaccumulation and toxicity that have not been resolved, thus, limited recycling, reuse, and regeneration techniques associated with these methods.

In light of these setbacks, biological synthesis has emerged as a salient method in the production of nanoparticles. This method, also known as green synthesis, entails the use of plants with their roots, flowers, leaves, and fruits as precursors. Also, green synthesis involves the use of microorganisms with bacteria, fungus, and algae as precursors. The technology of using these biological precursors aims to reduce most of the limitations recorded by the non-green techniques and to improve upon the environmentally friendly desire of nanoscience technology [14]. To avoid the release of harmful materials as byproducts, the green synthesis of nanoparticles

Green syntheses are required to avoid the production that requires the manipulation of smaller structures in a manner that is dependable, replicable, and friendly to the ecosystem [12]. Some researchers were focused on the mass production of nanoparticles. Synthesis of monodisperse nanocrystals (40 g per single reaction) has been accomplished [15].

They tried to reduce the process cost by replacing expensive organometallic compounds (like iron pentacarbonyl) with inexpensive metal oleate complex, also to eliminate further size sorting process. Another important finding of their study is the ability to fabricate a wide range of monodisperse nanocrystals via this generalized synthesis technique [15].

3.1. Characterization of nano-size particles.

The reaction mechanisms associated with the synthesis of nanoparticles can better be understood using several tools and a combination of techniques to ensure reliability. The physical properties that make nanostructures unique include a variety of sizes, crystal structures, elemental composition, thickness, and density [1]. Nanoparticles present properties different from the bulk material since these NPs have a high surface to volume ratio. This parameter makes their reactivity exponentially different at the atomic and molecular level. Despite the small sizes and low quantities of nanoparticles, large scale production of these materials is required for applications in industries. Therefore, accurate and reliable characterization using a combination of techniques is required. The choice of a technique or combination of techniques is dependent on availability, cost, selectivity, precision, stability, simplicity, and adherence to materials of interest. The microscopy-based techniques include X-Ray diffraction (XRD), X-ray absorption spectroscopy (XAS), X-ray photoelectron spectroscopy (XPS), transmission electron microscopy (TEM), high resolution transmission electron microscopy (HRTEM), and Atomic force microscopy (AFM) [16], nuclear magnetic resonance (NMR) spectroscopy, Thermogravimetric analysis or thermal gravimetric analysis (TGA), Brunauer–Emmett–Teller (BET) technique, Low-energy ion scattering (LEIS), Photoluminescence (PL) spectroscopy, nanoparticle tracking analysis (NTA), differential centrifugal sedimentation (DCS), and dynamic light scattering (DLS) [17], Superparamagnetic relaxometry (SPMR), X-ray magnetic circular dichroism (XMCD), ferromagnetic resonance (FMR), vibrating sample magnetometry (VSM), quartz crystal microbalance (QCM), electrospray differential mobility analysis (ES-DMA), inductively coupled plasma optical emission spectrometry (ICP-OES) [18], superconducting quantum interference device magnetometry (SQUID), and Mössbauer spectroscopy (MS), vibrating sample magnetometry (VSM), magnetic susceptibility balance (MBS), superparamagnetic relaxometry (SPMR), selected area electron diffraction (SAED), aberration-corrected electron microscopy (ACEM) [19]. These techniques provide information on the sizes, morphological crystal structural characteristics, thickness, aggregation of nanoparticles, magnetic properties, and mass variation of the nanoparticles [1].

4. Applications of nano-sized particles in nanotechnology

Nanoscience or nanotechnology depends on the ability of science and engineering to modulate, characterize, and use matter at the atomic and molecular levels. The development of scientific tools enables scientists and engineers to regulate the structure and properties of matter and specific systems at the nanoscale unit. The novel properties generated in nanomaterials have positives in every field [5]. Some of the improved properties of nanocomposites include mechanical strength, toughness, and electrical or thermal conductivity of the material. These positives are well known in the production of medical appliances, telecommunication tools, and computer appliances, modern aerospace components, and security appliances [20].

Most nanomaterials are applied in industries in the form of composites. Nanocomposites are a combination of two or more materials, one possessing nano-size particles, modulated such that the derived material of interest performed better than the component materials. Nanocomposite structures possess unit cells that are repeated between the different phases [21]. Nanocomposites consist of a matrix and a reinforcement that is pillared to achieve better performance. Nanocomposites are classified based on applications and chemistry. The former includes functional and structural nanocomposites. Nanocomposites based on the chemistry of material are classified as polymer-based and non-polymer - based nanocomposites. Polymer-based nanocomposites include polymer-ceramic, inorganic-organic polymers, inorganic-organic hybrid, polymer layered silicates, polymer-polymer, and bio-composites [22]. The non-polymer-based nanocomposites include metal-metal oxides, metal-ceramic, and ceramic-ceramic nanocomposites. Applications are sense or detected based on the type of filler or pillared layer associated with the matrix. These include metal oxide-metal oxide-based nanocomposites, polymer-based nanocomposites, carbon-based nanocomposites, and noble metal-based nanocomposites [22]. The unique properties of nanocomposites make them useful in the manufacture of nanosensors and nanoprobes that are useful in biological, chemical analysis, fuel cells, separation chemistry, and catalytic reactions.

Applications of nanomaterials-based composites are available in the strengthening of fibers and films, anti-scratch and abrasive materials, fireproof materials, anti-scratch paint, anticorrosion barrier, and delivery of drugs, and cellular therapies. In environmental protection, pillared clay of nano-sized unit is useful as a water barrier [23]. The application of nano-sized particles in technological development is found in several sectors:

4.1. Nanotechnology in the construction industry.

Nanotechnology in construction involves using nanoparticles such as alumina and silica as additives to building materials and coating of farm implements [24, 25]. Nano-cement is under development when it comes to production, huge opportunities in the fields of composites, electronic and ceramics applications would be found. Fire-protective glass is another application of nanotechnology. In which silica NPs are sandwiched between glass panels, in case of fire, the heat will turn it to an opaque rigid layer, so the heat and light have to be prevented from entering. Nanoparticles are also used as a protective coating on paints to protect from corrosion. The characteristics of this layer repel water and can protect metal [26]. Nanomaterials are used to create an ultra-thin protective layer. This layer, which resistant to corrosion and temperature, compromise of quartz-glass. It enhances surface elasticity, flexibility, and strength. hydrophobic

4.2. Nanotechnology in the food industry.

The food sector has invested a lot of money in nanoscience. Nanotechnology was first introduced to the food industry in 2003 [27]. Information on nanomaterials stability was reported by the United States Food and Drug Administration (FDA) in 2011 [28]. Now, nanotechnology has been implemented during different steps in the food industry like processing (adding specific taste and nutrient density) and packaging (incorporating clay nanoparticles in beer bottles prevent gases from penetration inside/outside the bottle resulting in elongate the flavor. The nanotechnology-based food like Canola Active Oil, designed to deliver minerals, and vitamins to the human body (Shemen Industries, Israel) [29], TiO_2 in different types of juices, Nanotea (Qinhuangdao Taiji Ring Nano-Products Co., China), and Nanoceuticals Slim Shake Chocolate (RBC Life Sciences Inc., USA) [30] are in the market. Nanolaminates can be used in the edible coatings, used as barriers to moisture, lipid, gases, in French fries, candies, chocolate, meats, vegetables, fruit, and bakery products. These coatings are applied as carriers of functional agents, including antioxidants, flavors, colors, and antimicrobials and nutrients [31, 32]. Silver nanoparticles are used as sensors as they are effective against vancomycin-resistant Enterococcus and fungi [33, 34] while gold nanoparticles are still under study [35].

However, most of the nanoparticles that are implemented in the food industry are out of food; they are used in package processing; there are only two nanoparticles involved in food involve FeO as colorant and TiO_2 as an additive. The latter is widely used in the food industry like puddings, candy, juice, white sauces, and gum [36]—additionally, ZnO, which is used as nutritional dietary supplements in animal foods.

Introducing recent nanoparticles to the food industry is still limited by the legislation [37-39]. Nanoclay is suggested as food packaging materials in the food industry; it enhances water permeance [40], toughness [41], and corrosion resistance [42] on the other hands, some reports aware against migration risk [43-45]. Another application of nanoparticles in the food industry is toxin and pathogen detections. To increase the food production, nanoparticles were used on commercial-scale as nonfertilizer (Land Green & Technology Co., Ltd., Taiwan) [46], nano-pesticides (Bio-Nanotechnology Co., Giza, Egypt), while nonherbicides are still under research and development [47].

Wang and Duncan [35] addressed the recent trends, opportunities, and challenges in the food and agricultural sector. They concluded that organizing the manufacturing and disposal processes need regulations, legislation, and increasing the awareness of the people to accept nanotechnology-based food.

4.3. Nanotechnology in electronics and information technology.

Nanotechnology is strongly contributed to the electronics industry (i.e., Luminescent materials and agricultural lighting). Also, smaller, faster, and more efficient systems that can store huge data have been developed. The major contribution includes developing transistors (14nm) in 2014 by Intel. A smaller one (1nm) was introduced to the market by Lawrence Berkeley National Lab in 2016. More energy-efficient televisions with ultra-thin displayers that use quantum dots to produce more vibrant colors are now being sold. Other nanomaterials like cellulosic and graphene NPs are involved in electronics to enable flexible, lightweight, and highly efficient electronics. There are also other applications that include flash memory chips for smartphones, antimicrobial coatings on keyboards, and ultra-responsive hearing aids.

4.4. Nanotechnology in the medical sector.

The recent advance in the application of nanotechnology in medicine is nanomedicine, inclusive of the formulation of transgenic plants and animals. Also, gold nanoparticles, which are used as potential treatments for cancer and as probes for the detection of targeted sequences of nucleic acids, have emerged [48]. The engineering of advanced nanoporous materials could improve gene sequencing technologies that reduce the cost and increase the speed of instrumentation.

In order the reduce the negative impact of chemotherapy, nanomedicine researchers are working on encapsulating nanoparticles to deliver medication to the cancer cell. The scientists also aimed to engineer NPS to mimic the structure of human bone and to use graphene nanoribbons to help repair spinal cord injuries. They are looking at ways that nanotechnology can improve vaccines. The unique size and surface area of nanoparticles allow them to deliver or carry proteins DNA, RNA, and small-molecule drugs inside the human body [48]. Wound dressing containing Ag NPs are present in the American market; it provides disinfection against150 kind of pathogens. Gold NPs, which can scatter light, have been used in vitro [49]. Incorporating noble metals like silver into bandages improves their antimicrobial characteristics. Due to their unique structural, thermal, and electronic characteristics, CNTs were investigated in drug and gene delivery [50], bullet-resistant materials. As body care products, TiO_2 and ZnO are used widely in sunscreens, Fe_2O_3 are used in lipsticks.

However, it is highly recommended to provide the companies with the toxicological data and the consumers with all the relevant safety assessment data [51]. Nanomaterials should be treated and considered as new materials since decreasing the size to nanoscale may alter all the material properties [52].

4.5. Nanotechnology in the renewable energy sector.

Nanotechnology is improving the efficiency of fuel production using modified catalysis. This technology translates into the use of renewable energy in powering agriculture and reducing fuel consumption in agricultural vehicles. Researchers are incorporating carbon nanotubes into high-tension wires in the electric grid to lower their resistance, thus reducing loss in the transmitted power.

Nanotechnology is incorporating into the solar panels to increase efficiency and lower the cost. Also, nanomaterials are being incorporated into batteries to increase their charging speed, power density, and to make it more efficient and lighter weight. Carbon nanotubes are also used in windmill blades to make it stronger, longer, and lighter-weight than traditional blades to increase the electricity generation. Nanotechnology is being pursued to recycle waste heat in computers, vehicles, and power plants.

4.6. Nanotechnology in the oil industry.

The driving forces for applying nanoscience in the oil and gas industry are the difficulty of discovering new oil reservoirs also to trapping 30-50% of oil in their reservoirs. Also, this technology is useful in the production of raw materials and energy in the manufacture of fertilizers and pesticides. Recently, this technology played significant roles in oil recovery [53], corrosion inhibition, drilling process, petroleum refining, reduction of oil viscosity, and hydrocarbon reduction. Although SiO_2 and FeO and TiO_2 are the most traditional nanoparticles used in the oil industry, according to the literature, Feo and CaO reduce loss in drilling fluid, FeO, and SiO_2 enhance compressive strength in cementation, TiO_2 and SiO_2 reduce losses in mud fluid [53].

Researchers aimed to design new composites like $ZnOSiO_2$@Xanthan in order to increase their performance. The challenges to transfer these NPs from lab to industry are the high cost, difficulty in manufacturing, agglomeration, and negative impact on the environment.

Nano-catalysts such as MgO and CaO have been used in oil transesterification to biodiesel [54]. Cellulose-based nanoparticles have been used as nano-fillers in industrial applications [55]. Nanotechnology enhances the separation of gas from oil, which increases the yield, nanotubes create strong and light oil. A specialized laboratory has developed nanoparticles in the advanced fluid that increase the drilling speed [56]. Subsurface nanosensors could be injected in oil and gas wellbores for recovery [57].

Nanotechnology can contribute to the gas industry via introducing nano-catalysts, nano-membrane for gas-liquid separation, and nanoparticles used in transportation and electricity transmission [56]

Silicon in the solar cell was replaced by TiO_2 in Graetzel cell, resulting in a reduction in the cost and improve the cell efficiency through an increase in the rays collected via the large surface area. Nanotechnology reduces the size of equipment, which decreases fuel consumption.

4.7. Nanotechnology in the textile industry.

The routes for nanotechnology in textile and dyeing industry are the use of landscape fabric for weed control and reduction of production cost, hygienic and antibacterial characteristics (i.e., Ag, SiO_2, ZnO, TiO_2), fabric durability (i.e., CNT, ZnO, Al_2O_3, SiO_2) [58, 59], comfort and cleaning issues (i.e., CNT, SiO_2 and TiO_2) [60, 61].

4.8. Nanotechnology in environmental remediation.

Scientist and Engineers are developing solid-state fermentation to produce eco-friendly environmental materials and nano-membranes based on MoS_2, is superior to conventional filter by 2-5 times. A nanoparticle is under development to substitute ordinary coagulants used in water treatment in order to decrease the cost. A nano-fibers composed of potassium manganese oxide nanowires were developed for cleanup application in oil. They have excellent absorptivity (20 times of their weight). Nasa has developed highly sensitive sensors that can be used to detect the quality of air around fire. CNTs were used as membranes to capture CO_2 from power plant exhaust.

4.9. Nanotechnology in the military.

The researchers seek to develop nanotechnology to accommodate military presence and farming structures in the battlefield, nano-weapons already produced, but the challenge is to govern their usage [62, 63]. Dying the soldiers' uniforms with mobile nano-pigments yields better camouflage. Since the color of the uniform will change with the soldered place resulting in better camouflage [64]. The technology of smart weapons is also under development. Other important applications of nanoparticles are to fabricate nano-polymer that can be woven into soldiers' uniforms. The uniform can be injected with nanoparticles to protect soldiers from the hard environment like high temperature and chemicals [65-68]. But still, the challenge to decrease the negative impact of these nanoparticles on soldiers in case of these particles break off and reach the solider body [69].

5. Public perception and the debate on the labeling of nanotechnology products

Public response to nanotechnology is being shaped by values, beliefs, issues, concerns, and inner sentiments that are usually established for any new invention worldwide [70]. For any nanoproduct, public perception is based on the user's knowledge of the obvious functions, benefits, and dangers associated with the nanoproducts. In most cases, nanotechnology is inbuilt in bulk and desires a lot of explanation as to why there are improved performances of one product over a similar product [71]. Nanoproducts, like every other product, are designed for public use, and the marketability of such products is dependent on the public knowledge of its benefits and side effects if any. There are no known standard procedures put in place on promoting information education and communication campaign (IEC) on the ingredients contained in nanoproducts and the dangers associated with the use of such products.

There are limited studies aimed at providing public perception on nanotechnology, and the available few are based on a scientific approach rather than a well-defined structured public opinion. Consequent to this gap, a bigger picture of the information is tilted towards the influence of sociodemographic factors. While the positive ethos is there towards nanotechnology and nanoproducts, there are still issues and concerns based on the possible risks and safety of these products. The implant of nanochips in vaccines has raised tremendous concerns on the motives of producers, promoters, and suppliers would be vaccines in the medical field. These concerns have brought to the fore the requirement of proper labeling of bulk products containing nanomaterials.

There is an ongoing debate as to whether labeling of bulk materials containing nanoparticles should be voluntary or obligatory. Some opinions are out there that consumer products containing nanomaterials, namely food, cosmetics, ecological detergents, biocidal products, and textiles, should be accompanied by mandatory labeling. The question is, why are products generally labeled? Is it important consumers get to know and appreciate the content of any material in use? What are the issues behind producers finding it difficult to properly label their products? Are there no warning signs that are required to be incorporated into the label design? These questions are better answered based on the legal requirements of countries and individual communities.

Therefore, consumers would need to do risk assessment and management before arriving at purchase decisions. As it stands, it would be illegal and abuse of international human rights for any people or group of people or nations to forcefully administer any bulk material containing nanotechnology input without the free will and consent of the consumer. Proper labeling of bulk materials containing engineered and modulated nanoproducts has, therefore, become necessary because this input will promote risk control and greater technology regulations. In the real sense, labeling of nanoproducts will enable consumers to make final decisions on the use of such products, especially where there are limited legal frameworks.

6. Challenges in the application of nanotechnology

There is limited knowledge about nano-sized particles utilized or produced on the industrial scale. It is resulting in insufficient safe procedures in handling. In Europe, numerous research programs tried to assess the occupational and environmental risk of nano-sized particles (Nano care, Nano health, Nanoderm, Nanotox, Impart, Nano safe) [83].

Despite the recent application of nano-sized particles worldwide, it still faces significant challenges:

1. Obstacles related to patent like difficulty in looking for it among a lot of patents where the author could utilize terms like tiny, micro-level, etc. there also additional obstacles like consuming much time in logistics and fulfilling the patentability requirements, also the existence of various applications for the same patent [84].
2. Scaling-up: a lot of production methods are difficult to be scaled-up due to special requirements of purification, restricted operation conditions, complexation of the process [85].
3. Control: production of nano-sized particles needs a special control of structure, morphology, and particle size.
4. Reliability: some nano-sized particles were studied in the lab scale. Much work is still needed to scaling up the process like the investigation of nano adsorbent for removal of a specific pollutant while the wastewater contains a lot of pollutants.
5. Cost: still much work is needed to reduce the cost of synthesis, regeneration, reuse of nano-sized -particles and -devices.
6. Environmental consideration: handling and disposal of nano-sized particles should be environmentally assessed.

7. For developing nano-devices, there will be an additional challenge. Besides minimizing the size of the device, engineers have to develop a power system with high efficiency to serve this nano-device.
8. Particle size: the size of nanoparticle ranges from 1-100 nm. This variation in sizes makes it difficult to be produced within specific product standards.
9. Safety: several nano-sized particles have revealed toxic effects [86]. Particles have a size <2.5µm revealed harmful effect [86, 87]. Consequently, the mass production of nano-sized particles depends on the evaluation of the risk of these particles during handling and release to the environment [88]. The effect on humans, especially workers and protective methods, should be known [83]. However, the International standardization organization reported standards in nanotechnology (TC 229, Nanotechnologies) in 2005 that shows risk assessment steps for nanomaterials.
10. Legislation and regulation: the involvement of nano-sized particles in the industry is limited to local and international legislations. Still, the risk of these materials is not fully assessed [88-90].
11. Researchers: insufficiency of data, infrastructure, and facilities are the main obstacles in some nanotechnology laboratories. On the other hand, the researchers need to learn basic and multidisciplinary sciences [91].
12. Responsibility: It is important to know the answer to two questions: who controls nanomaterials in the market? And who benefits from the implementation of nanotechnology? [31].

Concerning developing countries, there are additional challenges [92].

More investment in nanoscience-based research could strengthen nanotechnology. Increasing support and funds to R&D from governmental and private organizations are offering great opportunities for the nanotechnology market. Factor like involving nanotechnology in medical imaging and diagnosis drives the fast growth of the nanotechnology market.

7. Conclusion

Technology-based on nano-sized particles has made some considerable advances. However, this nanotechnology is still growing and faces some hurdles, especially with the recent development of its use in vaccine tracking and administration, food production, biotechnology, military, and electronic applications. A complicated matrix of scientific and engineering challenges is steadily rising and would need some policy statements and effective legislation from stakeholders to help stabilize the gains made in the different sectors.

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Conflicts of Interest

The authors declare no conflict of interest.

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