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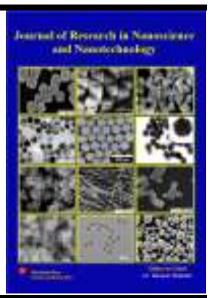

Currents Scenario of Nanomaterials: The Treasure

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ABSTRACT

Nanoparticle (NPs) becomes a treasure for scientific community. The size related properties offer ample opportunities for amazing discoveries. The unpredictable and exceptional nature of nanoparticles contributes their prospective utilization in many technological applications. At the same time, it also creates challenges for scientific society. In this review, we have covered applications of nanoparticles research and highlight their current development in various fields. The parameter includes the role of nanomaterials in catalysis and in food packaging applications. The industrial contributions of nanomaterials in architecture and construction, in cosmetics and beauty, in textile and in refinery have been discussed. Association as in defense appliances, in agriculture, in biomedical research, and in energy production also explained. The chosen parameters are not directly related to each other, but explain broadness of nanotechnology in commercial applied science relevance.

Keywords:
Applications, Nanomaterial's types,
Nanoparticles preparation, Relevance

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1. Introduction

Nanoparticles (NPs) have surprisingly a long record. Their preparation is constrained to man-made materials. Naturally occurring NPs including organic (proteins, polysaccharides, viruses, among others) and inorganic compounds (iron oxyhydroxides, aluminosilicates, metals, among others) were produced by weather conditions, volcano eruptions, wildfires or microbial processes[1-3].The existences of nanoparticles in nature are from ancient times; but now a day's it were prepared in synthetic laboratories.

The credit of scientific breakthrough in NPs research goes to Michael Faraday. His systematic studies on the interaction of light with metal NPs began modern colloid chemistry and be the exposure for Nanoscience and Nanotechnology [4]. In 1857 he discovered on 'Experimental Relations of Gold (and other Metals) to Light' to the Royal Society of London [5]. Faraday prepared a colloidal dispersion in a two-phase system consisting aqueous solution of gold salt with solution of phosphorus in carbon disulfide. After short reaction time the bright yellow color of the Na $[AuCl_4]$

solution turned into ruby color; characteristic of gold NPs [6]. NPs are wide class of materials of any peculiar substances with one dimension less than 100 nm at least [7]. Scientist found in their studies that size may influence with physiochemical properties (*viz.* optical properties) of a substance. This finding highlights the importance of nanomaterials. NPs are not simple molecules itself and composed of three layers. The surface layer is functionalized with a variety of small molecules, metal ions, surfactants and polymers. The shell layer has chemically different material from the core in all aspects, and central portion the core [8]. With such exceptional characteristics, these materials got enormous interest among scientist community and explore in multidisciplinary area. The NPs can be employed for drug delivery [9], chemical and biological sensing [10], gas sensing [11], CO_2 capturing and other related applications [12]. In this review, we provide a general overview on the application of NPs in different fields with future accepts and recommendations.

2. Nanoparticles and Classification

Nanotechnology is used in manipulation of matter at a tiny scale (generally > 1 nm and < 100 nm). At this size, atoms and molecules work differently and provide a variety of surprising and interesting applications, where conventional techniques may reach their limits. Nanoparticles are classified based on one, two and three dimensions [13].

2.1. One Dimension Nanoparticles

One dimensional system, *viz*. thin film or manufactured surfaces, has been used for decades in electronics, in chemistry and in engineering. These thin films are used in information storage systems, chemical and biological sensors and fibre optic systems, magneto optic and optical devices [14].

2.2. Two Dimension Nanoparticles

Carbon nanotubes (CNTs): Carbon nanotubes are hexagonal network of carbon atoms with appropriate diameter (1 nm) and length (100 nm) and rolled up into cylinder, as a layer of graphite. CNTs are generally found in single walled carbon nanotubes (SWCNTs) and multi-walled carbon nanotubes (MWCNTs). The small dimensions of CNTs experienced with their remarkable physical, mechanical and electrical properties and make them unique materials. The mechanical strength of CNTs is sixty times greater than the best steels. It has a great capacity for molecular absorption and found chemically stable [15,16].

2.3. Three Dimension Nanoparticles

Fullerenes (Carbon 60): Fullerene is spherical cage compound composed of interconnected carbon in pentagons and hexagons and resemble like a soccer ball. Fullerene can be subjected to extreme pressure and regain their original shape when the pressure is released. These molecules do not combine with each other, offering their application as lubricants. Also utilize in the electronic field from data storage to production of solar cells as nanoelectronic material. Because of the empty design fullerenes can be filled with different biological active molecules and may utilize for their potential medical applications [17].

Dendrimers: Dendrimers represents a class of controlled-structure polymers with nanometric dimensions (diameter usually 10 to 100 nm) with multiple functional groups on their surface and used as ideal carriers for targeted drug delivery. Dendrimers have different reactive surface groupings (in nano size), compatible with DNA for their making their fruitful use in medical and biomedical research areas. The structure and function of dendrimers has been well studied; it not only encapsulates functional molecules as therapeutic agents inside their core but also fabricate metallic nanostructure and nanotubes in its cavity [18,19].

Quantum Dots (QDs): Quantum dots (diameter in between 2 to 10 nm) are small devices that contain a tiny droplet of free electrons. QDs can be synthesized from various types of semiconductor materials through colloidal synthesis or electrochemistry. The most commonly used QDs are Cadmium Selenide (CdSe), Cadmium Telluride (CdTe), Indium Phosphide (InP), and Indium Arsenide (InAs). QD nanocrystals are generally composed of atoms from groups II and VI (examples CdSe, CdS, and CdTe) or II and V (such as in P) at their core. QDs also provide enough surface area to attach therapeutic agents for simultaneous drug delivery, in *in-vivo* imaging and in tissue engineering. QDs widely used for optical and optoelectronic devices, information storage and quantum computing.colour coded quantum dots are used for fast DNA Testing [20,21].

3. Preparation of Nanoparticles

The selection procedure for preparation of nanoparticles depends on physicochemical character of the material used; because mode of preparation plays a very significant role in the preparation of NPs. Different techniques used in preparation are discussed below:

3.1. Emulsion-Solvent Evaporation Method

This is one of the most widely used method for the preparation of Nanoparticles. In this method volatile solvents were used to prepare solutions. Initially emulsion was formulated with using Dichloromethane (DCM) and Chloroform, but now these days Ethyl Acetate (EtOAc) will be the preferred choice due to its low toxicological profile in order to obtain particles size > 500 nm. Emulsification-solvent evaporation involves two steps. In the first step organic phase will be emulsified into aqueous phase and in second step organic solvents were allow to evaporate followed by precipitation as nanospheres. The ultracentrifugation technique has been applied to collect these nanospheres from NPs suspension, which has been subsequently washed with distilled water in order to remove stabilizer residue or any free active ingredient. Stirring rate, amount and type of dispersing agent, thickness of organic and aqueous phase and temperature are the main factor to controlled the size of the nanoparticles [22,23] (see Figure 1).

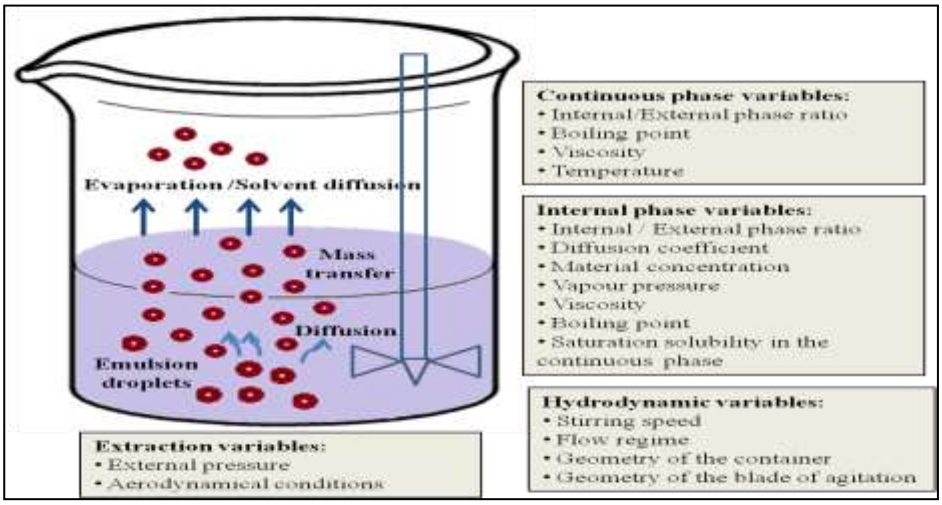


Fig. 1. Emulsion-solvent evaporation method

3.2. Emulsion-Solvent Diffusion Method

This is the modified procedure of solvent evaporation technique, utilized encapsulating molecule dissolved in water-miscible solvent (*viz.* benzyl alcohol, propylene carbonate) and mixed with small amount of water-immiscible organic solvent. The immiscible solvents spontaneously diffused (Emulsified) between the two phases organic and aqueous (in the presence of stabilizer) and form nanosized particles. Then solvent abolish by evaporation or filtration [24-26], (see Figure 2).

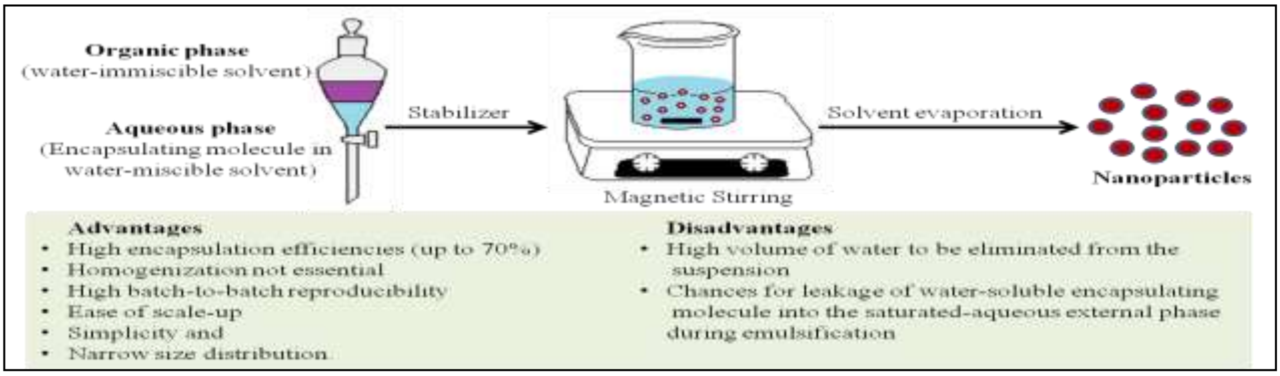


Fig. 2. Emulsion-solvent diffusion method

3.3. Salting-out Method

The salting out method is an improvisation scheme for emulsification-solvent diffusion technique; where water-miscible solvent separates from aqueous solution through salting out effect as presented in Figure 3. Initially the active material dissolved in acetone and then subsequently emulsified into aqueous gel containing the salting-out agent. The $MgCl_2$, $CaCl_2$ and Mg $(CH_3COO)_2$ were used as electrolytic agent and polyvinylpyrrolidone or hydroxyethylcellulose served as stabilizer. The emulsion formed is diluted with water to increase the diffusion rate. This induces nanoparticle formation [27-29].

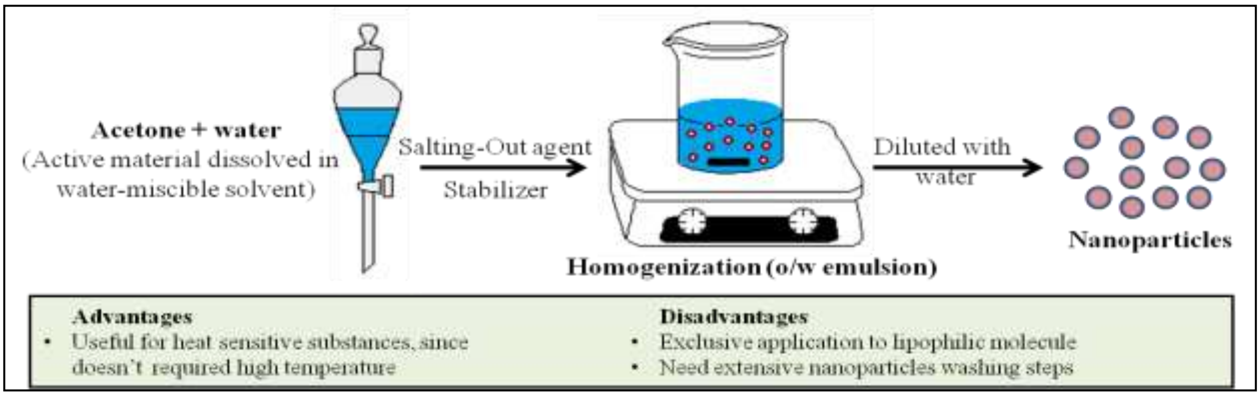


Fig. 3. Salting-out method

3.4. Solvent-Displacement/Precipitation Method

This is the facile, mild, low energy process and well suited for poorly soluble active material involves in NPs synthesis. In this method organic phase (having active ingredient) allow to diffuse into aqueous phase in the presence or absence of surfactants, resulting nanosphere formation. Polymers, drug or lipophilic surfactant are dissolved in a semipolar water miscible solvent such as acetone or ethanol. The solution is then poured or injected into an aqueous solution containing stabilizer under magnetic stirring (as shown in Figure 4). Nanoparticles formed instantaneously by the rapid solvent diffusion. The mixing rate of organic phase into aqueous phase affects the particles size. With decreasing mixing time of both phases the particle size can be controlled. The Nanoprecipitation, without using surfactant of hydrophobic compounds in a non-solvent solution leads to scattering of NPs which effect on nanosized particles and such process is termed as "Ouzo" effect [30-32].

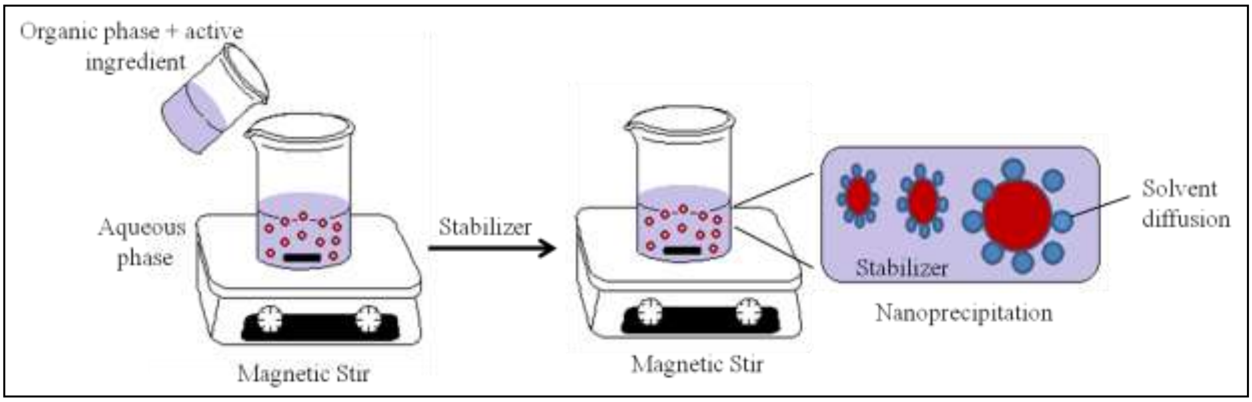


Fig. 4. Solvent-displacement/precipitation method

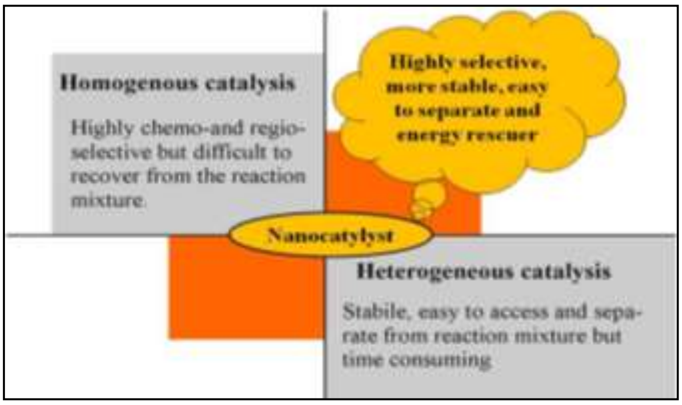
4. Characterisation of Nanoparticles

Several instruments and a variety of reliable methodologies can be used to understand the chemical mechanisms connected to the creation of nanoparticles. A wide range of sizes, crystal formations, elemental composition, thickness and density are only a few of the physical characteristics that distinguish nanostructures. Nanoparticles exhibit properties that are different from those of the bulk material. Their reactivity is exponentially different at the atomic and molecular level due to this characteristic. Nanoparticles come in small sizes and in small numbers, yet large-scale manufacture of these materials is necessary for industrial applications. As a result, precise and trustworthy characterization utilizing a variety of methodologies is necessary. The selection of a technique or set of techniques depends on factors such as accessibility, cost, selectivity, precision, stability, ease of use and adherence to target materials. The techniques that rely on microscopy include X-ray diffraction (XRD),X-ray absorption spectroscopy (XAS),X-ray photoelectron microscopy(XPS),transmission electron microscopy(TEM),high resolution transmission electron microscopy(HRTEM),and atomic force microscopy(AFM),nuclear magnetic resonance(NMR),thermogravimetric analysis or thermal gravimetric analysis(TGA), SQUID (superconducting quantum interference device magnetometry), MS (Mossbauer spectroscopy), VSM (vibrating sample magnetometry), MBS (magnetic susceptibility balance), SPMR (superparamagnetic relaxometry), SAED (selected area electron diffraction), and ACEM (-corrected electron microscopy) are other methods of magnetometry. These methods reveal details on the nanoparticles' sizes, morphological and structure features, thickness, aggregation, magnetic properties, and mass change [33-35].

5. Nanomaterials in Catalysis

Catalyst is a driving force behind the development of any chemical industry [36]. It develops in three directions: heterogeneous, homogeneous and enzymatic. With the development of nanosciences, nanocatalysis has a sphere of influence interfaces between homogeneous and heterogeneous. A nanocatalyst contributes a lot in reaction but still it has some challenges and opportunity.It also adds in use of natural resources more efficiently and generates considerable interest in academic and industrial research due to their potential benefits.

In homogeneous catalysis, nanocatalyst and reactants are in same medium. The nanoparticles formed a suspension or solution in a solvent. The important parameter is to consider during designing a nanocatalysts is to prevent its aggregation with others in solution; because nanoparticles naturally attracted towards one another in these conditions, and will clump together to form larger particles if not prevented. It is difficult to recover these particles from a homogenous solution after catalytic function; additional steps were required to do so. An environmental risk was also associated with accumulation of nanoparticles in ecosystem, if can't recovered [36]. In heterogeneous catalysis, catalyst is usually solid or immobilized on some solid inert support; hence easily recover from reaction mixture through filtration. Therefore, it considered to be friendlier to environment, as depicted in Figure 5 (a) & (b). Metal nanoparticles catalysts supported on materials like alumina, silica and carbon fibres play a very significant role in enabling these advantages [37].



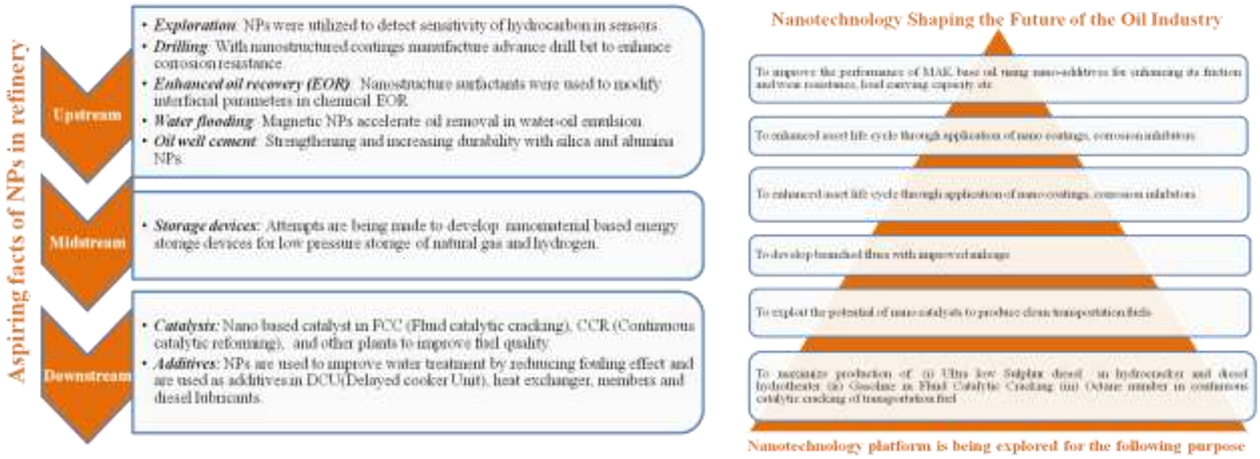
(a)

(b)

Fig. 5. (a) Homogenous and Heterogeneous catalysis (b) Benefits of nanocatalyst

6. Nanomaterials in Oil Refinery

Today, global warming has become a truth and we can't escape this reality. The pollution in air, water and soil were result of the excess carbon dioxide emission. This caused due to the industrial emissions, motor vehicle exhaust, oil spills, unorganized solid and liquid waste disposal and rapid industrialization. In view of these challenges, the oil industry is on the lookout for advanced technology that helps to implement environment friendly strategies [38,39]. The oil and gas industry are divided into three areas: Upstream (exploration of oil), midstream (transportation of oil) and downstream (refining of oil) (Figure 6(a)). Nanoparticles have managed to be the part of almost all aspects. In case of clean fuels, especially carbon neutral fuels, nanotechnology could become a game changer in development of novel catalysts for conversion of biomass to bio-chemicals / fuels. With emergence of natural gas-based economy in most part of the world, nanotechnology will play critical role for efficient and safe energy storage. In view of this, nanotechnology is envisaged to offer path breaking solutions to meet clean planet objective in coming years [40-42]. The Figure 6(b) highlights that how nanotechnology sharpens and booming the future of oil industry.



(a) (b)

Fig. 6. (a) Aspiring facts of NPs in refinery (b) Role of nanotechnology in oil industry

The exceptional properties of functionalized nanoparticles have created potential applications in oil stores. For example, surface-actuated nanoparticles can be utilized in improved oil recuperation procedures to settle emulsions and froths towards portability c of the product such as the shelf life of the product. Smart packaging's are often outlined control. Nanotechnology-based functionalized particles can be infused straightforwardly into supply developments as sensors to empower upgraded goals of subsurface imaging bringing about improved oil store, field portrayal methods and liquid property observing. Nanotechnology-Started control of interfacial attributes and atomic change can prompt upgraded oil and gas recuperation [43].

Nanotechnology-based materials, for example, nanoparticles, graphene and carbon nanotubes have great nanoscale properties that can be tackled for oil and gas investigation and recuperation. The small size of nanoparticles can bring about some advantageous highlights, for example, huge surface-to-volume proportion, to which different materials can join in manners that make for more grounded or increasingly lightweight items. The association of a dissolvable with the outside of the molecule can beat the thickness hindrance which as a rule makes materials either buoy or sink in a fluid bringing about the development of nanofluid [44-46].

i) Nanotechnology upgraded materials that give quality and continuance to expand execution and dependability in boring, forbidden merchandise, and pivoting parts.
ii) Improved elastomers, basic to profound boring and penetrating in high temperature and high weight situations.
iii) Erosion the executives for seaward and coastal and offices application.
iv) Natural administration for recognizable proof of ecologically cordial and feasible of nanomaterials.
v) Lighter-weight, unbending and more grounded auxiliary composites for boring stages/offices and improve and better-performing penetrating.
vi) Little/smaller scale drill entire assessment instruments to diminish boring expenses to give more noteworthy ecological affectability as a result of drill squander.

7. Nanomaterials in Food Packaging Applications

The increasing demand for high food quality, quantity, hygiene and non-polluting waste products are the common needs that have been encouraging scientists to search the robust and green biodegradable nanocomposites, which gives new challenges and opportunities for the preparation of nanocomposites in food industry. These types of nanomaterials show the great advantageous properties due to their high surface area, fine particle size, high reactivity, high strength and ductibility. Food packaging is one of the most beneficial steps to maintain the hygiene and quality of food products for storage, transportation and end-use. Physical and mechanical properties of nano-food packaging materials have been continuously developed, in order to provide materials with improved flame resistance, permeability, tensile strength and many more properties to extend the life of the food. These properties of nano-food packaging materials can offer consumers healthier and safe packaged foods. Figure 7, highlighting that how nanotechnology serves for better preservation, packaging, processing and safety of food life.

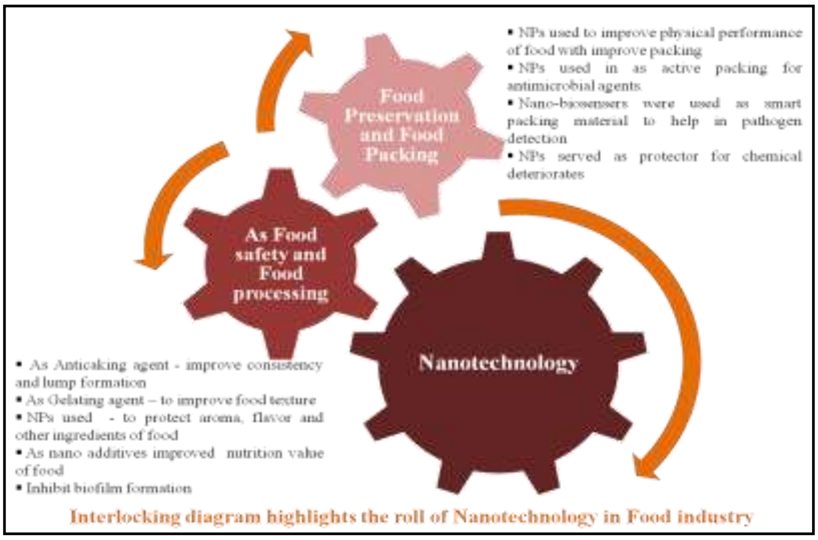


Fig. 7. How nanotechnology serving for better food life?

Types of packaging are described here.

7.1. Active Packing

There are several active packaging systems are available in market, out of all packaging systems, active packaging is a best packaging trick to modify the environmental or surrounding conditions for extending food life, safety, quality and taste. This type of packaging provides inert barrier between the food product and outside environmental conditions [47,48].

7.2. Intelligent and Responsive Packaging

In intelligent packaging technique food packaging is mainly based on carrying out detecting, sensing, recording, tracing, communicating. Intelligent packaging provides technical logic to extend life, safety, improve quality, provide information, and warn about possible problems. Methylene blue, acid, antioxidants, mineral oil and sugar, elements (Na, K, Ca, Si, Al, and Mg) are the mostly used components in intelligent packaging [49,50]. Responsive packaging technologies are based on three types of 3 important design features: prevention of cross-contamination, selection of the target analytes, and choice of the transduction system. The components of responsive packages should be based on stimuli-responsive materials, surfaces, hydrogels, particles, and supramolecules [51,52].

7.3. Smart Packaging

Smart packaging is to identify the internal condition as little and cheap labels or tags connected onto primary packaging like pouches, trays and bottles, or a lot of usually onto secondary packaging such as shipping containers to facilitate communication throughout the supply chain. Smart packaging is that the sort of packaging won't to indicate the interior condition of the merchandise like the time period of the merchandise. Nanomaterial based sensors are placed on the packaging material of the food product. The sensors sense the conditions and properties of the product and express the results in the form of different types of signals. The device expresses the condition of the barrier and properties of the materials (permeability of gasses i.e., oxygen). It conjointly detects the microbic load within the nutrient and explains concerning the time period of the merchandise. Nanosensors are good for the consumer for judging the properties of the product and satisfied their needs [53,54].

7.4. Modified Atmospheric Packaging (MAP)

MAP is applied to increase the period by removing or exchange the air encompassing food merchandise, sterilization the amounts of greenhouse emission (CO_2) and (N_2), eliminating extension of the post-harvest life, thus prolong the primary fresh conditions of food products (vegetables, fruits, meat, and fish) [55,56].

7.5. Antimicrobial Packaging

The food manufactures have been facing a number of challenges related to the food safety. Food safety means food will not cause any harm to human health when it is consumed according to its intended use. Many microbial agents (i.e. bacteria) can cause food spoiling when they have perfect conditions to reproduce [57]. Nanotechnology has helped in many ways to keep the microbial agents in food at acceptable level. In the antimicrobial packaging, the antimicrobial agents are utilized in order to manage the food spoiling microbes in food things. Various forms of silver nano-particles are used in large amounts and have the capability to control a large range of microbes [58,59].

7.6. Biodegradable l Packaging

Biodegradable packaging is incredibly useful technique, because non-biodegradable packaging contains a significant issue of disposal. In fact, industries ought to pay great quantity of their earnings on the disposal of such non-biodegradable materials. These non-biodegradable materials accumulate within the soil and cause environmental pollution, toxicity, and heating. Therefore, putrescible kind of packaging materials is introduced [60,61]. Biodegradable packaging is synthesized to use the material having degradable properties for instance, carbohydrates, super molecule and nano-oxide metal particles. These materials are often used as biodegradable packaging along with the nano-clays [62-64].

8. Nanomaterials in Construction Engineering

One of the most active research areas nowadays spans a wide range of fields, including construction materials and applied science. Products made using nanotechnology in construction include those that are advantageous because of their lighter construction, stronger structural composites, low maintenance coating, higher building material properties, decreased thermal transfer rate of fireside retardation and insulation, accrued sound absorption of acoustic absorbent material, accrued reflectivity of glass, water repellents, nano-clay crammed polymers, self-disinfecting surfaces, air cleaners, nano-sized sensors and star cell [65].The most common building material used nowadays is Portland cement. Applications for nanoparticles in construction technology range from the creation of standard mechanical qualities for concrete, corrosion protection for steel reinforcement, materials and goods like paints, sealants, and glass, to the creation of thermal and pyroresistant materials [66,67]. The following are some significant uses of nanomaterials in the building sector:

i) To increase durability, strength and as a pollution-reducing agent, construction materials like carbon nanotubes and nanofibres utilize nanomaterials.
ii) Nanomaterials are able to create self-cleaning steel and corrosion-free materials.

Nanomaterials are employed to improve the mechanical and physical characteristics of cement, including its resistance to creep, porosity, and permeability [68,69]. The following nanomaterials utilized in the construction and architectural sectors.

In order to enhance their physical and chemical properties, a variety of nanomaterials and nanoproducts are used as building materials. The following are the principal applications:

Nanomaterials used in architecture and construction industries

Numerous nanomaterials and nano products are employed in construction materials in an effort to enhance their physical and chemical qualities. These are the primary applications:

i) To increase the concrete's strength and durability.
ii) Heat insulation and UV defense.
iii) The corrosion and deterioration of the reinforcing steel can be improved with a little number of nanomaterials.
iv) Construction materials can be treated with nanocomposites to protect them from bacteria, dust, fingerprints, and moisture.
v) Nanomaterials can be used in the production of new types of solar panels and cells.
vi) The most appropriate materials utilized in building technology include waterproofing materials, paints, glues, sealants, telecommunication and illumination electrical parts and components.
vii) To create water purification, treatment and filtering equipment.

Different applications of nanomaterials in construction:

i) Nanocement: Cement with nanoparticle size modifications can be utilized to improve mixing with other building materials. It has been found that adding cement with nanoparticle size will make concrete stronger than adding carbon fibers or nanocarbon tubes [70].
ii) Nanoglass: TiO_2 in nano form can be used to create nanoglass, which has anti-fouling, self-cleaning, and sterilizing qualities.
iii) Nano steel: Scientists claimed that by reducing the cementite phase of steel to a nanoscale, stronger steel cables might be created. Copper nanoparticles are used to eliminate the evenness of the steel's surface. When it comes to fracture-related issues, vanadium and molybdenum nanoparticles can be employed as additives to enhance the qualities of high strength bolts [71-73].

iv) Nanometer: Thick coatings can be employed as a chemical and abrasion-resistant concrete coating material. Nitrides, phosphorus and nano Al_2O_3 are a few examples of nanoscale materials that can exhibit special surface characteristics that allow charged species to adsorb on them [74].

v) Smart nano-based dust-like (aggregate): Sensors can be employed as wireless sensors that are implanted in concrete, sprinkled on the structure's surface, or included into the mix as nanomaterial-based sensors for concrete structures [75]. The advent strength by offering fire resistance. The application of nanomaterials is expanding to all facets of building technology. The nanotechnology produced materials also extend the lifetime of the constructions over extended times. A paradigm shift has already begun in the building industry. As a result, nanotechnology has the potential to completely change the growth of the construction materials industry, nanotechnology has significantly decreased the rising cost of construction materials. These nanoparticles are highly efficient in producing self-improving, self-repairing concretes and enhancing material [76-78].

9. Nanomaterials in Medical, Cosmetics and Beauty Industry

By using designed nano devices, nanostructures, nanodrugs, nanorobots, nanomaterials are employed as a nanomedicine that serves as a control, constructed and maintained dose of human and animal health at a molecular level. The methods and equipment, which rely on this system, is the key to nanomaterials success in the medical field [79-81]. The advantages of nanomedical devices include their small size, which allows them to fit inside the body in a way that standard medical equipment cannot. Nanomedical devices can be inserted into the human body by blood vessels or the ends of catheters into various cavity inside the body, as demonstrated by the use of surgical nanorobots.

Nanotechnologies, nanomaterials and nano instruments all play a role in the potential applications of nanomedicines. Nanotechnology is employed for quick diagnoses, quick healing and genetic material restoration, whereas nanomaterials and nanoinstruments are crucial therapy aids and active ingredient carriers [82-84].

The increased use of nanomaterials in the production of cosmetics is a sign of the technology's high potential. It shows the variety of nanomaterials used in the beauty industry, including those that are already in use, as well as nanoemulsions and nanoparticles of minerals such as oxide (TiO_2), philosopher's wool (ZnO), alumina, silver, silica, copper and calcium halide. Nanotechnologies have the potential to significantly alter business and lifestyle due to the unique characteristics and behavior of nanomaterials [85]. The utilization of nanoparticles as encapsulating material vehicles for active agent delivery is due to:

i) These delayed releases of sensitising agents, reduces the direct contact of strong sensitive agents with skin.

ii) It reduces the use of additives and agents.

iii) It increases the amount of time that active chemicals are delivered, increasing the acceptability of the product. In contemporary cosmetic and beauty care applications, nanocrystals, micro emulsions, nanoemulsions, fullerenes and dendrimers are also being investigated (as presented in Figure 8) Materials designed for application to skin include nanoemulsions and nanopigments. Nanoemulsions can be used to suspend unstable vitamins. The entrapped load is released when a nanoemulsion comes into contact with the skin; the industry refers to them as nanocapsules, liposomes, lyphazones etc [86,87].

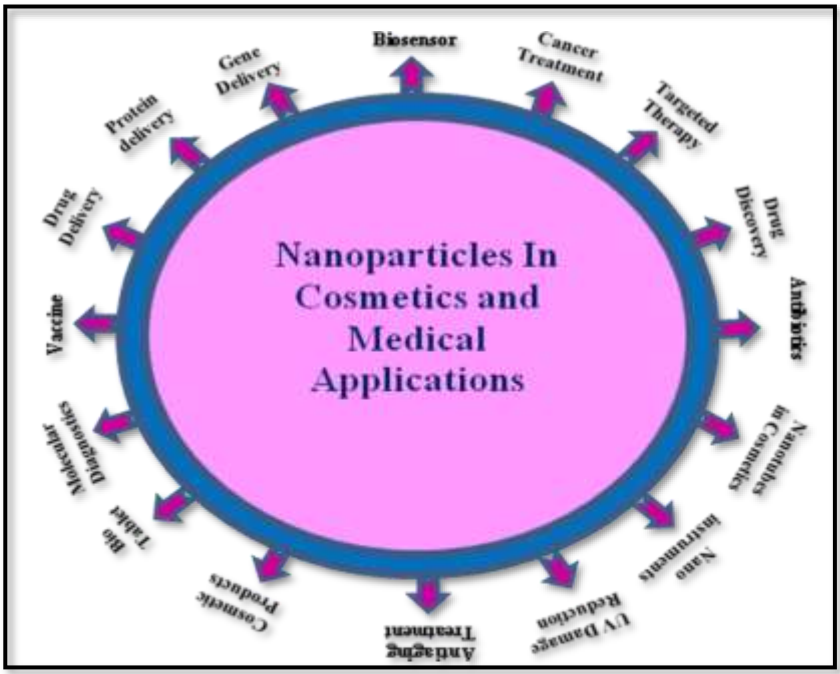


Fig. 8. Medicinal applications of nanoparticles

Different types nanomaterials used in cosmetics

9.1. Liposomes

Liposomes are used in cutaneous applications as moisturizing agents and as systems for safeguarding active substances. These spherical vesicles have a liquid centre and are made of phospholipids. These vesicles can include either lipotropic or hydrophilic active substances. However, liposome's have the capacity to enter the skin and deliver active substances to the desired location [88]. In order to cure dry and rough skin, dermal and care nanomaterials with empty or moisture-loaded liposome can lessen transdermal and interlayer water loss. They also make lipids and water accessible to the corneum [89,90].

9.2. Nanoemulsions

Due to the formation of droplets in the submicron range, nanoemulsions are also known as "ultrafine emulsions." As a delivery vehicle for lipotropic substances such essential oils, tastes, colours and fatty acids. Nanoemulsion is one of the emerging technologies being used in the cosmetic sector. Due to their distinctive qualities of small driblet size (in the range of 20-200 nm), high surface space, transparent or semitransparent look, high solubilization capability, low consistence and high kinetic stability due to sedimentation, action and in some cases and coalescency, these technological applications of nanoemulsions have increased the advancements in cosmetic applications.

As they facilitate the skin penetration of active substances and hence raise their concentration within the skin, nanoemulsions are a very effective delivery technology for the transportation of lipotropic chemicals, which is crucial in the development of cosmetic products. As a result, the properties of Nano emulsion are compatible with the fundamental procedure for creating products like body lotions, skin creams and sunscreens, shampoos, deodorants, etc [91-93].

9.3. Nanocapsule

Nanocapsules are microscopic particles made by a polymeric shell around an aqueous or fatty centre. Usually these are used in dermatological applications. It has been noted that the usage of nanocapsules reduces the damaging UV filter penetration [94,95].

9.4. Solid Lipid Nanoparticles

These are lipid droplets that are greasy and stabilized by surfactants at body temperature. They have been discovered to improve the penetration of active compounds [96], protect the encapsulated chemicals from degradation, and employed for the regulated delivery of cosmetic agents over an extended period of time [97].

9.5. Nanocrystals

Nanocrystals have a size of less than 1 m. These are found in aggregates with atom counts ranging from a few hundred to tens of thousands. These crystals are very useful in the cosmetic, pharmaceutical and beauty industries because of their small size, which allows them to be deeply absorbed and encapsulated in cosmetic products [98,99].

9.6. Nanosilver and Nanogold nanomaterial

The antibacterial capabilities of nanosilver are enhanced by cosmetic nanomaterials. The makers of several underarm deodorants using nanoparticles and silver claim that these products provide 24-hour protection from microorganisms that causes odours and injury. Additionally, it has been found that nano-sized gold like nanosilver is very effective at killing germs in the oral cavity [100].

9.7. Niosomes

Surfactants are a component of niosomes. These surfactants have a nonionic character in particular. Niosomes are used in the cosmetic and aesthetic industries because they can boost the stability and potency of medications and other active components that have been absorbed into the body [101].

10. Nanomaterials in Textile Industry

Textiles are used in many different fields. The main characteristics that make it a valuable material for humans are strength, hardness, ductility and flexibility. Textile materials are currently a cutting-edge alternative for the next generation of textiles due to these reasons and their multifunctional qualities. These recent advances in material and nanomaterial research offer fresh and primary solutions for a variety of fields, including the healthcare sector, athletic training, the military and uniforms. Scientists from a variety of disciplines including engineering, chemistry, textile engineering, material science and computer science have worked diligently to develop these novel textile processes. In general, smart textile refers to a textile substrate that detects and responds to various environmental stimuli (such as thermal, mechanical, chemical, electrical, magnetic, and optical) [102-106], (see Figure 9).

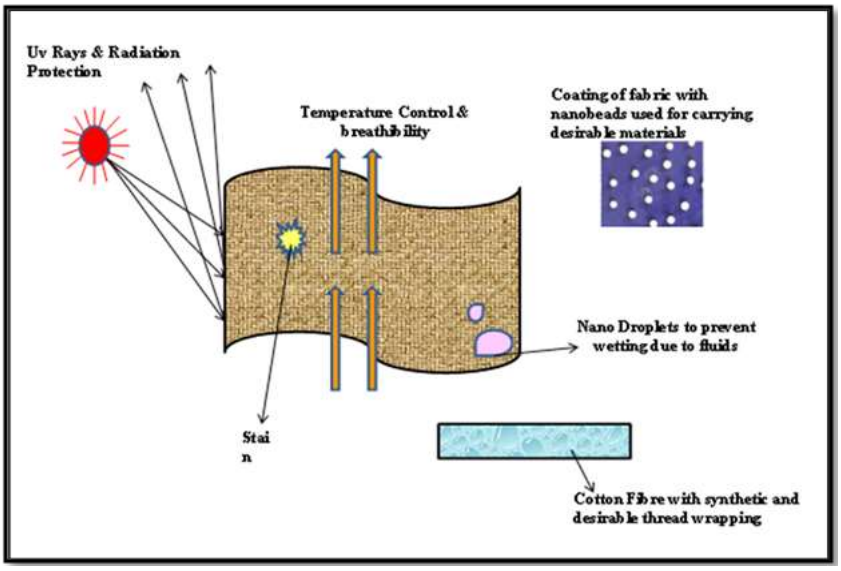


Fig. 9. Cotton fibre nano material

11. Nanomaterials in Agriculture

The usage of nanomaterials and applications of instruments for utilizing the physical and chemical properties of active ingredients at molecular levels from industries to agriculture can give thanks to the development of nanotechnology. Nanomaterials have a lot of potential in agriculture due to their small size; they may be precisely used to maintain an improved agricultural inventive solution to a variety of issues. Numerous nanomaterials use has the ability to increase food quality and storage, absorb numerous nanoscale micronutrients from the soil and lessen the potentially harmful effects of agrochemicals.

The neighbourhood of these tasks such as sustainability, susceptibility, human health and healthy life, includes food, agriculture and natural resources. The goal of introducing nanomaterials into agriculture is to minimize nutrient losses in fertilization, eliminate harmful chemical dispersion and increase output through improved nutrient delivery to plants nutrient and pest management systems, as described in Figure 10 [107-109].

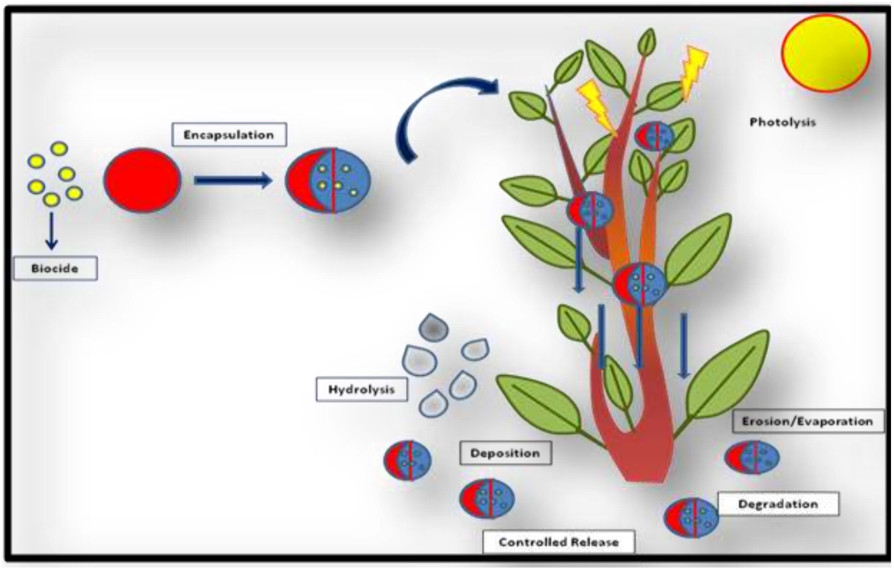


Fig. 10. Nanomaterials in plant survival applications

For quickly controlling plant diseases nanotechnology offers the nanotools to boost the potential of agriculture and food production. The most important applications of nanotechnology in agriculture include specific ones like encapsulation to create nanosize agrochemicals loaded with active ingredients to trail products and increase the nutrients levels to enhance plant fertility without polluting soils, water, and protection against various pathogens. To maintain the healthy growth of agricultural plants, nanosensors can be used to identify and monitor the nature, quality and fertility of the soil [110-112].

11.1. Nanofabrication

Nanofabrication is well known for the systematic design and production of tools that can measure precise dimensions at the nanoscale. Conventionally, nanofabrication can be carried out using a top-down strategy, which involves removing one atom at a time until the desired structure is obtained, or a bottom-up approach, which involves assembling a structure atom by atom. On the basis of a knowledge of the nanodynamics of interacting nanomaterials and interacting nanostructures, nanoparticles for use in farming may be created by combining the top-down and bottom-up methodologies [113].

11.2. Nano-bio Farming

Nanomaterials can boost crop productivity, improve crop nutrition and boost crop value or environmental cleanup. One such area is the use of particles in farming, which produces nanoparticles for use in agriculture by raising plants in specific soil. After harvest, the nanoparticles are frequently mechanically removed from the plant component. This technique generates fresh, original suggestions for raising crop yields [114,115].

11.3. Nanosensors

A highly new and promising tool for use in agricultural and food production is the discovery of nanosensors. Nanosensors have a great deal of potential to increase agricultural production, efficiency, sustainability, and security. When compared to outdated, conventional chemical and physical processes, sensors offer quite sensitive and accurate approaches. Microorganisms, several sorts of contaminants, and food freshness can all be detected by nanosensors [116]. Nano biosensors are used in food analysis and are created by combining nanosensors with biology, chemistry and nanotechnology. Nanosensors can track a wide range of agrochemicals including pesticides, herbicides, fertilizers, insecticides, diseases and crop growth, as well as soil parameters (such as moisture content and soil pH). Smart gadgets called nanosensors are utilized to provide early notice of changing climatic conditions. These artificial sensors are capable to provide real time-based data and accurate measurements can allow farmers to grow food materials [117,118].

11.4. Aptasensors

Aptasensors are actually quite useful tool in agriculture. Aptamers are made up of naturally occurring or artificially produced single-stranded nucleic acid or peptide molecules that are less than 25 kDa in size. Because of their exact and well-maintained three-dimensional architectures, these sensors are highly sensitive particular, selective towards their targeted site like proteins, ions and microorganisms. Aptasensor technology is based on the characteristic of the nanoparticle being used.

Aptasensors have been employed in the agricultural industry for the evaluation of food safety, allergic and toxic atrial detection and pollutant detection [119,120].

11.5. Nanobarcode

Nanoscale tags called nanobarcodes are utilized in agricultural, veterinary and animal husbandry products for non-biological purposes like tracking and authentication. These items are mostly produced using an electroplating technique, which is extremely scalable and semi-automated. Plant resilience to environmental challenges including drought and diseases has improved the advancements in nanotechnology and biotechnology. Plant gene trait resources may be quickly and cost effectively identified and used using nanotechnology-based gene sequencing [121].

11.6. Nanoagrochemical

These nanoscale formulations have a number of potential benefits over the use of regular insecticides and herbicides. The most effective and advantageous conventional methods to control pathogens and pests are nanomaterials in the form of nanopesticides and nanoherbicides. This is because these pests and the pesticides used to treat them have an impact on the environment and farmers economies, with 90% of applied pesticides failing to reach the targeted site due to runoff and airborne application errors. According to scientists, overuse of pesticides can lead to increased disease and pest resistance, decreased soil microflora, decreased organic process, increased pesticide bioaccumulation, pollinator decline and habitat destruction for animals and birds [122-125].

12. Nanomaterials in Energy

A major accomplishment in the fields of energy supply, energy security and development, particularly in the production of renewable energy, is the use of nanotechnologies to produce efficiency that grows with decreasing size while also being environmentally friendly and cost-effective. Solar energy, wind energy, fusion and fission reactors, clean coal, hydrogen gas production, storage, shipping and transportation, fuel cells, numerous battery types are just a few of the areas where nanotechnology has proven useful. The cost of solar photovoltaic cells and solar cells is reduced via nanotechnology. Together with the photo-catalytic reduction of carbon dioxide to methanol, industrial photo conversion of water and light to produce hydrogen, redesigning long distance electrical energy transportation, developing nano based quantum conductors, power cables, super-conductors to reduce or eliminate current loss and thermal dropouts, improving the storage capacity and power efficiency of super-capacitors and batteries, hydrogen vessels and pressure tanks [126,127].

13. Nanomaterials in Defense

The interesting strength of nanostructure materials, which include mechanical and physical properties markedly superior to those of conventional grain materials, has been the main focus of recent developments in the research of these materials [128]. These nanoparticles produce the novel and improved properties. Numerous applications of engineering science are found in the military [129]. Nanoparticles utilized for microbic purposes, new types of pharmaceutical paper, helmet designs, light-weight army vehicles, intelligent or sensible coating, or aviation materials [130]. Nanoparticles used for soldier protection and hiding movement, which are attention-grabbing, are an example of those suitable for food storage, security material and counterfeiting safety [131].

Soldiers must wear protective materials such as coats, helmets, chemical or biological protecting consumer goods. Nylon, nomex and kevlar are the three major textile fibres that are frequently used in protective equipment for military personnel. Their distinct qualities like flame retardancy, great strength and antiballistic capabilities make them excellent for use by those in the defense industry and other highly technological applications. Since armour protection is one of the most crucial elements of survival. Nanomaterials are used in a variety of military applications [132], as described in Figure 11.

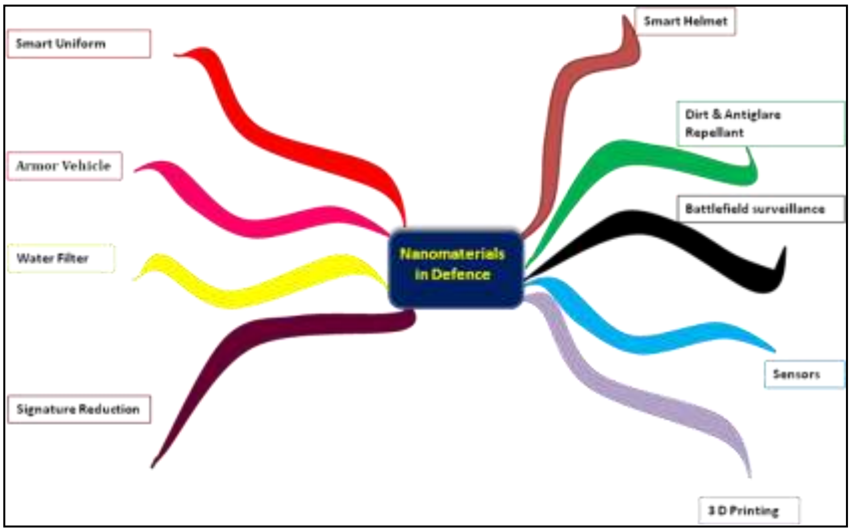


Fig. 11. Applications of nanomaterial in defense

13.1. Armour Vehicle

Military troops are regularly exposed to risks on land and sea. In addition to the ordinary vehicle fleet used as troop and supply transporters, the defense forces are given a broad variety of fighting vehicles, including as armoured vehicles, armoured deterring deliberate attacks. To guard against collisions with space junk, certain vessels have specialized armour. These vehicles are constructed to resist tough terrain while participating in operations. The level of armour protection differs for each vehicle depending on its intended use. Thanks to nanoparticles and nano fibre reinforced polymers, it is projected that the armoured tank will be forty to sixty percent lighter [133].

13.2. Sensible Uniform

With the study of nanomaterials, the idea of functional uniforms for soldiers has come back. For troops, these nanoparticles serve as fabrics that are mud, stress fire-resistant. These garments shield a trooper's body from external threats including bullets, grenade fragments, biological agents and chemicals while also providing insulation, ventilation and natural cooling. To create a suit with integrated chemical and biological sensors, a network of nanoparticles with fascinating, deactivating and decontaminating capabilities is being developed [134].

13.3. Water Filter

Nanomaterials are also used to purify potable water of impurities. With this technique, you may cheaply remove a great deal of harmful and polluting pollutants from water. For soldiers, it's a relatively cheap, simple and quite useful technique [135].

13.4. Helmet

One of the most important pieces of a soldier's combat gear is the helmet. In addition to the conventional materials of synthetic fibres like Kevlar and Aramid, which give greater protection against explosion shock waves and small arm fire, modern helmets frequently have the option to include a vision system and camera. Experts are striving to lighten the helmet in order to enhance trajectory performance. Due to their high strength, low weight and intelligent absorption properties, chemical compound nanoparticles were created as a potential replacement for constructing helmets [136].

13.5. 3D Printing

The number of uses for nanoparticles and 3D printing in the military is endless. Currently, bio-printing of tissues, implants, tooth replacement and prosthetic limbs research and development is progressing remarkably swiftly [137]. This involves printing electrical circuits for engine ports, radars, bridge components, small arms, artillery cannons and communication systems.

13.6. Battlefield Police Investigation

When deployed on the battlefield or behind enemy lines, nanosensors can be used to detect and identify one's own soldiers, aircraft, vehicles, and other assets. The target acquisition and fire guiding to the target functions of these battlefield sensor networks will be helpful. On-body sensors will convey information about the soldier’s physical condition, whereabouts, and psychological state while they are in the operational zone, aiding commanders in decision-making [138].

13.7. Antiglare and Dirt Repellent

Driving safely is essential, especially at night and in direct sunshine. The light penetrating property via the windscreen or windows may be adjusted by coating the window surface with nanometer-sized nanostructuring, which generates a refraction index gradient flowing from the outside to the inside. The light waves are essentially not reflected as a result. Additionally, it has been demonstrated that hollow silica nanoparticles have antiglare, anti-frost, anti-corrosive properties can prevent clear screens from fogging up. Additionally, this kind of aterial can be used to coat consoles, front and back windscreens and view mirrors [139-141].

14. Conclusion

One common kind of nanomaterials that has contributed in the development of nanotechnology is nanoparticles with various properties. Due to recent advancements in the properties of innovative nanomaterial’s and their applications, scientists are interested in such methods to produced their nanocomposites. This review article included a definition of nanotechnology and explained how nanomaterials are created. Nanomaterial’s have wide applications in different industries. Tiny sizes make them very important for all types of practical usage in industry. Industry uses nanoparticles to enhance the goods quality for customer’s satisfaction. The use of nanoparticles in the food industry increased food quality and gave it a wonderful aroma and flavor. Nanomaterials are used by the agriculture sector as agrochemicals, to make lands fertile and to reduce their toxicity. Nonmaterial's can be used in the textile industry to develop distinctive textiles with a variety of uses. By utilizing nanoparticles, the cosmetic industry can reduce the toxic effect of its products. These materials have been used in medical and pharmaceutical industries to prepare novel medications and better treatment substitute with the target of improving patient care. Many industries, like oil and gas, construction, defense, water and environmental based, energy and aerospace sectors, are also using nonmaterial's to enhance their goods and get over any obstacles they may face. Nanoparticles are used in the growth of industry because they can assist in minimizing the use of conventional materials by promoting the display of developed materials and reducing the use of energy. Nanomaterials amazing multifunctional characteristics have the potential to significantly alter the aviation industries operations. Nanotechnology has established itself as a crucial enabling innovation for a wide range of uses, turning into a major concern for the advancement of science and innovation strategies. It is now used in many aspects of the modern world, specifically in the areas of electronics, space, medical services, food, cosmetics, composites, and energy.

References

1. Buonsanti, Raffaella, and Nanfeng Zheng. "The Inorganic Chemistry of Nanoparticles." *Inorganic Chemistry* 60, no. 7 (2021): 4179-4181. https://doi.org/10.1021/acs.inorgchem.1c00681
2. Yanar F, Carugo C, Zhang X. "Nanocarrier-mediated cancer therapy with cisplatin: A meta-analysis with a promising new paradigm." *Molecules* 28 (2023):1-24.
3. Roy, Angira, Ciaran P. Healey, Nathaniel E. Larm, Piyuni Ishtaweera, Maryuri Roca, and Gary A. Baker. "The huge role of tiny impurities in nanoscale synthesis." ACS Nanoscience Au 4, no. 3 (2024): 176-193. https://doi.org/10.1021/acsnanoscienceau.3c00056
4. Faraday, Michael. "X. The Bakerian Lecture.—Experimental relations of gold (and other metals) to light." *Philosophical transactions of the Royal Society of London* 147 (1857): 145-181. https://doi.org/10.1098/rstl.1857.0011
5. Oliveira, Ana Elisa F., Arnaldo César Pereira, Mayra AC Resende, and Lucas Franco Ferreira. "Gold Nanoparticles: a didactic step-by-step of the synthesis using the turkevich method, mechanisms, and characterizations." Analytica 4, no. 2 (2023): 250-263. https://doi.org/10.3390/analytica4020020
6. Altammar, Khadijah A. "A review on nanoparticles: characteristiccs, synthesis, applications, and challenges." *Frontiers in microbiology* 14 (2023): 1155622. https://doi.org/10.3389/fmicb.2023.1155622
7. Joudeh, Nadeem, and Dirk Linke. "Nanoparticle classification, physicochemical properties, characterization, and applications: a comprehensive review for biologists." *Journal of Nanobiotechnology* 20, no. 1 (2022): 262. https://doi.org/10.1186/s12951-022-01477-8
8. Lombardo, Domenico, Mikhail A. Kiselev, and Maria Teresa Caccamo. "Smart nanoparticles for drug delivery application: development of versatile nanocarrier platforms in biotechnology and nanomedicine." *Journal of nanomaterials* 2019, no. 1 (2019): 3702518. https://doi.org/10.1155/2019/3702518
9. Ivanišević, Irena, Stjepan Milardović, and Petar Kassal. "Recent advances in (Bio) chemical sensors for food safety and quality based on silver nanomaterials." *Food technology and biotechnology* 59, no. 2 (2021): 216-237. https://doi.org/10.17113/ftb.59.02.21.6912
10. Boudaden, Jamila, Armin Klumpp, Hanns-Erik Endres, and Ignaz Eisele. "Towards low cost and low temperature capacitive CO2 sensors based on amine functionalized silica nanoparticles." *Nanomaterials* 9, no. 8 (2019): 1097. https://doi.org/10.3390/nano9081097
11. Alguacil, Francisco Jose. "Nanomaterials for CO2 Capture from Gas Streams." *Separations* 11, no. 1 (2023): 1. https://doi.org/10.3390/separations11010001
12. Joudeh, Nadeem, and Dirk Linke. "Nanoparticle classification, physicochemical properties, characterization, and applications: a comprehensive review for biologists." *Journal of Nanobiotechnology* 20, no. 1 (2022): 262. https://doi.org/10.1186/s12951-022-01477-8

13. Khonina, Svetlana N., Nikolay L. Kazanskiy, and Muhammad A. Butt. "Optical fibre-based sensors—An assessment of current innovations." *Biosensors* 13, no. 9 (2023): 835. https://doi.org/10.3390/bios13090835
14. Kirchner, Eva-Maria, and Thomas Hirsch. "Recent developments in carbon-based two-dimensional materials: synthesis and modification aspects for electrochemical sensors." *Microchimica Acta* 187, no. 8 (2020): 441. https://doi.org/10.1007/s00604-020-04415-3
15. Albu-Yaron, Ana, Sudarson S. Sinha, and Reshef Tenne. "Nanotubes from two-dimensional materials in contemporary energy research: historical and perspective outlook." *ACS Energy Letters* 5, no. 5 (2020): 1498-1511. https://doi.org/10.1021/acsenergylett.0c00185
16. Kour, Ravinder, Sandeep Arya, Sheng-Joue Young, Vinay Gupta, Pankaj Bandhoria, and Ajit Khosla. "Recent advances in carbon nanomaterials as electrochemical biosensors." *Journal of The Electrochemical Society* 167, no. 3 (2020): 037555. https://doi.org/10.1149/1945-7111/ab6bc4
17. Puente Santiago, Alain R., Olivia Fernandez-Delgado, Ashley Gomez, Md Ariful Ahsan, and Luis Echegoyen. "Fullerenes as key components for low-dimensional (photo) electrocatalytic nanohybrid materials." *Angewandte Chemie International Edition* 60, no. 1 (2021): 122-141. https://doi.org/10.1002/anie.202009449
18. Wang, Juan, Boxuan Li, Li Qiu, Xin Qiao, and Hu Yang. "Dendrimer-based drug delivery systems: History, challenges, and latest developments." *Journal of Biological Engineering* 16, no. 1 (2022): 18. https://doi.org/10.1186/s13036-022-00298-5
19. Santos, Ana, Francisco Veiga, and Ana Figueiras. "Dendrimers as pharmaceutical excipients: synthesis, properties, toxicity and biomedical applications." *Materials* 13, no. 1 (2019): 65. https://doi.org/10.3390/ma13010065
20. Parvizian, Mahsa, Julia Bechter, Jan Huber, Noura Chettata, and Jonathan De Roo. "An Experimental introduction to colloidal nanocrystals through InP and InP/ZnS quantum dots." *Journal of Chemical Education* 100, no. 4 (2023): 1613-1620. https://doi.org/10.1021/acs.jchemed.2c01167
21. Ebrahim, Fadia, Omar Al-Hartomy, and S. Wageh. "Cadmium-Based Quantum Dots Alloyed Structures: Synthesis, Properties, and Applications." *Materials* 16, no. 17 (2023): 5877. https://doi.org/10.3390/ma16175877
22. Alkholief, Musaed, Mohd Abul Kalam, Md Khalid Anwer, and Aws Alshamsan. "Effect of solvents, stabilizers and the concentration of stabilizers on the physical properties of poly (D, L-lactide-co-glycolide) nanoparticles: Encapsulation, in vitro release of indomethacin and cytotoxicity against HepG2-cell." *Pharmaceutics* 14, no. 4 (2022): 870. https://doi.org/10.3390/pharmaceutics14040870
23. Chen, Guanyu, and Jingyuan Wen. "Poly (lactic-co-glycolic acid) based double emulsion nanoparticle as a carrier system to deliver glutathione sublingually." *Journal of Biomedicine* 3 (2018): 50-59. https://doi.org/10.7150/jbm.27148
24. Domínguez-Delgado, Clara Luisa, Zubia Akhtar, Godfrey Awuah-Mensah, Braden Wu, and Hugh David Charles Smyth. "Effects of process and formulation parameters on submicron polymeric particles produced by a rapid emulsion-diffusion method." *Nanomaterials* 12, no. 2 (2022): 229. https://doi.org/10.3390/nano12020229
25. Pineda-Reyes, Ana María, Mauricio Hernández Delgado, María de la Luz Zambrano-Zaragoza, Gerardo Leyva-Gómez, Nestor Mendoza-Munoz, and David Quintanar-Guerrero. "Implementation of the emulsification-diffusion method by solvent displacement for polystyrene nanoparticles prepared from recycled material." *RSC advances* 11, no. 4 (2021): 2226-2234. https://doi.org/10.1039/D0RA07749F
26. Ortiz de Solorzano, Isabel, Laura Uson, Ane Larrea, Mario Miana, Victor Sebastian, and Manuel Arruebo. "Continuous synthesis of drug-loaded nanoparticles using microchannel emulsification and numerical modeling: effect of passive mixing." *International journal of nanomedicine* (2016): 3397-3416. https://doi.org/10.2147/IJN.S108812
27. Essa, Divesha, Pierre PD Kondiah, Yahya E. Choonara, and Viness Pillay. "The design of poly (lactide-co-glycolide) nanocarriers for medical applications." *Frontiers in bioengineering and biotechnology* 8 (2020): 48. https://doi.org/10.3389/fbioe.2020.00048
28. Pineda-Reyes, Ana María, Mauricio Hernández Delgado, María de la Luz Zambrano-Zaragoza, Gerardo Leyva-Gómez, Nestor Mendoza-Munoz, and David Quintanar-Guerrero. "Implementation of the

emulsification-diffusion method by solvent displacement for polystyrene nanoparticles prepared from recycled material." *RSC advances* 11, no. 4 (2021): 2226-2234. https://doi.org/10.1039/D0RA07749F
29. Alekhya, Amand, and Abbaraju Krishna Sailaja. "Formulation and evaluation of letrozole nanoparticles by salting out technique and determination of anti-cancer activity by MTT assay." *Nano Biomedicine and Engineering* 14, no. 3 (2022): 246-253. https://doi.org/10.5101/nbe.v14i3.p246-253
30. Nyabadza, Anesu, Éanna McCarthy, Mayur Makhesana, Saeid Heidarinassab, Anouk Plouze, Mercedes Vazquez, and Dermot Brabazon. "A review of physical, chemical and biological synthesis methods of bimetallic nanoparticles and applications in sensing, water treatment, biomedicine, catalysis and hydrogen storage." *Advances in Colloid and Interface Science* (2023): 103010. https://doi.org/10.1016/j.cis.2023.103010
31. Maslanka Figueroa, Sara, Daniel Fleischmann, Sebastian Beck, and Achim Goepferich. "Thermodynamic, spatial and methodological considerations for the manufacturing of therapeutic polymer nanoparticles." *Pharmaceutical research* 37 (2020): 1-11. https://doi.org/10.1007/s11095-020-2783-4
32. Plucinski, Alexander, Zan Lyu, and Bernhard VKJ Schmidt. "Polysaccharide nanoparticles: From fabrication to applications." *Journal of Materials Chemistry B* 9, no. 35 (2021): 7030-7062. https://doi.org/10.1039/D1TB00628B
33. Mourdikoudis, Stefanos, Roger M. Pallares, and Nguyen TK Thanh. "Characterization techniques for nanoparticles: comparison and complementarity upon studying nanoparticle properties." *Nanoscale* 10, no. 27 (2018): 12871-12934. https://doi.org/10.1039/C8NR02278J
34. Laborda, Francisco, Eduardo Bolea, Gemma Cepriá, María T. Gómez, María S. Jiménez, Josefina Pérez-Arantegui, and Juan R. Castillo. "Detection, characterization and quantification of inorganic engineered nanomaterials: A review of techniques and methodological approaches for the analysis of complex samples." *Analytica chimica acta* 904 (2016): 10-32. https://doi.org/10.1016/j.aca.2015.11.008
35. Joudeh, Nadeem, and Dirk Linke. "Nanoparticle classification, physicochemical properties, characterization, and applications: a comprehensive review for biologists." *Journal of Nanobiotechnology* 20, no. 1 (2022): 262. https://doi.org/10.1186/s12951-022-01477-8
36. Isahak, Wan Nor Roslam Wan, and Ahmed Al-Amiery. "Catalysts driving efficiency and innovation in thermal reactions: A comprehensive review." *Green Technologies and Sustainability* (2024): 100078. https://doi.org/10.1016/j.grets.2024.100078
37. Kumah, Elizabeth Adjoa, Raoul Djou Fopa, Saeed Harati, Paul Boadu, Fatemeh Vida Zohoori, and Tannaz Pak. "Human and environmental impacts of nanoparticles: a scoping review of the current literature." *BMC Public Health* 23, no. 1 (2023): 1059. https://doi.org/10.1186/s12889-023-15958-4
38. Mandari, Venkatesh, and Santhosh Kumar Devarai. "Biodiesel production using homogeneous, heterogeneous, and enzyme catalysts via transesterification and esterification reactions: A critical review." *BioEnergy Research* 15, no. 2 (2022): 935-961. https://doi.org/10.1007/s12155-021-10333-w
39. Agista, Madhan Nur, Kun Guo, and Zhixin Yu. "A state-of-the-art review of nanoparticles application in petroleum with a focus on enhanced oil recovery." *Applied sciences* 8, no. 6 (2018): 871. https://doi.org/10.3390/app8060871
40. Guo K, Hansen VF, Li HL, Yu Z X. "In-situ and ex-situ catalytic upgrading of heavy crude oil." *Fuel* 211 (2018):697–703. https://doi.org/10.1016/j.fuel.2017.09.097
41. Alsaba, Mortadha T., Mohammed F. Al Dushaishi, and Ahmed K. Abbas. "A comprehensive review of nanoparticles applications in the oil and gas industry." *Journal of Petroleum Exploration and Production Technology* 10, no. 4 (2020): 1389-1399. https://doi.org/10.1007/s13202-019-00825-z
42. Sadegh Rajabi, M., Rasoul Moradi, and H. Pirouz Kavehpour. "An overview of nanotechnology in upstream and downstream of oil and gas industry: challenges and solutions." *Journal of Energy Resources Technology* 144, no. 8 (2022): 080801. https://doi.org/10.1115/1.4052913
43. Afolabi, Richard O., and Esther O. Yusuf. "Nanotechnology and global energy demand: challenges and prospects for a paradigm shift in the oil and gas industry." *Journal of Petroleum Exploration and Production Technology* 9, no. 2 (2019): 1423-1441. https://doi.org/10.1007/s13202-018-0538-0

44. Alsaba, Mortadha T., Mohammed F. Al Dushaishi, and Ahmed K. Abbas. "A comprehensive review of nanoparticles applications in the oil and gas industry." *Journal of Petroleum Exploration and Production Technology* 10, no. 4 (2020): 1389-1399. https://doi.org/10.1007/s13202-019-00825-z
45. Fu, Lipei, Kaili Liao, Bo Tang, Lujun Jiang, and Weiqiu Huang. "Applications of graphene and Its derivatives in the upstream oil and gas industry: a systematic review." *Nanomaterials* 10, no. 6 (2020): 1013. https://doi.org/10.3390/nano10061013
46. Khan, Nazia Rodoshi, and Adib Bin Rashid. "Carbon-Based Nanomaterials: A paradigm shift in biofuel synthesis and processing for a sustainable energy future." *Energy Conversion and Management: X* (2024): 100590. https://doi.org/10.1016/j.ecmx.2024.100590
47. Zhe, Zhang, and An Yuxiu. "Nanotechnology for the oil and gas industry–an overview of recent progress." *Nanotechnology Reviews* 7, no. 4 (2018): 341-353. https://doi.org/10.1515/ntrev-2018-0061
48. Shaikh, Salman, Mudasir Yaqoob, and Poonam Aggarwal. "An overview of biodegradable packaging in food industry." *Current Research in Food Science* 4 (2021): 503-520. https://doi.org/10.1016/j.crfs.2021.07.005
49. Huang, Yukun, Lei Mei, Xianggui Chen, and Qin Wang. "Recent developments in food packaging based on nanomaterials." *Nanomaterials* 8, no. 10 (2018): 830. https://doi.org/10.3390/nano8100830
50. Dodero, Andrea, Andrea Escher, Simone Bertucci, Maila Castellano, and Paola Lova. "Intelligent packaging for real-time monitoring of food-quality: Current and future developments." *Applied Sciences* 11, no. 8 (2021): 3532. https://doi.org/10.3390/app11083532
51. Abekoon, Thilina, B. L. S. K. Buthpitiya, Hirushan Sajindra, E. R. J. Samarakoon, J. A. D. C. A. Jayakody, Komali Kantamaneni, and Upaka Rathnayake. "A comprehensive review to evaluate the synergy of intelligent food packaging with modern food technology and artificial intelligence field." *Discover Sustainability* 5, no. 1 (2024): 160. https://doi.org/10.1007/s43621-024-00371-7
52. Ali, Fayaz, Imran Khan, Jianmin Chen, Kalsoom Akhtar, Esraa M. Bakhsh, and Sher Bahadar Khan. "Emerging fabrication strategies of hydrogels and its applications." *Gels* 8, no. 4 (2022): 205. https://doi.org/10.3390/gels8040205
53. Lu, Peilin, Dongxue Ruan, Meiqi Huang, Mi Tian, Kangshun Zhu, Ziqi Gan, and Zecong Xiao. "Harnessing the potential of hydrogels for advanced therapeutic applications: Current achievements and future directions." *Signal transduction and targeted therapy* 9, no. 1 (2024): 166. https://doi.org/10.1038/s41392-024-01852-x
54. Osmólska, Emilia, Monika Stoma, and Agnieszka Starek-Wójcicka. "Application of biosensors, sensors, and tags in intelligent packaging used for food products—A review." *Sensors* 22, no. 24 (2022): 9956. https://doi.org/10.3390/s22249956
55. Drago, Emanuela, Roberta Campardelli, Margherita Pettinato, and Patrizia Perego. "Innovations in smart packaging concepts for food: An extensive review." *Foods* 9, no. 11 (2020): 1628. https://doi.org/10.3390/foods9111628
56. Chaudhary, Pallavi, Faria Fatima, and Ankur Kumar. "Relevance of nanomaterials in food packaging and its advanced future prospects." *Journal of inorganic and organometallic polymers and materials* 30, no. 12 (2020): 5180-5192. https://doi.org/10.1007/s10904-020-01674-8
57. Czerwiński, Krzysztof, Tomasz Rydzkowski, Jolanta Wróblewska-Krepsztul, and Vijay Kumar Thakur. "Towards impact of modified atmosphere packaging (MAP) on shelf-life of polymer-film-packed food products: Challenges and sustainable developments." *Coatings* 11, no. 12 (2021): 1504. https://doi.org/10.3390/coatings11121504
58. Fadiji, Tobi, Mahdi Rashvand, Michael O. Daramola, and Samuel A. Iwarere. "A review on antimicrobial packaging for extending the shelf life of food." *Processes* 11, no. 2 (2023): 590. https://doi.org/10.3390/pr11020590
59. Suvarna, Vasanti, Arya Nair, Rashmi Mallya, Tabassum Khan, and Abdelwahab Omri. "Antimicrobial nanomaterials for food packaging." *Antibiotics* 11, no. 6 (2022): 729. https://doi.org/10.3390/antibiotics11060729
60. Duda-Chodak, Aleksandra, Tomasz Tarko, and Katarzyna Petka-Poniatowska. "Antimicrobial compounds in food packaging." *International Journal of Molecular Sciences* 24, no. 3 (2023): 2457. https://doi.org/10.3390/ijms24032457

61. Moshood, Taofeeq D., Gusman Nawanir, Fatimah Mahmud, Fazeeda Mohamad, Mohd Hanafiah Ahmad, and Airin AbdulGhani. "Sustainability of biodegradable plastics: New problem or solution to solve the global plastic pollution?." *Current Research in Green and Sustainable Chemistry* 5 (2022): 100273. https://doi.org/10.1016/j.crgsc.2022.100273
62. Kibria, Md Golam, Nahid Imtiaz Masuk, Rafat Safayet, Huy Quoc Nguyen, and Monjur Mourshed. "Plastic waste: challenges and opportunities to mitigate pollution and effective management." *International Journal of Environmental Research* 17, no. 1 (2023): 20. https://doi.org/10.1007/s41742-023-00507-z
63. Kumar, Rakesh, Anurag Verma, Arkajyoti Shome, Rama Sinha, Srishti Sinha, Prakash Kumar Jha, Ritesh Kumar et al. "Impacts of plastic pollution on ecosystem services, sustainable development goals, and need to focus on circular economy and policy interventions." *Sustainability* 13, no. 17 (2021): 9963. https://doi.org/10.3390/su13179963
64. Mangal, Mangal, Chebrolu Venkateswara Rao, and Tamal Banerjee. "Bioplastic: an eco-friendly alternative to non-biodegradable plastic." *Polymer International* 72, no. 11 (2023): 984-996. https://doi.org/10.1002/pi.6555
65. Ncube, Lindani Koketso, Albert Uchenna Ude, Enoch Nifise Ogunmuyiwa, Rozli Zulkifli, and Isaac Nongwe Beas. "An overview of plastic waste generation and management in food packaging industries." *Recycling* 6, no. 1 (2021): 12. https://doi.org/10.3390/recycling6010012
66. Singh A, Suki M, Sharma R, Ingle P. Applications of Nanotechnology: A Review. *Int J Adv Res Chem Sci* 7 (2020):16-32.
67. Egirani, Davidson E., Nabila Shehata, and Mohamed H. Khedr. "A review of nano materials in agriculture and allied sectors: Preparation, characterization, applications, opportunities, and challenges." *Materials International* 2, no. 3 (2020): 0421-32. https://doi.org/10.33263/Materials23.421432
68. Seevakan, K., and B. Sheeba. "Applications of nanotechnology and nanomaterials in construction." *International Journal of Pure and Applied Mathematics* 119, no. 12 (2018): 6275-6286.
69. Abdalla, Jamal A., Rami A. Hawileh, A. Bahurudeen, V. Jittin, KI Syed Ahmed Kabeer, and B. S. Thomas. "Influence of synthesized nanomaterials in the strength and durability of cementitious composites." *Case Studies in Construction Materials* 18 (2023): e02197. https://doi.org/10.1016/j.cscm.2023.e02197
70. Raj, R. Samuvel, G. Prince Arulraj, N. Anand, Balamurali Kanagaraj, Eva Lubloy, and M. Z. Naser. "Nanomaterials in geopolymer composites: A review." *Developments in the Built Environment* 13 (2023): 100114. https://doi.org/10.1016/j.dibe.2022.100114
71. Du, Sen, Junliang Wu, Othman AlShareedah, and Xianming Shi. "Nanotechnology in cement-based materials: A review of durability, modeling, and advanced characterization." *Nanomaterials* 9, no. 9 (2019): 1213. https://doi.org/10.3390/nano9091213
72. Wang, Chuangye, Wenjing Zhao, Huixin Jiang, Mengyu Cui, Yu Jin, Ruixue Sun, Xufeng Lin, and Longli Zhang. "Molybdenum disulfide composite materials with encapsulated copper nanoparticles as hydrogen evolution catalysts." *RSC advances* 12, no. 21 (2022): 13393-13400. https://doi.org/10.1039/D2RA02012B
73. Zhang, Jialu, Cheng Shen, and Guangfen Diao. "Application and microstructure properties of nanomaterials in new concrete materials." *Journal of Nanomaterials* 2022, no. 1 (2022): 7396295. https://doi.org/10.1155/2022/7396295
74. Dahlan, Ammar Sadik. "Smart and functional materials based nanomaterials in construction styles in nano-architecture." *Silicon* 11 (2019): 1949-1953. https://doi.org/10.1007/s12633-018-0015-x
75. Jung, Yu-Jin, and Sung-Hwan Jang. "Crack Detection of Reinforced Concrete Structure Using Smart Skin." *Nanomaterials* 14, no. 7 (2024): 632. https://doi.org/10.3390/nano14070632
76. Huseien, Ghasan Fahim. "Potential applications of core-shell nanoparticles in construction industry revisited." *Applied Nano* 4, no. 2 (2023): 75-114. https://doi.org/10.3390/applnano4020006
77. Thammadi, Swetha Priya Darshini, and Sateesh Kumar Pisini. "Nanotechnology and building construction: Towards effective stakeholder engagement." In *IOP Conference Series: Earth and Environmental Science*, vol. 1084, no. 1, p. 012074. IOP Publishing, 2022. https://doi.org/10.1088/1755-1315/1084/1/012074

78. Saleem, Haleema, Syed Javaid Zaidi, and Nasser Abdullah Alnuaimi. "Recent advancements in the nanomaterial application in concrete and its ecological impact." *Materials* 14, no. 21 (2021): 6387. https://doi.org/10.3390/ma14216387
79. Malik, Shiza, Khalid Muhammad, and Yasir Waheed. "Emerging applications of nanotechnology in healthcare and medicine." *Molecules* 28, no. 18 (2023): 6624. https://doi.org/10.3390/molecules28186624
80. Kong, Xiangyi, Peng Gao, Jing Wang, Yi Fang, and Kuo Chu Hwang. "Advances of medical nanorobots for future cancer treatments." *Journal of Hematology & Oncology* 16, no. 1 (2023): 74. https://doi.org/10.1186/s13045-023-01463-z
81. Rezaei, Razieh, Mohsen Safaei, Hamid Reza Mozaffari, Hedaiat Moradpoor, Sara Karami, Amin Golshah, Behroz Salimi, and Hossein Karami. "The role of nanomaterials in the treatment of diseases and their effects on the immune system." *Open access Macedonian journal of medical sciences* 7, no. 11 (2019): 1884. https://doi.org/10.3889/oamjms.2019.486
82. Malik, Shiza, Khalid Muhammad, and Yasir Waheed. "Nanotechnology: A revolution in modern industry." *Molecules* 28, no. 2 (2023): 661. https://doi.org/10.3390/molecules28020661
83. Moshed, Abu Mohammad Azmal, Mohammad Khairul Islam Sarkar, and Md Abdul Khaleque. "The application of nanotechnology in medical sciences: new horizon of treatment." *Am. J. Biomed. Sci* 9, no. 1 (2017): 1-14. https://doi.org/10.5099/aj170100001
84. Sharma, Anjali, Pooja Agarwal, Zahra Sebghatollahi, and Neelima Mahato. "Functional Nanostructured Materials in the Cosmetics Industry: A Review." *ChemEngineering* 7, no. 4 (2023): 66. https://doi.org/10.3390/chemengineering7040066
85. Sharma, Anjali, Pooja Agarwal, Zahra Sebghatollahi, and Neelima Mahato. "Functional Nanostructured Materials in the Cosmetics Industry: A Review." *ChemEngineering* 7, no. 4 (2023): 66. https://doi.org/10.3390/chemengineering7040066
86. Kaul, Shreya, Neha Gulati, Deepali Verma, Siddhartha Mukherjee, and Upendra Nagaich. "Role of nanotechnology in cosmeceuticals: a review of recent advances." *Journal of pharmaceutics* 2018, no. 1 (2018): 3420204. https://doi.org/10.1155/2018/3420204
87. Preeti, Sharda Sambhakar, Rohit Malik, Saurabh Bhatia, Ahmed Al Harrasi, Chanchal Rani, Renu Saharan, Suresh Kumar, Geeta, and Renu Sehrawat. "Nanoemulsion: an emerging novel technology for improving the bioavailability of drugs." *Scientifica* 2023, no. 1 (2023): 6640103. https://doi.org/10.1155/2023/6640103
88. Nsairat, Hamdi, Dima Khater, Usama Sayed, Fadwa Odeh, Abeer Al Bawab, and Walhan Alshaer. "Liposomes: Structure, composition, types, and clinical applications." *Heliyon* 8, no. 5 (2022). https://doi.org/10.1016/j.heliyon.2022.e09394
89. Akombaetwa, Nakamwi, Ange B. Ilangala, Lorraine Thom, Patrick B. Memvanga, Bwalya Angel Witika, and Aristote B. Buya. "Current advances in lipid nanosystems intended for topical and transdermal drug delivery applications." *Pharmaceutics* 15, no. 2 (2023): 656. https://doi.org/10.3390/pharmaceutics15020656
90. Zoabi, Amani, Elka Touitou, and Katherine Margulis. "Recent advances in nanomaterials for dermal and transdermal applications." *Colloids and Interfaces* 5, no. 1 (2021): 18. https://doi.org/10.3390/colloids5010018
91. Akombaetwa, Nakamwi, Ange B. Ilangala, Lorraine Thom, Patrick B. Memvanga, Bwalya Angel Witika, and Aristote B. Buya. "Current advances in lipid nanosystems intended for topical and transdermal drug delivery applications." *Pharmaceutics* 15, no. 2 (2023): 656. https://doi.org/10.3390/pharmaceutics15020656
92. Zoabi, Amani, Elka Touitou, and Katherine Margulis. "Recent advances in nanomaterials for dermal and transdermal applications." *Colloids and Interfaces* 5, no. 1 (2021): 18. https://doi.org/10.3390/colloids5010018
93. Zhou, Hong, Dan Luo, Dan Chen, Xi Tan, Xichen Bai, Zhi Liu, Xiangliang Yang, and Wei Liu. "Current advances of nanocarrier technology-based active cosmetic ingredients for beauty applications." *Clinical, Cosmetic and Investigational Dermatology* (2021): 867-887. https://doi.org/10.2147/CCID.S313429
94. Deng, Siyuan, Maria Rosa Gigliobianco, Roberta Censi, and Piera Di Martino. "Polymeric nanocapsules as nanotechnological alternative for drug delivery system: current status, challenges and opportunities." *Nanomaterials* 10, no. 5 (2020): 847. https://doi.org/10.3390/nano10050847
95. Siddique, Jamal Akhter, Fahad Mabood Husain, and Manisha Singh. "Nanoemulsions: Current trends in skin-care products." In *Nanotechnology for the Preparation of Cosmetics Using Plant-Based Extracts*, pp. 49-73. Elsevier, 2022. https://doi.org/10.1016/B978-0-12-822967-5.00005-9

96. Ashfaq, Rabia, Akhtar Rasul, Sajid Asghar, Anita Kovács, Szilvia Berkó, and Mária Budai-Szűcs. "Lipid Nanoparticles: An Effective Tool to Improve the Bioavailability of Nutraceuticals." *International Journal of Molecular Sciences* 24, no. 21 (2023): 15764. https://doi.org/10.3390/ijms242115764
97. Mehta, Meenu, Thuy Anh Bui, Xinpu Yang, Yagiz Aksoy, Ewa M. Goldys, and Wei Deng. "Lipid-based nanoparticles for drug/gene delivery: An overview of the production techniques and difficulties encountered in their industrial development." *ACS Materials Au* 3, no. 6 (2023): 600-619. https://doi.org/10.1021/acsmaterialsau.3c00032
98. Pyo, Sung Min, Martina Meinke, Cornelia M. Keck, and Rainer H. Müller. "Rutin—increased antioxidant activity and skin penetration by nanocrystal technology (smartCrystals)." *Cosmetics* 3, no. 1 (2016): 9. https://doi.org/10.3390/cosmetics3010009
99. Awan, Fatima, Muhammad Shahidul Islam, Yeyu Ma, Cindy Yang, Zengqian Shi, Richard M. Berry, and Kam C. Tam. "Cellulose nanocrystal–ZnO nanohybrids for controlling photocatalytic activity and UV protection in cosmetic formulation." *ACS omega* 3, no. 10 (2018): 12403-12411. https://doi.org/10.1021/acsomega.8b01881
100. Fytianos, Georgios, Abbas Rahdar, and George Z. Kyzas. "Nanomaterials in cosmetics: Recent updates." *Nanomaterials* 10, no. 5 (2020): 979. https://doi.org/10.3390/nano10050979
101. Muzzalupo, Rita, and Elisabetta Mazzotta. "Do niosomes have a place in the field of drug delivery?." *Expert opinion on drug delivery* 16, no. 11 (2019): 1145-1147. https://doi.org/10.1080/17425247.2019.1663821
102. Asif, A. K. M. A. H., and Md Zayedul Hasan. "Application of nanotechnology in modern textiles: A review." *International Journal of Current Engineering and Technology* 8, no. 2 (2018): 227-231. https://doi.org/10.14741/ijcet/v.8.2.5
103. Choi, Yongho, Sang-Duk Lee, and Shin Hwan Yoo. "Characteristics and application of nanomaterials on sportswear fabric." *International Journal of Applied Engineering Research* 6704 (2017): 6709.
104. Saleem, Haleema, and Syed Javaid Zaidi. "Sustainable use of nanomaterials in textiles and their environmental impact." *Materials* 13, no. 22 (2020): 5134. https://doi.org/10.3390/ma13225134
105. Sawhney, Amar Paul Singh, Brian Condon, Kanwar Vikas Singh, Su-Seng Pang, Guoqiang Li, and David Hui. "Modern applications of nanotechnology in textiles." *Textile Research Journal* 78, no. 8 (2008): 731-739. https://doi.org/10.1177/0040517508091066
106. Rai, Shivani, and Aditya Rai. "Nanotechnology-The secret of fifth industrial revolution and the future of next generation." *Nusantara Bioscience* 7, no. 2 (2015). https://doi.org/10.13057/nusbiosci/n070201
107. Prasad, Ram, Atanu Bhattacharyya, and Quang D. Nguyen. "Nanotechnology in sustainable agriculture: recent developments, challenges, and perspectives." *Frontiers in microbiology* 8 (2017): 1014. https://doi.org/10.3389/fmicb.2017.01014
108. Achari, Gauri A., and Meenal Kowshik. "Recent developments on nanotechnology in agriculture: plant mineral nutrition, health, and interactions with soil microflora." *Journal of agricultural and food chemistry* 66, no. 33 (2018): 8647-8661. https://doi.org/10.1021/acs.jafc.8b00691
109. Neme, Kumera, Ayman Nafady, Siraj Uddin, and Yetenayet B. Tola. "Application of nanotechnology in agriculture, postharvest loss reduction and food processing: food security implication and challenges." *Heliyon* 7, no. 12 (2021). https://doi.org/10.1016/j.heliyon.2021.e08539
110. Xu, Zhi Ping. "Material nanotechnology is sustaining modern agriculture." *ACS Agricultural Science & Technology* 2, no. 2 (2022): 232-239. https://doi.org/10.1021/acsagscitech.1c00204
111. Shang, Yifen, Md Kamrul Hasan, Golam Jalal Ahammed, Mengqi Li, Hanqin Yin, and Jie Zhou. "Applications of nanotechnology in plant growth and crop protection: a review." *Molecules* 24, no. 14 (2019): 2558. https://doi.org/10.3390/molecules24142558
112. Srivastava, Anup K., Atul Dev, and Surajit Karmakar. "Nanosensors and nanobiosensors in food and agriculture." *Environmental Chemistry Letters* 16 (2018): 161-182. https://doi.org/10.1007/s10311-017-0674-7
113. Li, Zheng, Tao Yu, Rajesh Paul, Jingyuan Fan, Yuming Yang, and Qingshan Wei. "Agricultural nanodiagnostics for plant diseases: recent advances and challenges." *Nanoscale Advances* 2, no. 8 (2020): 3083-3094. https://doi.org/10.1039/C9NA00724E

114. Saritha, Golla Nagaraju Gari, Thattantavide Anju, and Ajay Kumar. "Nanotechnology-Big impact: How nanotechnology is changing the future of agriculture?." *Journal of Agriculture and Food Research* 10 (2022): 100457. https://doi.org/10.1016/j.jafr.2022.100457
115. Singh, Rajesh Kumar, Debjeet Sharma, Shifali Choudhary, Hridesh Harsha Sarma, B. Venudevan, Songthat William Haokip, and Anshuman Lal. "The Key Benefits and Application of Nanotechnology in Agriculture." *International Journal of Environment and Climate Change* 13, no. 10 (2023): 3308-3314. https://doi.org/10.9734/ijecc/2023/v13i102998
116. Gupta, Renu, Tanushri Saxena, Neera Mehra, Rajni Arora, and Arunima Sahgal. "Nanopesticides: Promising Future in Sustainable Pest Management." *Journal of Advanced Applied Scientific Research* 5, no. 2 (2023). https://doi.org/10.46947/joaasr522023515
117. Thakur, Meenu, Bo Wang, and Madan L. Verma. "Development and applications of nanobiosensors for sustainable agricultural and food industries: Recent developments, challenges and perspectives." *Environmental Technology & Innovation* 26 (2022): 102371. https://doi.org/10.1016/j.eti.2022.102371
118. Miguel-Rojas, Cristina, and Alejandro Pérez-de-Luque. "Nanobiosensors and nanoformulations in agriculture: new advances and challenges for sustainable agriculture." *Emerging topics in life sciences* 7, no. 2 (2023): 229-238. https://doi.org/10.1042/ETLS20230070
119. Shawon, Zayed Bin Zakir, Md Enamul Hoque, and Shiplu Roy Chowdhury. "Nanosensors and nanobiosensors: Agricultural and food technology aspects." In *Nanofabrication for smart nanosensor applications*, pp. 135-161. Elsevier, 2020. https://doi.org/10.1016/B978-0-12-820702-4.00006-4
120. Liu, Mei, Arshad Khan, Zhifei Wang, Yuan Liu, Gaojian Yang, Yan Deng, and Nongyue He. "Aptasensors for pesticide detection." *Biosensors and Bioelectronics* 130 (2019): 174-184. https://doi.org/10.1016/j.bios.2019.01.006
121. Phopin, Kamonrat, and Tanawut Tantimongcolwat. "Pesticide aptasensors—state of the art and perspectives." *Sensors* 20, no. 23 (2020): 6809. https://doi.org/10.3390/s20236809
122. Manjunatha, R. L., Dhananjay Naik, and K. V. Usharani. "Nanotechnology application in agriculture: A review." *Journal of Pharmacognosy and Phytochemistry* 8, no. 3 (2019): 1073-1083.
123. Alvarado, Katherine, Mónica Bolaños, Carmen Camacho, and Elías Quesada. "Nanobiotechnology in agricultural sector: overview and novel applications." (2019). https://doi.org/10.4236/jbnb.2019.102007
124. Kah, Melanie, Rai Singh Kookana, Alexander Gogos, and Thomas Daniel Bucheli. "A critical evaluation of nanopesticides and nanofertilizers against their conventional analogues." *Nature nanotechnology* 13, no. 8 (2018): 677-684. https://doi.org/10.1038/s41565-018-0131-1
125. Camara, Marcela Candido, Estefânia Vangelie Ramos Campos, Renata Aparecida Monteiro, Anderson do Espirito Santo Pereira, Patrícia Luiza de Freitas Proença, and Leonardo Fernandes Fraceto. "Development of stimuli-responsive nano-based pesticides: emerging opportunities for agriculture." *Journal of nanobiotechnology* 17 (2019): 1-19. https://doi.org/10.1186/s12951-019-0533-8
126. Li, Lingxiangyu, Zhenlan Xu, Melanie Kah, Daohui Lin, and Juliane Filser. "Nanopesticides: A comprehensive assessment of environmental risk is needed before widespread agricultural application." (2019): 7923-7924. https://doi.org/10.1021/acs.est.9b03146
127. Pandey, Garima. "Nanotechnology for achieving green-economy through sustainable energy." *Rasayan J Chem* 11, no. 3 (2018): 942-950. https://doi.org/10.31788/RJC.2018.1133031
128. Kumaş, Kazım, and Ali Özhan Akyüz. "An overview on the use of nanotechnology in the renewable energy field." *International Journal of Energy Applications and Technologies* 7, no. 4 (2020): 143-148. https://doi.org/10.31593/ijeat.764240
129. Pandey, Garima. "Nanotechnology for achieving green-economy through sustainable energy." *Rasayan J Chem* 11, no. 3 (2018): 942-950. https://doi.org/10.31788/RJC.2018.1133031
130. Sharma, Manjula, and Vimal Sharma. "Chemical, mechanical, and thermal expansion properties of a carbon nanotube-reinforced aluminum nanocomposite." *International Journal of Minerals, Metallurgy, and Materials* 23 (2016): 222-233. https://doi.org/10.1007/s12613-016-1230-3
131. Soni, Asmith K., and Roshan K. Jha. "Nanotechnology's Applications and Potential in Various Fields." *Cureus* 16, no. 4 (2024). https://doi.org/10.7759/cureus.59234

132. Rathod, Vivek T., Jayanth S. Kumar, and Anjana Jain. "Polymer and ceramic nanocomposites for aerospace applications." *Applied Nanoscience* 7 (2017): 519-548. https://doi.org/10.1007/s13204-017-0592-9
133. Biswas, Rahul, Mahabub Alam, Animesh Sarkar, Md Ismail Haque, Md Moinul Hasan, and Mominul Hoque. "Application of nanotechnology in food: processing, preservation, packaging and safety assessment." *Heliyon* 8, no. 11 (2022). https://doi.org/10.1016/j.heliyon.2022.e11795
134. Bhattacharjee, Shovon, Rakesh Joshi, Abrar Ahmad Chughtai, and Chandini Raina Macintyre. "Graphene modified multifunctional personal protective clothing." *Advanced materials interfaces* 6, no. 21 (2019): 1900622. https://doi.org/10.1002/admi.201900622
135. Tsirogiannis, Evangelos Ch, Evangelos Daskalakis, Mohamed H. Hassan, Abdalla M. Omar, and Paulo Bartolo. "Ballistic design and testing of a composite armour reinforced by CNTs suitable for armoured vehicles." *Defense Technology* 32 (2024): 173-195. https://doi.org/10.1016/j.dt.2023.04.013
136. Selim, Mohamed S., Sherif A. El-Safty, Mohamed A. Shenashen, and Ahmed Elmarakbi. "Advances in polymer/inorganic nanocomposite fabrics for lightweight and high-strength armor and ballistic-proof materials." *Chemical Engineering Journal* (2024): 152422. https://doi.org/10.1016/j.cej.2024.152422
137. Roy, Arpita, Apoorva Sharma, Saanya Yadav, Leta Tesfaye Jule, and Ramaswamy Krishnaraj. "Nanomaterials for remediation of environmental pollutants." *Bioinorganic Chemistry and Applications* 2021, no. 1 (2021): 1764647. https://doi.org/10.1155/2021/1764647
138. Hu, Qian-ran, Xing-yu Shen, Xin-ming Qian, Guang-yan Huang, and Meng-qi Yuan. "The personal protective equipment (PPE) based on individual combat: A systematic review and trend analysis." *Defense Technology* 28 (2023): 195-221. https://doi.org/10.1016/j.dt.2022.12.007
139. Jain, Keerti, Rahul Shukla, Awesh Yadav, Rewati Raman Ujjwal, and Swaran Jeet Singh Flora. "3D printing in development of nanomedicines." *Nanomaterials* 11, no. 2 (2021): 420. https://doi.org/10.3390/nano11020420
140. Pragadeswaran, S., S. Madhumitha, and S. Gopinath. "Certain investigation on military applications of wireless sensor network." *International Journal of Advanced Research in Science, Communication and Technology* 3, no. 1 (2021): 14-19. https://doi.org/10.48175/IJARSCT-819
141. Zhang, Ruicong, Zhibo Zhang, Jiecai Han, Lei Yang, Jiajun Li, Zicheng Song, Tianyu Wang, and Jiaqi Zhu. "Advanced liquid crystal-based switchable optical devices for light protection applications: principles and strategies." *Light: Science & Applications* 12, no. 1 (2023): 11. https://doi.org/10.1038/s41377-022-01032-y