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A Review on Green Synthesized Metal Nanoparticles Applications

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ABSTRACT

Nanotechnology pertains to the manipulation of materials at exceedingly small scales, specifically between 1 and 100 nanometers. Materials at this scale exhibit significantly different properties compared to the same materials at larger scales. An emerging trend is the utilization of nanoparticles (NPs) to address environmental issues. Metallic nanoparticles are among the several nanoparticles that are extensively utilized in environmentally sustainable endeavors. A sustainable, economical, and enduring approach is to synthesize nanoparticles through a more ecologically friendly procedure instead of a physical or chemical method. Plant components primarily function as reducing and capping agents in eco-friendly synthesis. Diverse metallic nanoparticles of various sizes and shapes have been created utilizing extracts from plant materials, including leaves, bark, fruits, and flowers. The synthesis of Nobel laureate metal nanoparticles is essential to the medical sector. A diverse array of glycosides and phenolic compounds constitutes numerous organic constituents in plants, facilitating the synthesis of metal nanoparticles. The absence of detrimental by-products in metal nanoparticle synthesis is the primary significance of green synthesis. The nanoparticles generated by an eco-friendly approach demonstrate several significant biological activity. A substantial body of literature demonstrates that the synthesized nanoparticles are efficacious against both gram-positive and gram-negative bacteria, including *E. coli*, *Bacillus subtilis*, *Klebsiella pneumoniae*, and *Pseudomonas fluorescens*. The synthesized nanoparticles not only display antifungal efficacy against several cancer cell lines, including those of breast cancer, but also demonstrate antifungal activity against *Trichophyton simii*, *Trichophyton mentagrophytes*, and *Trichophyton rubrum*. Moreover, they exhibit potent antioxidant properties. The dimensions and morphology of these metal nanoparticles substantially influence their functionalities. Particles characterized by a large surface area and diminutive size provide significant potential for medical applications. This paper aims to provide a comprehensive summary of current advancements in the synthesis of nanoparticles utilizing biological entities and their numerous potential applications.

Keywords- Metal nanoparticles, Green synthesis, nanotechnology.

I. INTRODUCTION

In recent years, nanotechnology has become a transformative force in all scientific fields. A functional material or device measuring between 1 and 100 nanometers (nm) is classified within nanotechnology, which includes the scientific and engineering processes related to its design, synthesis, characterization, manipulation, and application[1]. Nanoscale materials possess characteristics such as melting temperature, charge capacity, tensile strength, and other specific properties. The applications of nanotechnology in biomedical, healthcare, drug delivery, environmental, electronic, magnetic, space science, sensor, energy storage and conversion, among others, have significantly expanded over the past several decades, as has the number of industrial research and development firms effectively utilizing nanotechnology in their domains.

The emerging discipline of nanobiotechnology has led to the development of many nanobiomaterials with potential applications in biology and medicine. Regrettably, the majority of techniques for synthesizing these nanoparticles are costly and potentially detrimental to biological systems, human health, and the environment due to the utilization of hazardous substances. This is notwithstanding their potential antimicrobial properties. Consequently, environmentally friendly technologies for nanoparticle synthesis have been devised. This method employs biological systems such as yeast, fungi, bacteria, and plant extracts as a safer and more environmentally sustainable alternative to chemical approaches, avoiding the usage of hazardous compounds. Numerous factors contribute to the popularity of plant extracts. These encompass extensive and readily accessible reserves, global distribution capability, safe handling, a diverse array of metabolites with significant reduction potential, and minimal energy and waste requirements[2].

In the field of nanoparticles, a novel terminology has arisen in recent years: metallic nanoparticles. Metallic nanoparticles are produced utilizing noble metals with beneficial health properties, including gold, silver, and platinum. Researchers are currently focusing on the synthesis of metal nanoparticles, nanostructures, and nanomaterials due to their significant properties advantageous for catalysis, composite polymer formulations, disease diagnosis and treatment, sensor technology, and the labeling of optoelectronic media. Nanoparticles exist in several forms, with metallic and non-metallic types being the most prevalent and widely recognized[3]. Prominent metallic and metal oxide nanoparticles include cobalt, titanium, aluminum oxide, copper, silver, gold, palladium, magnesium, manganese oxide, platinum, zinc oxide, magnetite, and cerium dioxide; notable non-metallic nanoparticles comprise carbon, silicon, nitric oxide, chitosan, fullerenes, and graphene oxide nanoparticles. The remarkable properties of metal nanoparticles, stemming from their high surface-to-volume ratio and metal-specific behaviors at the nanoscale, have prompted substantial scientific research and examination[4].

II. CLASSIFICATION OF NANOPARTICLES

The detrimental effects of physical and chemical methods can be mitigated through the eco-friendly synthesis of nanoparticles using diverse biological agents. Certain approaches entail synthesizing nanoparticles in a regulated environment characterized by low pH, pressure, and temperature; others exclude the use of potentially hazardous substances; and some do not require the addition of external agents for reduction, capping, or stabilization of the nanoparticles. Recent studies have enumerated nanoparticles (NPs) composed of metal, metal oxide, or dioxide[5]. These encompass core/shell (CS) nanoparticles, nanoparticles coated with polymers, silver nanoparticles (Ag-NPs), copper nanoparticles (Cu-NPs), copper oxide nanoparticles (CuO-NPs), zinc oxide nanoparticles (ZnO-NPs), gold nanoparticles (Au-NPs), nanoparticles of platinum (Pt), palladium (Pd), silicon (Si), nickel (Ni), iron oxide nanoparticles (FeO-NPs), titanium dioxide nanoparticles (TiO_2-NPs), and zirconium dioxide nanoparticles (ZrO_2-NPs). Each of these nanoparticles possesses distinct features and applications. Fig 1 illustrates the categorization of NPs according to their characteristics.

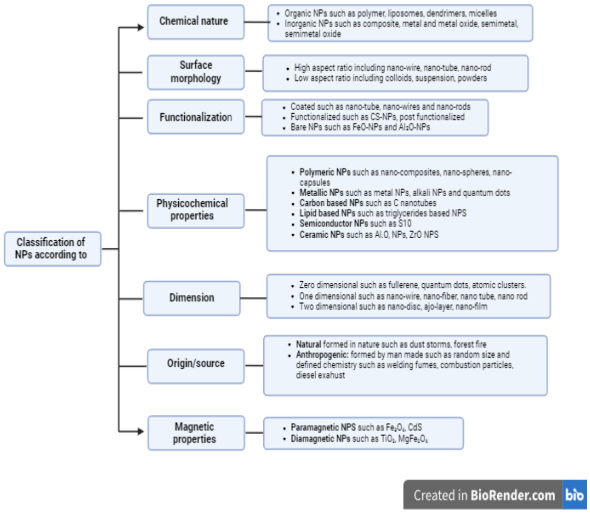

Fig.1: Classification of NPs from different approaches

2.1. Characterization of green metal nanoparticles:

Characterization is a crucial phase in nanotechnology development as it yields information regarding the particles' dimensions, morphology, composition, and synthesis methods. Multiple microscopy techniques, including atomic force microscopy (AFM), scanning electron microscopy (SEM), transmission electron microscopy (TEM), and confocal laser scanning microscopy (CLSM), are employed to analyze the produced nanoparticles. These techniques elucidate information regarding the nanomaterials' dimensions, morphology, and crystalline structure [6]. Magnetic techniques and other methods are more specialized for particular categories of materials. Examples of these methods include SQUID, VSM, FMR, and XMCD. A multitude of supplementary techniques elucidate the optical characteristics, elemental content, structure, and many general and specialized physical properties of the nanoparticle samples. Examples of these methods include scattering, X-ray analysis, and spectroscopy. Characterizing the microstructure and dispersion (dimensions and spatial distribution) of nanoparticles in relation to various process parameters is essential for optimizing the material properties of magnetic nanoparticles [7]. The absorption and scattering of light by a substance can be quantified by UV/visible spectroscopy. Given the sensitivity of the optical characteristics of gold and silver plasmonic nanoparticles to factors such as size, shape, concentration, aggregation state, and the refractive index near the nanoparticle surface, ultraviolet/visible spectroscopy serves as an essential instrument for the detection, characterization, and analysis of these nanoparticles.passage electron microscopy is a high-magnification imaging technique that captures the passage of an electron beam through a substance. The utilization of transmission electron microscopy (TEM) imaging is the definitive method for directly evaluating nanoparticle morphology, size distribution, grain size, and particle dimensions [8].

2.2. Approaches of synthesis of nanoparticles

There are two primary approaches to synthesizing nanoparticles: the top-down method and the bottom-up method. Furthermore, nanoparticle synthesis employs three separate methodologies: physical, chemical, and biological. Fig 2 presents a schematic representation of the various methods employed for the synthesis of nanoparticles and their corresponding uses [9].

Techniques like mechanical milling/alloying and sputtering diminish particle size to the nanoscale, accomplishing the requisite bulk of materials by top-down processes. The surface structure of a material is vital to its surface chemistry and physical properties; thus, this technique may result in surface flaws, imposing significant limitations. The synthesis of nanoparticles by physical processes exemplifies a top-down approach, while techniques utilizing chemicals and biological means represent bottom-up approaches. Physical methods include evaporation-condensation, electrolysis, diffusion, laser ablation, sputter deposition, pyrolysis, plasma arcing, and high-intensity ball milling are frequently utilized in nanoparticle creation [10]. The primary disadvantages of these techniques are their elevated energy consumption, substantial operational costs, and restricted output rates. Synthesis employing bottom-up methodologies, including co-precipitation, sol-gel, and atomic condensation, initiate with the self-assembly of molecules or atoms into nuclei, subsequently progressing to the formation of nanoscale particles. The production strategies in bottom-up synthesis mostly rely on biological and chemical principles. Conversely, the predominant and conventional methods for synthesizing metallic nanoparticles include chemical reduction, micro-emulsion/colloidal synthesis, electrochemical synthesis, and heat degradation. The chemical reduction of nanoparticles from their respective metal salt precursors, achieved by the addition of appropriate reducing agents, is a commonly employed approach for nanoparticle synthesis due to its minimal operational and equipment demands. The synthesis has examined various reducing and stabilizing agents, such as sodium borohydride ($NaBH_4$), potassium bitartrate, formaldehyde, methoxypolyethylene glycol, and hydrazine. Chemical methods, while economically advantageous for mass manufacturing, possess restricted applicability in biomedical and therapeutic domains owing to their environmental repercussions stemming from harmful chemical usage and the generation of hazardous by-products [11].

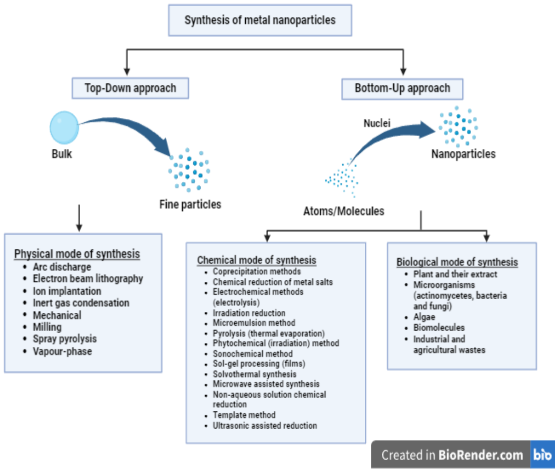

Fig. 2: Various method employed for the synthesis of nanoparticles

2.3. Green Synthesis of NPs

Biosynthetic nanoparticles, commonly referred to as green nanoparticles, can be synthesized via a diverse array of resources, including plants and their derivatives, algae, fungi, yeast, bacteria, and viruses. This technique facilitates the synthesis of nanoparticles at moderate temperatures, pH levels, and pressures, and it is significantly more economical than traditional synthesis methods. Noble metal salt precursors are combined with biomaterials to initiate the synthesis of nanoparticles [12]. Biomaterials comprise several compounds that promote the formation of nanoparticles from their metal salt precursors, including proteins, alkaloids, flavonoids, reducing sugars, polyphenols, and others. Observing the color change of the colloidal solution is an effective initial step in confirming the reduction of the metal salt precursor to its subsequent nanoparticles [13]. Recent investigations have elucidated the synthesis of Ag, Au, Cu, Pt, Cd, Pd, Ru, Rh, and other metals using various biological agents. An illustration of a bottom-up technique is the green synthesis of nanoparticles, which entails biomolecules such as enzymes, proteins, polysaccharides, and carbohydrates secreting metallic ions for oxidation or reduction, leading to the production of nanoparticles [14]. Our understanding of how bacteria create nanoparticles remains limited because various types of microorganisms interact with metal ions in distinct manners. Nanoparticles can be synthesized either intracellularly or extracellularly, contingent upon the type of microorganism. Scientific studies on the biological creation of nanoparticles have utilized extracts from living cells. Subsequently, we will present a comprehensive summary of the predominant biological mechanisms for NP production [15].

2.4. Plant-mediated NPs biosynthesis

A diverse array of bioactive phytochemicals exists in plants. The capacity of different plant parts to produce nanoparticles of various shapes differs [16]. The capacity to synthesize nanoparticles of the many morphologies enumerated in Table 1 is ascribed to the distinct phytochemicals present in plant extracts derived from seeds, leaves, barks, roots, and fruits. Additional reducing or surface stabilizing agents are unnecessary, as phytochemicals have a dual purpose. Three distinct solvents water, methanol, and ethanol may be employed to prepare the extract [17]. Water is the preferred solvent because of its accessibility and environmental safety. The selection criteria for a plant part are determined by its specific type. The bio-reduction of metal ions to synthesize metallic nanoparticles entails the involvement of active biomolecules, including terpenoids, polyphenols, sugars, alkaloids, phenolics, and proteins. Researchers have investigated the potential for producing a diverse array of nanoparticles utilizing various plant components [18].

Researchers in plant-based nanoparticle biosynthesis predominantly focus on utilizing plant extracts or specific plant compounds, as this method is more straightforward than whole plant biosynthesis. This method offers enhanced control and versatility, increased yield, simplified isolation, and improved scalability [19]. Numerous methods, such as hot/cold extraction, Soxhlet extraction, and the application of diverse solvents, exist for the extraction of phytochemicals. The efficacy of metal reduction and the capping and stability of nanoparticles is contingent upon the molecular composition of the extract. The specific roles of particular compounds in plant extracts are still ambiguous due to their considerable complexity and heterogeneity [20]. Molecules with hydroxyl, carbonyl, amino, or methoxide functional groups participate in the reduction of metal ions. These groups engage in electrostatic interactions with metal ions and subsequently undergo a reduction process. Plant components, including alkaloids, flavonoids, polyphenols, enzymes, cofactors, and secondary metabolites, are integral to the process [21].

2.4.1. Leaf extract-mediated synthesis

The synthesis of metallic nanoparticles with diverse functions has widely employed leaf extract. The synthesis of cylindrical AgNPs has been recorded utilizing Tropaeolum majus leaf extracts in both methanolic and aqueous solutions. This extract comprises reducing phytochemicals, tannins, terpenoids, flavonoids, and cardiac glycosides [22]. Nonetheless, the extract of parsley leaves was determined to include the flavonoids apigenin, quercetin, oxypeucedanin hydrate, cosmosiin, and apiin, which were utilized in the synthesis of AuNPs. The leaf extract of Solanum lycopersicum contains phytochemicals suitable for the synthesis of flower-shaped FeO nanoparticles [23]. The phytochemicals comprised alcohols, phenols, carboxylic acids, alkanes, aldehydes, aromatics, and aliphatic amines. Moreover, it has been recorded that the phytochemicals present in Psidium guajava leaf extract can generate several metallic nanoparticles, including tin, titanium oxide (TiO_2), zero-valent iron (ZVI), zinc oxide (ZnO), spherical-shaped gold (Au), silver (Ag), copper (Cu), copper oxide (CuO), tin, and titanium dioxide (TiO_2) [24]. The extract possesses a high concentration of phytochemicals, including triterpenoids, glycosides, flavonoids, and essential oils. Origanum majorana has demonstrated the presence of volatile bioactive compounds that may be utilized in the production of CeO2 nanoparticles. Synthesis of silver nanoparticles with leaf extracts of Piper nigrum, Ziziphus spinachristi, and Eucalyptus globules [25].

2.4.2. Bark and stem extract-mediated synthesis

The manufacture of metallic nanoparticles also utilizes extracts from bark and stem segments. The stem bark of Elaeodendron croceum includes flavonoids and terpenoids that facilitate the conversion of Ag ions to AgNPs [26]. The stability of the nanoparticles was achieved by the carbonyl-amine and acid groups of the protein moieties. Graphene oxide (GO) functionalized with silver nanoparticles (AgNPs) has been produced utilizing flavonoids and protein components derived from *Catharanthus roseus* bark. The production of AuNPs has utilized O-dihydroxy compounds and other oxidizable materials present in Abroma augusta bark extract. Organic constituents of *Tecoma stans* (L.) flower, bark, and leaf extract have been utilized to synthesize MgO nanoparticles [27].

2.4.3. Fruits and flowers

Reports indicate that flowers and fruits serve as excellent reducing agents in the creation of nanoparticles. The principal components in the synthesis of AuNPs from the fruit extracts of *Litsea cubeba* (LC) and *Mimusops elengi* were alkaloids, flavonoids, lignans, and steroids [28]. The synthesis of AgNPs and AuNPs by the ultrasound-assisted method was attributed to the flavonoids, kaempferol, and anthocyanin found in the *Clitoria ternatea* flower extract. Flavonoids in jasmine flower extract were utilized to synthesize AgNPs [29]. Gold nanoparticles, measuring between 50 and 150 nm

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and exhibiting various shapes (triangular, hexagonal, spherical), were manufactured utilizing flower extract from *Gnidia glauca*. Aqueous extracts of *Moringa oleifera* fruit pulp have been utilized to synthesize bimetallic nanoparticles of silver and copper. Evidence indicates that the alkaloids and flavonoids included in *Morinda citrifolia* L fruit extract are essential for the synthesis of CeO_2. Moreover, other plant compounds including flavonoids, triterpenoids, steroids, cardenolides, and alkaloids have been examined for the synthesis of FeO, CuO, and ZnO nanoparticles [30].

Table 1: Green synthesis of MNPs by different researchers using plant extracts.

MNPs	**Plant sources**	**Shape/Size**	**Experimental Conditions**	**References**
Palladium (Pd)	*Hippophae rhamnoides* Linn leaf	Quasi–spherical 3.6–9.9nm	Temperature: 80°C; duration: 25min	31
	Cinnamom zeylanicum bark extract	Spherical; 15–20nm	Temperature: 30°C; pH:1.0–11.0; duration:72h	32
	Banana peel extract	50nm	Temperature:40–100°C; pH:2.0–5.0; duration: 3min	33
	Catharanthus roseus leaf	spherical;38nm	Temperature: ambient; duration:12h	34
	Terminalia chebula fruit	2.5–14nm	Temperature:60°C; duration:2h	35
	Rosmarinus officinalis	Semi-spherical; 15–90nm	Temperature:ambient; duration:40min	36
	Anogeissus latifolia	Spherical; 2.3–7.5nm	Temperature: ambient; duration: 24h	37
Gold(Au)	*Cassia fistula* stem bark	Rectangular and triangular; 55.2–98.4nm	Temperature: ambient	38
	Crassocephalum rubens leaf	Spherical; 10–20nm	Temperature: 50°C; duration:10 min	39
	Simarouba glauca leaf	Spherical, rod polygonal, and triangular; 68nm	Temperature: 30–100°C; pH:2.0–12.0; duration: 15–60 min	40
	Hygrophila spinosa	Spherical; 20–50nm	Temperature:ambient	41
	Croton Caudatus Geisel leaf	Spherical; 20–50nm	Temperature:ambient; duration:15 min	42
	Moringa oleifera flower	Triangular, hexagonal, and spherical; 5nm	Temperature: ambient; duration:60 min	43
Silver(Ag)	*Acalypha indica* Linn	Spherical; 20–30nm	Temperature: 27°C; pH:7.0; duration:30 min	44
	Chenopodium album leaf	Spherical;10–30nm	Temperature: 20-100°C; pH: 2.0–10.0; duration:15min	45
	Hibiscus rosasinensis leaf	Spherical; 13nm	Temperature: 30 and 60 °C; pH: 3.0–9.0	46
	Calendula officinalis seed	Spherical; 2–10nm	Temperature: 60 °C; pH: 8.0; duration:6h	47
	Phyllanthus emblica fruit	Spherical; 16.29nm	Temperature: 65°C; duration:2h	48
Platinum (Pt)	*Anacardium occidentale* leaf	Irregular rod shaped	Temperature: ambient; pH: 6.0–8.0	49
	Cacumen platycladi	Spherical; 2–2.9nm	Temperature: 30–90 °C; duration:25h	50
	Diopyros kaki leaf	Spherical and plate;2–20nm	Temperature: 25–95°C	51
	Ocimum sanctum leaf	Rectangular and triangular; 23nm	Temperature: 100°C; duration:1h	52
Copper (Cu)	*Mul berry* fruit (Morusal baL.)	Sphericalandnon–regular; 50-200nm	Temperature: ambient; duration:5h	53
	Crotalaria candicans leaf	Spherical; 5–20nm	Temperature:80 °C	54
	Clove (*Syzygium aromaticum*) buds	Spherical; 15–20nm	Temperature:30° C; duration:15min	55

Selenium (Se)	*Ocimum tenuiflorum*	Monodispersed and spherical; 15–20nm	Temperature: ambient; duration:75h	56
	Murraya koenigii	Spherical; 50–150 nm	Temperature: 30°C; duration: 5min	57
	Zinziber officinale fruit	Spherical; 100–150 nm	Temperature: ambient; pH:9.0; duration:75h	58
Iron(Fe)	Tea leaves extract	30–100 nm	Temperature: 80°C; duration:3h	59
	Moringa oleifera seeds	Spherical; 2.6–6.2 nm	Temperature: ambient; duration:30min	60
	Trigonellafoenum graecum seed	7–14 nm	Temperature: 30°C; duration: 5min	61

2.5. Microbial mediated NPs biosynthesis

Microorganisms may produce nanoparticles in a compact manufacturing environment using a safe, cost-effective, and eco-friendly method. These bacteria exhibit rapid growth, are readily cultivable, and may flourish under conditions of ambient temperature, pH, and pressure. They are both renewable and economical. Table 2 illustrates the documented biosynthesis of many nanoparticles, including gold, silver, uraninite, quantum dots, magnetite, selenium, lead, mercury, silicon dioxide, zirconium dioxide, yeast, viruses, and fungi. Biogenic nanoparticles have distinct forms, sizes, and crystallinities due to genetically regulated assembly. Reductases, naphthoquinones, flavonoids, and anthraquinones are microorganisms that convert metal ions to their nanoscale form. The electron shuttle or charge capping mechanism predominantly facilitates the reduction of metal ions, whereas enzymes, peptides, proteins, amino acids, and both aromatic and aliphatic compounds also contribute significantly. Potential drawbacks of microbial synthesis of nanoparticles include the necessity for specialized equipment for microbial cultivation, management, and maintenance; variability in product quality dependent on growth conditions; and biosafety concerns related to specific microbial strains [62].

2.5.1. Bacterial mediated synthesis of NPs

Bacteria are frequently utilized for the synthesis of inorganic particles via intracellular or extracellular mechanisms. Prokaryotic bacteria enable the creation of metal nanoparticles. The bacterial manufacture of nanoparticles is beneficial due to its minimal environmental requirements, simplicity in purification, high yield, and ease of handling [63]. Consequently, bacteria have become the most extensively researched microbes, referred to as "the factory of nanomaterials," and selected for the manufacture of nanoparticles.The production of nanoparticles, including Au and Ag nanoparticles, was effectively achieved by bacteria. While numerous different bacteria serve as Ag inhibitors and can accumulate Ag on their outer membranes, constituting around 25% of their entire mass, Ag is renowned for its biocidal properties, rendering it advantageous for the commercial extraction of Ag from ore minerals. Prokaryotic bacteria were demonstrated to be responsible for the synthesis of nanoparticles in the bacterial domain [64]. The primary novel metal nanoparticles (NPs) synthesized by the Ag-resistant bacteria Pseudomonas stutzeri in a highly concentrated AgNO3 media. Recent years have demonstrated the synthesis of Ag-NPs with sizes ranging from 43.52 to 142.97 nm utilizing *Bacillus thuringiensis*. The production of Ag-NPs utilized bacteria from the *Klebsiella pneumoniae*, *Morganella psychrotolerans*, and *Bacillus licheniformis* genera. In contrast, Lactobacillus sp. and Bacillus subtilis facilitated the creation of titanium dioxide nanoparticles. *Pseudomonas aeruginosa*, *Rhodopseudomonas capsulata*, *Bacillus subtilis*, *Bacillus licheniformis*, and *Escherichia coli* DH5α were utilized for the synthesis of gold nanoparticles, while *Rhodopseudomonas palustris*, *Clostridium thermoaceticum*, and Escherichia coli were previously utilized for the synthesis of cadmium nanoparticles. Bacteria possess numerous potential applications, including serving as biocatalysts in inorganic material creation, functioning as bioscaffolds in mineralization, and actively participating in nanoparticle synthesis [65]. Bacteria can synthesize nanomaterials in broth media during incubation, whether externally or intracellularly. The biosynthesis of nanoparticles by bacteria is a feasible, versatile, and efficient approach for industrial-scale manufacturing due to this phenomenon [66]. A summary of the dimensions and various applications of nanoparticles generated by multiple bacterial species is presented in Table 2. Bacteria were utilized in the synthesis of other metal nanoparticles, including CuNPs and CuONPs. Kaur *et al.*,(2015) documented the production of copper nanoparticles (CuNPs) using the supernatant derived from the cultivation of the marine bacterium Kocuria flava. In this study, the cell-free liquid was amalgamated with copper nitrate and incubated at 30 ◦C for a duration of one day. The experiment yielded CuNPs with an average size ranging from 5 to 30 nm, exhibiting spherical or quasi-spherical morphology. The biogenesis of spherical CuONPs, averaging 80 nm in size, was conducted using Endophytic Streptomyces sp. by mixing the aqueous biomass filtrate with $CuSO_4.5H_2O$ and thereafter incubating the mixture in the dark at 35 °C for 6 hours [67].

2.5.2. Fungi mediated synthesis of NPs

Fungal metabolites have high efficacy in the fabrication of diverse nanoparticles, resulting in their widespread application in fungal biosynthesis. Fungi are considered a valuable addition to the existing array of microorganisms employed in nanoparticle manufacturing. Certain fungal species have gained widespread application due to their simplicity of laboratory manipulation and their capacity to produce substantial amounts of proteins or enzymes [68]. There is significant interest in utilizing fungi for the synthesis of metallic nanoparticles due to its several advantages over other organisms. Key advantages to consider include the presence of mycelium, which enhances surface area, economic feasibility, and the ease of scaling up and downstream processing. Fungal organisms, due to their tolerance and ability to bioaccumulate metals, have garnered heightened interest as a model system for investigating the biological production of metallic nanomaterials. The capacity to customize nanoparticle sizes and shapes while attaining a high degree of monodispersion is a benefit of fungus-mediated synthesis.

Like fungi, which are regarded as valuable for the synthesis of metal nanoparticles, bacteria contain fungi that exhibit superior load-bearing capacity, metal aggregation potential, and connectivity. In the laboratory, it is significantly simpler to work with than bacteria. The production of fungal natural products involves intricate mechanisms; for instance, fungi secrete several enzymes that can decrease silver ions, marking the initial phase of the synthesis process. Primary production in various scientific fields transpires both extracellularly and intracellularly; for instance, specific fungus, including *Aspergillus sp*. and Penicillium, exhibit a tendency to synthesize silver and gold nanoparticles.The environmentally sustainable method utilizes *Aspergillus niger*, *Fusarium solani*, and Aspergillus oryzae to manufacture silver nanoparticles through an extracellular mechanism. The fungal species Pleurotus sajor-caju can produce natural products via an extracellular method [69]. Trichoderma *viride* was employed to synthesize the nanoparticles having a spherical morphology. Stabilized silver hydrosol is generated by incorporating Ag ions into *Fusarium oxysporum*. Researchers evaluated the antibacterial activity of Ag NPs generated from *Phoma glomerata* against *Staphylococcus aureus* and *Escherichia coli*.

2.5.3. Yeast mediated synthesis of NPs

Yeast was considered a promising contender for semiconductor manufacture among eukaryotic bacteria. Following the application of a thiolate complex to mitigate the detrimental effects of metals, Candida glabrata synthesized 20Å monodispersed cadmium-sulfur quantum crystals [70]. The cadmium-sulfur nanoparticles synthesized by fission yeast exhibited a size range of 1-1.5 nm and were hexagonally structured. Research by Kowshik et al. indicates that MKY3 is a silver-resistant yeast that, when subjected to soluble silver during its development phase, precipitates nanoparticles ranging from 2 to 10 nm, encompassing nearly all of the silver present [71]. The researcher utilizes an innovative method using the varied thawing of the material to separate NPs. Rhodosporidium diobovatum, an aquatic yeast, was employed to synthesize Pd sulfide nanoparticles via an intracellular approach [72].

Metal lothionein and phytochelatins can generate nanoparticles, while glutathione and other metal-binding ligands enable yeast to withstand metal exposure [73]. Yeast can efficiently manufacture metal nanoparticles in substantial quantities. The designation "semiconductor crystal" was assigned to the yeast strain Candida glabrata due to its application in the synthesis of CdS nanocrystals, which served as quantum semiconductor crystallites. To date, there is no evidence that their metabolism utilizes nanoparticles [74]. The yeast-mediated synthesis of nanoparticles is a cellular detoxifying approach. Yeast synthesis occurs in two forms: intracellular and extracellular. The production of green nanoparticles employs various yeast strains, each characterized by distinct morphology, dimensions, and major applications, as illustrated in Table 2 [75].

2.5.4. Algae mediated synthesis of NPs

Algae are a collective term that refers to a wide variety of organisms that exhibit attributes that are similar to those of plants, such as the ability to perform photosynthesis. In the presence of solar light, algae nanoparticles (NPs) are now able to generate their nutrients, which comes with the additional benefit of releasing oxygen as a byproduct [76]. Certain algae, such as Chlorella Sp., have been found to have a tendency to accumulate large quantities of heavy metals, such as cadmium, copper, and nickel, according to the findings of recently conducted research [77]. The unicellular algae Chlorella vulgaris is said to possess antioxidant and anti-cancer properties, according to a rumour. Methods for the production of gold nanoparticles utilising *Sargassum wightii* outside of cells were also investigated [78].

Both the economy and the ecology are significantly impacted by algae, which are eukaryotic organisms that play a significant role. They are excellent for use as green biofactories in nanotechnology due to their low toxicity, as well as their capacity to bioaccumulate and decrease metal residues [79]. Table 2 presents a selection of the many strains of algae that are utilised in the manufacturing of environmentally friendly nanoparticles. Pigments, polysaccharides, and peptides are examples of the types of biomolecules that may be found in algae. These biomolecules contain carboxyl, cysteine, hydroxyl, and amine functional groups, which are responsible for guiding the reduction of metal ions and the encapsulating of freshly created nanoparticles [80]. This information was obtained through FTIR study. The biological pathway that ultimately results in the formation of nanoparticles is kicked off by the adsorption of metal ions onto the surface of a galactose cell. The metal ions are synthesised either intracellularly or extracellularly by enzymatic machinery that involves the cytoplasm, thylakoid membranes, and organelle membranes. This occurs after the metal ions are introduced into the cell by transmembrane protein molecules or through diffusion [81].

Table 2: Synthesis of MNPs by different biological sources

Organism	Sources	Type of MNPs	Size (nm)	References
Fungi	*Aspergillus flavus*	Ag	8-10	82
	Fusarium oxysporum	Ag, Au	20-50	83
	Verticillium	Ag	1-15	84
	Trichoderma viride	Ag	10-40	85
	Fusarium solani	Ag	5-35	86
	Pleurotussajor-caju	Ag	5-50	87
	Aspergillus flavus	Ag	5-30	88
	Volvariella volvacea	Ag, Au	20-150	89
	Aspergillus niger	Ag	20	90
	Klebsiella pneumonia	Se	100-400	91
	Colletotrichum sp.	Au	20-40	92
	Phaenerochaete chrysosporium	Ag	5-200	93
Bacteria	*Streptomyces HBUM171191*	Zn, Mn	10-20	94
	Morganella specie	Ag	20-30	95
	Escherichia coli	CdS	2-5	96
	Bacillus Cereus	Ag	5	97
	Rhodopseudomonaz capsulata	Au	10-20	98
	Thermomonospora species	Au	8	99
	Pseudomonas aeruginosa	Au	15-30	100
	Pseudomonas stutzeri	Ag	5-200	101
Yeast	*Candida glabrata*	CdS	2	102
	Saccharomycetes.cerevisiae	Sb_2O_3	3-10	103
	Candida glabrata(Yeast)	CdS	3-100	104
	Yeast strain MKY3	Ag	2-5	105
	Schizosaccharomyces pombe	CdS	1-5	106
	Torulopsis sp.	PbS	2-5	107
Algae	*Gelidiella acerosa*	Ag	22	108
	Chlorella vulgaris	Au	40-60	109
	Caulerpa racemosa	Ag	5-25	110

2.6. Other application of metal nanoparticles

2.6.1. Application of Nanomaterials in the Field of Agriculture

Agriculture is the principal means by which food for humans and other animals, as well as other useful goods and the fundamental elements required in a variety of industries (for example, fibres, leathers, starch, xylan, and sugars) are generated. Agricultural activities are also the major means by which products are manufactured. Increases in agricultural productivity will be beneficial to other sectors of the economy [111]. The application of nanotechnology has been beneficial to a number of agricultural subfields. In recent years, nanomaterials have been utilised in farming in two primary ways: as nanofertilizers to raise crop yields or as nanopesticides to eliminate insects, illnesses, and weeds that impede plant development. Both of these applications have allowed for significant advancements in agricultural practices. In the following section, we will discuss the role that nanopesticides and nanofertilizers play in the larger context of contemporary farming [112].

2.6.2. Nanofertilizers

A number of factors, including the overuse and continued application of artificial fertilisers, the scarcity of water, and the diminishing fertility of the soil, all contribute to the decrease in crop yields and are therefore important concerns in the agricultural sector [113]. It is possible for nanofertilizers to improve nutrient efficiency, reduce soil toxicity, and minimise the adverse effects of chemical fertiliser overtreatment when they are applied in the appropriate manner.NPs, which include carbon nanotubes (CNTs), titanium dioxide (TiO2), and silicon dioxide (SiO2), are included in nanoparticulate nanofertilizers. Research has shown that a mixture of titanium dioxide and silicon dioxide, when sprayed to soybeans, increases plant growth, nitrogen fixation, and seed germination [114]. The green synthesis of non-toxic, affordable, and ecologically safe TiO2 from plant extracts of Syzgium cumini, Moringa oleifera, Cucurbita pepo, and Trigonella foenum has recently been the focus of several investigations due to the well-established utility of TiO2 nanoparticles in plant growth [115]. These studies have been conducted in recent times. The usage of nanoparticles (NPs) that are packed with micronutrients such as molybdenum (Mo), copper (Cu), iron (Fe), nickel (Ni), manganese (Mn), and zinc (Zn) is common in the field of micronutrient nano fertilisers. It has been demonstrated that a combination of three different micronutrient nanoparticles (NPs)—ZnO, CuO, and B2 O3—is efficient in reducing the effects of drought stress on soybean plants [116].

2.6.3. Nanopesticides

The term "nanopesticides" refers to a wide variety of products that mix organic polymers with inorganic components, such as metal oxides, in a variety of shapes (particles, micelles). In recent times, novel formulations of pesticides that contain nanoparticles have been created and put into use. When it comes to safeguarding crops from pests, insects, and phytopathogens, these metallic nanoparticles have proven to be extremely effective in a variety of countries around the world of agriculture [117]. The nanopesticide known as nanostructured alumina (NSA) is one type of nanopesticide that has found substantial application. Through a contact with the positively charged bodies of insects, the pesticide known as NSA, which has a negative charge, causes insects to lose water during their life cycle. When an insect's cuticles get detached from its body as a result of dryness, the insect dies. During the past few years, a number of different nanoparticles (NPs) have also been explored for their considerable insecticidal potential. Despite the fact that X. perforans is a prevalent pathogen that causes tomato spot disease, TiO2 and ZnO nanoparticles have an antibacterial activity against this organism. Numerous studies have demonstrated that imidacloprid (IMI) is both effective and safe for the environment when used against sucking insects such as Martianus dermestoides. Further enhancement of its efficacy is achieved through the utilisation of nano-IMI, which is more photodegradable [118].

2.6.4. Metal nanoparticles in Food Industry

MNPs are primarily utilised in agriculture and the food business for a variety of purposes, including but not limited to the following capabilities: nutritional absorption, targeted nutrient and bioactive chemical delivery, active ingredient stability, antibacterial action against foodborne pathogens, and enhancement of organoleptic properties table 3 [119]. A significant number of them are associated with novel packaging concepts that are able to extend the shelf life of items while maintaining their levels of quality. Using MNPs as sensors to evaluate the quality and safety of food is yet another application for these nanoparticles. Develop antimicrobial chemicals that have the ability to prevent the growth of bacteria and increase the amount of time that food can be stored [120]. One of the many ways that MNPs have the potential to eliminate bacteria is by inhibiting the formation of biofilms. This is only one of the many uses for MNPs. Develop packaging that is biodegradable, active, or smart, with improved protection against ultraviolet light and antimicrobial activity, enhanced thermal and hydrophobic properties (with reduced water vapour permeability), the ability to change the colour of the product, enhanced radical and oxygen scavenging activities, enhanced mechanical properties (with higher tensile strength, thinner films, more transparency, and improved barrier properties), and so on. There are four distinct types of functional nanomaterial-based improved food packaging: biochemically improved packaging (with improved biodegradability, edibility, biocompatibility, low-waste, and eco-friendly features); improved packaging with active functions (effect on packaged foods with regard to taste, freshness, and shelf life); and improved packaging with smart functions (e.g., nanosensors to monitor food conditions such as oxygen levels, freshness, and the presence of pathogens) [121]. However, in order to actively explore the development and applications of nanoparticles (NPs), there are hurdles that must be solved. These challenges are related to the performance of nanomaterials as well as their tendency to be harmful. When it comes to the food industry, having legislation that govern the production, utilisation, and disposal of nanomaterials is of the utmost importance [122]. An increase in public comprehension and acceptance of these advances is also necessary in order to facilitate the production of novel food and agricultural products that are made possible by nanotechnology [123-124].

Table 3: Applications of NPs/Nanotechnologies in various aspects of Food Science and Technology.

Application	MNPs	Function	References
	TiO2	Antimicrobial, coating in packaging material, detection of volatile compounds	125
	Nanoemulsion	Quality enhancement of beverages, sweeteners, and processed food	126
	Nanoencapsulation	Enhancement of taste, color, and odor of food	127

Food Production		materials	
	AgNPs, Ag–ZnONPs	Packaging of meat, fruit, and dairy products by AgNPs doped non degradable and edible polymers and oils; antimicrobial property	128
	Low-density polyethylene film + Ag, ZnO NPs, TiO_2, kaolin	Orange juice, blueberry, strawberry	129
	Ethylene vinyl alcohol + AgNPs	Chicken, pork, cheese, lettuce, apples, peels, eggshells	130
Food preservation and packaging	Polyvinylchloride + AgNPs	Minced beef	131
	Polyethylene + Ag, TiO2 NPs	Fresh apples, white sliced bread, fresh carrots, soft cheese, atmosphere packaging milk powder, fresh orange juice	132
	Nanoclay-polymer nanocomposites	Meats, cheese, confectionery, cereals, boil-in-the-bag foods, extrusion-coating applications for fruit juices and dairy products, bottles for beer and carbonated drinks	133
	Ag-ZnO NPs	Nanostorage containers, bakeware, containers, cutting boards	134
	ZnNPs	Preservation and transport	135
Food supplement and value addition	Colloidal metal nanoparticles	Enhanced uptake	136
	Cellulose nanocrystal composites	Drug carrier	137
	Nanocochleates	Drug delivery, enhancement of taste and color of food materials	138

2.6.5. Metal nanoparticles in medicine/Drugs Industry

In the past ten years, there has been a significant amount of attention paid to pharmaceuticals that are founded on nanotechnology. Because of its distinctive characteristics, which include its diminutive size and the capacity to navigate through fine blood capillaries, arteries, junctions, and obstacles, nanoparticles (NPs) have been one of the most extensively researched and investigated fields [139]. The usage of these substances significantly enhances the bioavailability, solubility, toxicity protection, pharmacological activity, distribution, and stability of drugs within the body, as well as their protection against chemical and physical degradation. The ability of nanomedicines to bind with biomolecules has been proved to be superior, in addition to their ability to reduce inflammation and oxidative stress in tissues. There are thousands of different nanomedicines that have been produced, and each one of them has the potential to treat a wide range of various diagnoses and conditions. Despite the fact that a great number of others are still in the research and development phase, only a fraction of them have been granted clinical approval.The application of nanomaterials in pharmaceuticals is a demonstration of the promise of nanotechnologies in the medical field. These technologies make it possible to implement cutting-edge molecular-level interventions in the treatment of illnesses [140].

2.7. Role of MNPs in disease

2.7.1. Anticancer:

With their ability to induce oxidative stress, gold nanoparticles offer anti-cancer properties. Through their role as photocatalysts, they convert incident light into heat, which is capable of killing cancer cells. Nanoparticles of gold that have a cationic charge and a diameter of two nanometres are toxic when administered at doses that are meaningful. Nanoparticles of gold that have not been oxidised are known to exist [141]. A decreased protein-to-protein ratio was observed for smaller nanoparticles (NPs) in comparison to larger ones. According to the findings of the researchers, Hela cervical cancer cells that were treated with gold nanoparticles created a greater amount of reactive oxygen species (ROS), which oxidised proteins, lipids, and other tissues. On the other hand, intravenous injection of big NPs (50-250 nm) demonstrated their distribution in the liver, spleen, and blood, in contrast to the extensive distribution of AuNPs of 10 nm size throughout organs. In order to produce PtNPs, hexachloro platinic acid is reduced with sodium borohydride while capping agents are present [142]. This process is known as the PtNP production process. The bioactivity of PtNPs that were capped with poly (vinyl pyrrolidone) and folic acid was investigated via the utilisation of cell lines that are available for commercial use. The cell viability studies revealed that PVP-capped nanoparticles exhibited a lower level of toxicity, with a viability rate of 80%. On the other hand, folic acid-capped PtNPs exhibited a reduction in viability of MCF7 breast cancer cells to 24% after 72 hours of exposure at a dosage of 100 µg/ml [143].

2.7.2. Acquired immunodeficiency syndrome (AIDS):

In the case of acquired immune deficiency syndrome (AIDS), it is common knowledge that the human immunodeficiency virus (HIV) is the causative agent. HIV is a lentivirus, which means that it multiplies slowly and causes the immune system to gradually collapse. As a result, patients who have HIV are more likely to get serious opportunistic infections, which might possibly result in death. Berry et al. (2007) demonstrated that biocompatible AuNPs of varied sizes that were functionalised with the HIV-1 tat integral protein transduction domains (PTD) were effective in the process of developing nuclear-targeting therapies. As a consequence of this, a human fibroblast cell line was utilised for the utilisation of functionalised AuNPs in in vitro testing. According to reports, the nanoparticles with a size of 5 nanometres are able to easily pass through the plasma membrane. On the other hand, larger nanoparticles, which are defined as those that are older than 30 nanometres, are found to be preserved in the cytoplasm. This suggests that the diameter of the nuclear pores acts as a barrier to entry. With the use of AuNPs that are 5 nm or smaller, the researchers who participated in this investigation came to the realisation that it is possible to administer AIDS medications.

2.7.3. Thrombolytics:

The formation of thrombosis in a vital blood vessel results in the establishment of a blockage in that channel, which in turn causes symptoms such as thrombosis.Dhandapani and Iyer demonstrated that nanoparticles derived from Cassia auriculata has a thrombolytic effect. Within a few forty-five minutes, the particles were able to disintegrate blood clots. Additionally, we have demonstrated that biosynthesised silver nanoparticles (AgNPs) generated from bacterial extracts, paper wasp nest, seed and leaf extracts of S. dulcificum (wonder fruit plant), kolanut cobweb, pod, seed and seed shell, P. alliacea leaf and crude enzyme are capable of successfully dissolving blood clots. This is in line with the findings of other laboratories [144].

In a similar manner, the manufacture of AuNPs using bacterial extract and crude xylanases proved to be effective as thrombolytic agents. Furthermore, after five minutes of the reaction, the biosynthesis of AuNPs using B. safensis bacterial extract was able to induce the breakdown of blood clots in therapy [145].

2.7.4. Antiviral Activities:

The medical, pharmaceutical, and biotechnology industries face a huge challenge in the form of viruses because they are one of the leading causes of illness and mortality among humans. There are a large range of infectious diseases and infections that are known to be caused by viruses [146]. Some of these diseases and infections include herpes keratitis, infectious mononucleosis, viral encephalitis, chickenpox, hepatitis, influenza, and the common cold. There is evidence to show that silver nanoparticles are efficient antiviral agents against a variety of virus families. These virus families include hepadnaviridae, retroviridae, poxviridae, paramyxoviridae, herpesviridae, arenaviridae, and orthomyxoviridae[147]. Furthermore, the risk of virus resistance to AgNPs is reduced when compared to the possibility of virus resistance to standard antiviral drugs. Through the formation of multivalent contacts with viral surface components and cell membrane receptors, the nanoparticles are able to prevent the entry of viruses into cells. Antiviral medications are able to achieve their immediate and direct action on viral particles by attaching themselves to the proteins that are located on the viral coat and so altering the structure or function of these proteins [148].

2.7.5. Wound Healing:

It has been established that metal nanoparticles, provided that they are utilised as individual conjugates, have the potential to cure wounds. As a result of their combination with other wound dressing materials, nanoparticles facilitate the exclusion of bacteria that, in the absence of nanoparticles, have the potential to disturb and delay the normal healing processes at the wound site. A study that was conducted not too long ago demonstrated that burn wounds that were treated topically with chitosan-capped AgNPs healed more rapidly, with less inflammation, and in a shorter amount of time. A great number of people have become interested in copper nanoparticles (CuNPs) due to their biocidal qualities and potential applications in industry. Additionally, CuNPs have been utilised in gas sensors, catalytic processes, solar cells, and high-temperature superconductors. In the field of antibiotics, copper nanoparticles (CuNPs) are beneficial due to their outstanding physicochemical features. In the realm of medicine, they are utilised as a bactericidal agent to cover heat transfer systems, antimicrobial materials, superstrong materials, sensors, and catalysts. This is due to the fact that they possess antibacterial capabilities and matrix stability [149].

Both Acinetobacter baumannii and Pseudomonas aeruginosa are the germs that are most frequently responsible for the development of burn infections. As a result of the rapid growth of antibiotic-resistant infections and the accompanying spread of biofilms, the hunt for novel antimicrobials has become an important concern [150]. As a consequence of this, the number of clinical studies aimed at producing antibacterial bandages is expanding at a rapid rate.The urgent need to combat drug-resistant microorganisms and provide cutting-edge antimicrobial coatings for surgical ulcer treatments led to the creation of a more environmentally friendly way of manufacturing Ag and ZnO nanoparticles. These nanoparticles were then used to manufacture clinical nanoparticle-based antimicrobial wound treatments [151].

2.7.6. Applications in Dentistry

As a result of their biocompatibility, huge surface volume, and nanostructures, gold nanoparticles (AuNPs) have been utilised in the treatment of gum issues, dental cavities, tissue engineering, dental implantology, and cancer detection [152]. Due to the fact that AuNPs possess antibacterial and antifungal capabilities, a number of biomaterials make use of them in order to enhance their effectiveness. In doing so, they improve the material's mechanical qualities, which ultimately results in improved outcomes [153]. For the purpose of demonstrating the therapeutic effects of these substances, they are offered in a variety of sizes and concentrations.The disruption of bacterial enzyme systems occurs when Zn2+ ions have the ability to replace magnesium ions, which are essential for the enzymatic activity of dental plaque [154].

2.8. Application in textile industry

In recent years, there has been an increase in the use of nanoparticles (NPs) in the textile industry. This is due to the fact that NPs are known to impart beneficial features to both the production process and the fabrics. The utilisation of silver nanoparticles has resulted in the enhancement of the antibacterial, self-cleaning, and ultraviolet (UV) blocking characteristics of final fabrics [155]. Additionally, ZnO-NPs are utilised in the textile industry for the purpose of enhancing UV locking and antibacterial qualities. The textile industry ought to make use of inorganic nanoparticles, which are capable of blocking UV radiation, rather than organic nanoparticles [156]. In point of fact, titanium dioxide (TiO2) and zinc oxide (ZnO) are the most widely used nanoparticles (NPs) due to their chemical stability and the fact that they do not become toxic when subjected to high temperatures and ultraviolet radiation. It is possible for functional thin-film coatings to make use of the optical properties of nanoparticles (NPs), particularly nanocomposite materials, by applying heat to nanocrystalline AgNPs and generating carbonaceous nanomaterials, for instance [157].

Ceramics and metal oxides are examples of nanoparticles that are utilised in the process of finishing textiles. These nanoparticles are used to alter surface features and impart beneficial textile functions. When compared to larger particles, nanosized particles have a greater surface area, which indicates that they have the potential to boost the effectiveness of the medicinal substance. Furthermore, nanoparticles are transparent and do not have any discernible effect on the saturation or translucency of the textile bases throughout the manufacturing process. Fabrics that have been treated with nanoparticles of titanium dioxide and magnesium oxide, for example, have the potential to replace those that have been treated with active carbon, which were previously used to protect against biological and chemical dangers. Because of their photocatalytic activity, nanoparticles of titanium dioxide and magnesium oxide have the ability to destroy biological agents and dangerous chemicals. In order for these nanoparticles to adhere to textile surfaces, they can be electrostatically or spray-coated in advance. Simply by applying nanoparticles to the surface of fabrics, it is possible to transform them into materials that may be utilised as sensors. Fabrics that incorporate nanocrystalline piezo-ceramic particles have the ability to convert mechanical stresses into electrical impulses. This enables the monitoring of many bodily functions, such as the rhythm of the heart and the pulse, through the use of materials that are worn close to the skin[158].

2.9. Application in Wastewater Treatment

Water is the most essential component for the continued existence of humans. There are three of the most serious challenges that are affecting human necessities in the present day: pollution, an inadequate supply of aquatic sustainable resources, and an excessive human population. The use of nanotechnology presents a novel approach to the problem of water scarcity and concerns over water quality[159]. Recent developments in nanotechnology have made it feasible to treat wastewater with higher efficiency, which has led to the production of water that is cleaner, safer, and free of heavy metals and other toxins. One of the many applications for nanomaterials is the removal of toxic metals, inorganic and organic pollutants, and disinfecting. Other applications include the detection of illnesses and the removal of harmful metals. The remediation of wastewater has been accomplished by the application of a variety of techniques, including chemical, biological, and physical transformations. However, for the time being, researchers are working to discover methods of water purification that are less expensive. The application of nanotechnology presents a novel strategy for the effective removal of contaminants from wastewater at the present moment. The development of many approaches that combine various NPs has resulted in the successful removal of contaminants from wastewater[160].

Nanoparticles of aluminium, silicon, silver, and iron oxide all play a significant role in the development of membranes, the most prevalent use of which is the treatment of wastewater. Researchers Keum and Li investigated the use of iron oxide nanoparticles (NPs) as a possible approach to the removal of PBDE from wastewater[161]. As a result of its high adsorption capacity, low toxicity, and low cost, zeolites nanomaterial has found applications in the field of environmental remediation. The majority of zeolites are capable of removing heavy metals from polluted water, including Zn^{2+}, Cu^{2+}, Ni^{2+}, and Pb^{2+}. Through the utilisation of NPs, it has been possible to successfully remove dye from industrial wastewater[162].

III. MAJOR CHALLENGES AND FUTURE PERSPECTIVE

At the moment, there is an abundance of research prospects that are appealing in the field of nanomedicine. Numerous research that have been carried out over the course of the past twenty years have led to the submission of about one thousand five hundred patents and the conclusion of dozens of clinical trials. There have been numerous recent applications in the field of biotechnology for metals and metal oxide nanoparticles that have been widely synthesised. Some of these applications include the domains of medicine, agriculture, industry, and pollution remediation. Using a wide variety of living organisms, the development of environmentally friendly NP synthesis is a significant component of biotechnology. In contrast to more conventional methods, green NP synthesis offers a multitude of advantages, including the fact that it is simple to produce, economical, safe for the environment, and simple to scale up. As a result of the green synthesis of NPs, the following are the primary problems that were discovered:

- It is necessary to conduct additional research on optimisation in order to synthesise a particular size and form utilising the green approach.
- In order to find the most effective method for producing nanoparticles (NPs) with the physicochemical qualities that are desired, particularly for usage in biomedicine, additional study is required.
- Additional study is required for the mechanical component that is utilised in the production of green NP.
- In order to determine the role that each chemical plays in the biofabrication of nanoparticles (NPs), it is important to carry out a thorough examination of the metabolites that are present in the filtrate of biological biomass.
- One more thing that stands in the way of its commercialisation is the need to increase the production of NP using ways that are less harmful to the environment.
- A number of optimisation parameters, including pH, salt concentration, contact duration, and temperature, were shown to be associated with the stability of nanoparticles that produced high yields. It is dependent on the biological entities that are employed as to which of these ingredients are utilised.
- It is necessary to optimise a number of reaction parameters in order to optimise the yield of NPs and their stability while also reducing the turnaround time.

IV. CONCLUSION

In this review, we will investigate the uses of metal nanoparticles (NPs) created from microbes and plants, as well as the green production of these NPs. When it comes to the production of metal nanoparticles (NPs), green synthesis methods provide an alternative to the conventional physical and chemical processes that are clean, non-toxic, and favourable to the environment respectively. It has been established that a wide variety of plant and microbial sources can be used to synthesise metal and metal oxide nanoparticles (NPs). Some examples of these nanoparticles include gold, silver, platinum, nickel, selenium, copper, copper oxide, and titanium dioxide. Several research were conducted to investigate the effects of MeNPs in vitro as diagnostic agents, antiparasites, anticoagulants, antioxidants, anticancer agents, larvicidal agents, anticoagulant agents, and thrombolytic agents. In spite of the fact that this variety offers a multitude of benefits in terms of the uniqueness and adaptability of the properties of the final nanoparticles, it also makes it challenging for scientists to identify all of the molecular mechanisms that are involved in the synthesis process, as well as to evaluate all of the characteristics and potential limitations of the nanoparticles. Due to the fact that metal nanoparticles are extremely effective against a wide variety of harmful human illnesses, including MRSA and other multidrug-resistant bacteria, nanoparticles hold a great deal of potential for usage in medical applications. Two other use cases that could be considered are the agriculture and food processing sectors combined. Because there is such a wide variety of applications for these extremely small particles, there is an immediate need for extensive research into the numerous ways in which nanoparticles interact with living organisms, both on a local and a global scale.

REFERENCES

[1] Bolade, O. P., Williams, A. B., & Benson, N. U. (2020). Green synthesis of iron-based nanomaterials for environmental remediation: A review. *Environmental Nanotechnology, Monitoring & Management*, *13*, 100279.

[2] Lim, N. R. E., Santos, G. N. C., Ubando, A. T., & Culaba, A. B. (2021, March). Nanotechnology in the Philippines: Development of framework for technology adoption. In *IOP Conference Series: Materials Science and Engineering* (Vol. 1109, No. 1, p. 012031). IOP Publishing.

[3] Dikshit, P. K., Kumar, J., Das, A. K., Sadhu, S., Sharma, S., Singh, S., ... & Kim, B. S. (2021). Green synthesis of metallic nanoparticles: Applications and limitations. *Catalysts*, *11*(8), 902.

[4] Uddandarao, P., Balakrishnan, R. M., Ashok, A., Swarup, S., & Sinha, P. (2019). Bioinspired ZnS: Gd nanoparticles synthesized from an endophytic fungi Aspergillus flavus for fluorescence-based metal detection. *Biomimetics*, *4*(1), 11.

[5] Shedbalkar, U., Singh, R., Wadhwani, S., Gaidhani, S., & Chopade, B. A. (2014). Microbial synthesis of gold nanoparticles: current status and future prospects. *Advances in colloid and interface science*, *209*, 40-48.

[6] Akl, B. A., Nader, M. M., & El-Saadony, M. T. (2020). Biosynthesis of silver nanoparticles by Serratia marcescens ssp sakuensis and its antibacterial application against some pathogenic bacteria. *Journal of Agricultural Chemistry and Biotechnology*, *11*(1), 1-8.

[7] Arora, S., Jain, J., Rajwade, J. M., & Paknikar, K. M. (2008). Cellular responses induced by silver nanoparticles: in vitro studies. *Toxicology letters*, *179*(2), 93-100.

[8] Aziz, N., Faraz, M., Pandey, R., Shakir, M., Fatma, T., Varma, A., ... & Prasad, R. (2015). Facile algae-derived route to biogenic silver nanoparticles: synthesis, antibacterial, and photocatalytic properties. *Langmuir*, *31*(42), 11605-11612.

[9] Balraj, B., Senthilkumar, N., Siva, C., Krithikadevi, R., Julie, A., Potheher, I. V., & Arulmozhi, M. (2017). Synthesis and characterization of zinc oxide nanoparticles using marine Streptomyces sp. with its investigations on anticancer and antibacterial activity. *Research on Chemical Intermediates*, *43*, 2367-2376.

[10] Brown, A. N., Smith, K., Samuels, T. A., Lu, J., Obare, S. O., & Scott, M. E. (2012). Nanoparticles functionalized with ampicillin destroy multiple-antibiotic-resistant isolates of Pseudomonas aeruginosa and Enterobacter aerogenes and methicillin-resistant Staphylococcus aureus. *Applied and environmental microbiology*, *78*(8), 2768-2774.

[11] Castro, L., Blázquez, M. L., González, F., Muñoz, J. Á., & Ballester, A. (2015). Biosynthesis of silver and platinum nanoparticles using orange peel extract: characterisation and applications. *IET nanobiotechnology*, *9*(5), 252-258.

[12] Cheloni, G., Marti, E., & Slaveykova, V. I. (2016). Interactive effects of copper oxide nanoparticles and light to green alga Chlamydomonas reinhardtii. *Aquatic Toxicology*, *170*, 120-128.

[13] Cinelli, M., Coles, S. R., Nadagouda, M. N., Błaszczyński, J., Słowiński, R., Varma, R. S., & Kirwan, K. (2015). A green chemistry-based classification model for the synthesis of silver nanoparticles. *Green Chemistry*, *17*(5), 2825-2839.

[14] Cui, Y., Zhao, Y., Tian, Y., Zhang, W., Lü, X., & Jiang, X. (2012). The molecular mechanism of action of bactericidal gold nanoparticles on Escherichia coli. *Biomaterials*, *33*(7), 2327-2333.

[15] DeAlba-Montero, I., Guajardo-Pacheco, J., Morales-Sánchez, E., Araujo-Martínez, R., Loredo-Becerra, G. M., Martínez-Castañón, G. A., ... & Compeán Jasso, M. E. (2017). Antimicrobial properties of copper nanoparticles and amino acid chelated copper nanoparticles produced by using a soya extract. *Bioinorganic chemistry and applications*, *2017*(1), 1064918.

[16] Dhar, S. A., Chowdhury, R. A., Das, S., Nahian, M. K., Islam, D., & Gafur, M. A. (2021). Plant-mediated green synthesis and characterization of silver nanoparticles using Phyllanthus emblica fruit extract. *Materials Today: Proceedings*, *42*, 1867-1871.

[17] Dikshit, P. K., Kumar, J., Das, A. K., Sadhu, S., Sharma, S., Singh, S., ... & Kim, B. S. (2021). Green synthesis of metallic nanoparticles: Applications and limitations. *Catalysts*, *11*(8), 902.

[18] Gupta, K., & Chundawat, T. S. (2019). Bio-inspired synthesis of platinum nanoparticles from fungus Fusarium oxysporum: its characteristics, potential antimicrobial, antioxidant and photocatalytic activities. *Materials Research Express*, *6*(10), 1050d6.

[19] YokeshBabu, M., JanakiDevi, V., Ramakritinan, C. M., Umarani, R., Nagarani, N., & Kumaraguru, A. K. (2013). Biosynthesis of silver nanoparticles from seaweed associated marine bacterium and its antimicrobial activity against UTI pathogens. *Int. J. Curr. Microbiol. Appl. Sci*, *2*(8), 155-168.

[20] Aseyd Nezhad, S., Es-haghi, A., & Tabrizi, M. H. (2020). Green synthesis of cerium oxide nanoparticle using Origanum majorana L. leaf extract, its characterization and biological activities. *Applied Organometallic Chemistry*, *34*(2), e5314.

[21] Yulizar, Y., Juliyanto, S., Apriandanu, D. O. B., & Surya, R. M. (2021). Novel sol-gel synthesis of CeO2 nanoparticles using Morinda citrifolia L. fruit extracts: structural and optical analysis. *Journal of Molecular Structure*, *1231*, 129904.

[22] El-Borady, O. M., Ayat, M. S., Shabrawy, M. A., & Millet, P. (2020). Green synthesis of gold nanoparticles using Parsley leaves extract and their applications as an alternative catalytic, antioxidant, anticancer, and antibacterial

agents. *Advanced Powder Technology*, *31*(10), 4390-4400.

[23] Surendra, B. S., Mallikarjunaswamy, C., Pramila, S., & Rekha, N. D. (2021). Bio-mediated synthesis of ZnO nanoparticles using Lantana Camara flower extract: Its characterizations, photocatalytic, electrochemical and anti-inflammatory applications. *Environmental Nanotechnology, Monitoring & Management*, *15*, 100442.

[24] Rai, M., Yadav, A., & Gade, A. (2008). CRC 675—current trends in phytosynthesis of metal nanoparticles. *Critical reviews in biotechnology*, *28*(4), 277-284.

[25] Jeyaraj, M., Rajesh, M., Arun, R., MubarakAli, D., Sathishkumar, G., Sivanandhan, G., ... & Ganapathi, A. (2013). An investigation on the cytotoxicity and caspase-mediated apoptotic effect of biologically synthesized silver nanoparticles using Podophyllum hexandrum on human cervical carcinoma cells. *Colloids and Surfaces B: Biointerfaces*, *102*, 708-717.

[26] Durval, I. J. B., Meira, H. M., de Veras, B. O., Rufino, R. D., Converti, A., & Sarubbo, L. A. (2021). Green synthesis of silver nanoparticles using a biosurfactant from Bacillus cereus UCP 1615 as stabilizing agent and its application as an antifungal agent. *Fermentation*, *7*(4), 233.

[27] Gnanasekar, S., Murugaraj, J., Dhivyabharathi, B., Krishnamoorthy, V., Jha, P. K., Seetharaman, P., ... & Sivaperumal, S. (2018). Antibacterial and cytotoxicity effects of biogenic palladium nanoparticles synthesized using fruit extract of Couroupita guianensis Aubl. *Journal of applied biomedicine*, *16*(1), 59-65.

[28] Gopinath, P. M., Narchonai, G., Dhanasekaran, D., Ranjani, A., & Thajuddin, N. (2015). Mycosynthesis, characterization and antibacterial properties of AgNPs against multidrug resistant (MDR) bacterial pathogens of female infertility cases. *asian journal of pharmaceutical sciences*, *10*(2), 138-145.

[29] Hebbalalu, D., Lalley, J., Nadagouda, M. N., & Varma, R. S. (2013). Greener techniques for the synthesis of silver nanoparticles using plant extracts, enzymes, bacteria, biodegradable polymers, and microwaves. *ACS Sustainable Chemistry & Engineering*, *1*(7), 703-712.

[30] Iqtedar, M., Aslam, M., Akhyar, M., Shehzaad, A., Abdullah, R., & Kaleem, A. (2019). Extracellular biosynthesis, characterization, optimization of silver nanoparticles (AgNPs) using Bacillus mojavensis BTCB15 and its antimicrobial activity against multidrug resistant pathogens. *Preparative Biochemistry and Biotechnology*, *49*(2), 136-142.

[31] Nasrollahzadeh, M., Sajadi, S. M., & Maham, M. (2015). Green synthesis of palladium nanoparticles using Hippophae rhamnoides Linn leaf extract and their catalytic activity for the Suzuki–Miyaura coupling in water. *Journal of Molecular Catalysis A: Chemical*, *396*, 297-303.

[32] Khazaei, A., Rahmati, S., Hekmatian, Z., & Saeednia, S. (2013). A green approach for the synthesis of palladium nanoparticles supported on pectin: Application as a catalyst for solvent-free Mizoroki–Heck reaction. *Journal of Molecular Catalysis A: Chemical*, *372*, 160-166.

[33] Bankar, A., Joshi, B., Kumar, A. R., & Zinjarde, S. (2010). Banana peel extract mediated novel route for the synthesis of palladium nanoparticles. *Materials Letters*, *64*(18), 1951-1953.

[34] Yang, X., Li, Q., Wang, H., Huang, J., Lin, L., Wang, W., ... & Jia, L. (2010). Green synthesis of palladium nanoparticles using broth of Cinnamomum camphora leaf. *Journal of Nanoparticle Research*, *12*, 1589-1598.

[35] Kalaiselvi, A., Roopan, S. M., Madhumitha, G., Ramalingam, C., & Elango, G. (2015). Synthesis and characterization of palladium nanoparticles using Catharanthus roseus leaf extract and its application in the photo-catalytic degradation. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, *135*, 116-119.

[36] Kumar, K. M., Mandal, B. K., Kumar, K. S., Reddy, P. S., & Sreedhar, B. (2013). Biobased green method to synthesise palladium and iron nanoparticles using Terminalia chebula aqueous extract. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, *102*, 128-133.

[37] Rabiee, N., Bagherzadeh, M., Kiani, M., & Ghadiri, A. M. (2020). Rosmarinus officinalis directed palladium nanoparticle synthesis: investigation of potential anti-bacterial, anti-fungal and Mizoroki-Heck catalytic activities. *Advanced Powder Technology*, *31*(4), 1402-1411.

[38] Daisy, P., & Saipriya, K. (2012). Biochemical analysis of Cassia fistula aqueous extract and phytochemically synthesized gold nanoparticles as hypoglycemic treatment for diabetes mellitus. *International journal of nanomedicine*, 1189-1202.

[39] Thangamani, N., & Bhuvaneshwari, N. J. C. P. L. (2019). Green synthesis of gold nanoparticles using Simarouba glauca leaf extract and their biological activity of micro-organism. *Chemical Physics Letters*, *732*, 136587.

[40] Satpathy, S., Patra, A., Ahirwar, B., & Hussain, M. D. (2020). Process optimization for green synthesis of gold nanoparticles mediated by extract of Hygrophila spinosa T. Anders and their biological applications. *Physica E: Low-dimensional Systems and Nanostructures*, *121*, 113830.

[41] Kumar, P. V., Kala, S. M. J., & Prakash, K. S. (2019). Green synthesis of gold nanoparticles using Croton Caudatus Geisel leaf extract and their biological studies. *Materials Letters*, *236*, 19-22.

[42] Anand, K., Gengan, R. M., Phulukdaree, A., & Chuturgoon, A. (2015). Agroforestry waste Moringa oleifera petals mediated green synthesis of gold nanoparticles and their anti-cancer and catalytic activity. *Journal of Industrial and Engineering Chemistry*, *21*, 1105-1111.

[43] Sathishkumar, M., Pavagadhi, S., Mahadevan, A., & Balasubramanian, R. (2015). Biosynthesis of gold nanoparticles and related cytotoxicity evaluation using A549 cells. *Ecotoxicology and environmental safety*, *114*, 232-240.

[44] Krishnaraj, C., Muthukumaran, P., Ramachandran, R., Balakumaran, M. D., & Kalaichelvan, P. T. (2014). Acalypha indica Linn: biogenic synthesis of silver and gold nanoparticles and their cytotoxic effects against MDA-MB-231, human breast cancer cells. *Biotechnology Reports*, *4*, 42-49.

[45] Dwivedi, A. D., & Gopal, K. (2010). Biosynthesis of silver and gold nanoparticles using Chenopodium album leaf extract. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, *369*(1-3), 27-33.

[46] Philip, D. (2010). Green synthesis of gold and silver nanoparticles using Hibiscus rosa sinensis. *Physica E: Low-Dimensional Systems and Nanostructures*, *42*(5), 1417-1424.

[47] Baghizadeh, A., Ranjbar, S., Gupta, V. K., Asif, M., Pourseyedi, S., Karimi, M. J., & Mohammadinejad, R. (2015). Green synthesis of silver nanoparticles using seed extract of Calendula officinalis in liquid phase. *Journal of molecular liquids*, *207*, 159-163.

[48] Gurunathan, S., Han, J. W., Kwon, D. N., & Kim, J. H. (2014). Enhanced antibacterial and anti-biofilm activities of silver nanoparticles against Gram-negative and Gram-positive bacteria. *Nanoscale research letters*, *9*, 1-17.

[49] Sheny, D. S., Philip, D., & Mathew, J. (2013). Synthesis of platinum nanoparticles using dried Anacardium occidentale leaf and its catalytic and thermal applications. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, *114*, 267-271.

[50] Zheng, B., Kong, T., Jing, X., Odoom-Wubah, T., Li, X., Sun, D., ... & Li, Q. (2013). Plant-mediated synthesis of platinum nanoparticles and its bioreductive mechanism. *Journal of Colloid and Interface Science*, *396*, 138-145.

[51] Raut, R. W., Haroon, A. S. M., Malghe, Y. S., Nikam, B. T., & Kashid, S. B. (2013). Rapid biosynthesis of platinum and palladium metal nanoparticles using root extract of Asparagus racemosus Linn. *Adv Mater Lett*, *4*(8), 650-654.

[52] Song, J. Y., Kwon, E. Y., & Kim, B. S. (2010). Biological synthesis of platinum nanoparticles using Diopyros kaki leaf extract. *Bioprocess and biosystems engineering*, *33*, 159-164.

[53] Razavi, R., Molaei, R., Moradi, M., Tajik, H., Ezati, P., & Shafipour Yordshahi, A. (2020). Biosynthesis of metallic nanoparticles using mulberry fruit (Morus alba L.) extract for the preparation of antimicrobial nanocellulose film. *Applied Nanoscience*, *10*, 465-476.

[54] Lotha, R., Shamprasad, B. R., Sundaramoorthy, N. S., Nagarajan, S., & Sivasubramanian, A. (2019). Biogenic phytochemicals (cassinopin and isoquercetin) capped copper nanoparticles (ISQ/CAS@ CuNPs) inhibits MRSA biofilms. *Microbial pathogenesis*, *132*, 178-187.

[55] Khani, R., Roostaei, B., Bagherzade, G., & Moudi, M. (2018). Green synthesis of copper nanoparticles by fruit extract of Ziziphus spina-christi (L.) Willd.: Application for adsorption of triphenylmethane dye and antibacterial assay. *Journal of Molecular Liquids*, *255*, 541-549.

[56] Liang, T., Qiu, X., Ye, X., Liu, Y., Li, Z., Tian, B., & Yan, D. (2020). Biosynthesis of selenium nanoparticles and their effect on changes in urinary nanocrystallites in calcium oxalate stone formation. *3 Biotech*, *10*, 1-6.

[57] Yazhiniprabha, M., & Vaseeharan, B. (2019). In vitro and in vivo toxicity assessment of selenium nanoparticles with significant larvicidal and bacteriostatic properties. *Materials Science and Engineering: C*, *103*, 109763.

[58] Menon, S., KS, S. D., Agarwal, H., & Shanmugam, V. K. (2019). Efficacy of biogenic selenium nanoparticles from an extract of ginger towards evaluation on anti-microbial and anti-oxidant activities. *Colloid and Interface Science Communications*, *29*, 1-8.

[59] Lin, Z., Weng, X., Owens, G., & Chen, Z. (2020). Simultaneous removal of Pb (II) and rifampicin from wastewater by iron nanoparticles synthesized by a tea

extract. *Journal of Cleaner Production*, *242*, 118476.
[60] Katata-Seru, L., Moremedi, T., Aremu, O. S., & Bahadur, I. (2018). Green synthesis of iron nanoparticles using Moringa oleifera extracts and their applications: Removal of nitrate from water and antibacterial activity against Escherichia coli. *Journal of Molecular Liquids*, *256*, 296-304.
[61] Radini, I. A., Hasan, N., Malik, M. A., & Khan, Z. (2018). Biosynthesis of iron nanoparticles using Trigonella foenum-graecum seed extract for photocatalytic methyl orange dye degradation and antibacterial applications. *Journal of Photochemistry and Photobiology B: Biology*, *183*, 154-163.
[62] Dhillon, G. S., Brar, S. K., Kaur, S., & Verma, M. (2012). Green approach for nanoparticle biosynthesis by fungi: current trends and applications. *Critical reviews in biotechnology*, *32*(1), 49-73.
[63] Spagnoletti, F. N., Spedalieri, C., Kronberg, F., & Giacometti, R. (2019). Extracellular biosynthesis of bactericidal Ag/AgCl nanoparticles for crop protection using the fungus Macrophomina phaseolina. *Journal of environmental management*, *231*, 457-466.
[64] Sastry, M., Ahmad, A., Khan, M. I., & Kumar, R. (2003). Biosynthesis of metal nanoparticles using fungi and actinomycete. *Current science*, 162-170.
[65] Chan, S., & Don, M. (2012). Characterization of Ag nanoparticles produced by white-rot fungi and its in vitro antimicrobial activities. *The International Arabic Journal of Antimicrobial Agents*, *2*(3: 3), 1-8.
[66] Hulkoti, N. I., & Taranath, T. C. (2014). Biosynthesis of nanoparticles using microbes—a review. *Colloids and surfaces B: Biointerfaces*, *121*, 474-483.
[67] Fernández, J. G., Fernández-Baldo, M. A., Berni, E., Camí, G., Durán, N., Raba, J., & Sanz, M. I. (2016). Production of silver nanoparticles using yeasts and evaluation of their antifungal activity against phytopathogenic fungi. *Process Biochemistry*, *51*(9), 1306-1313.
[68] Gupta, A., Bonde, S. R., Gaikwad, S., Ingle, A., Gade, A. K., & Rai, M. (2014). Lawsonia inermis-mediated synthesis of silver nanoparticles: activity against human pathogenic fungi and bacteria with special reference to formulation of an antimicrobial nanogel. *IET nanobiotechnology*, *8*(3), 172-178.
[69] El Sayed, M. T., & El-Sayed, A. S. (2020). Biocidal activity of metal nanoparticles synthesized by Fusarium solani against multidrug-resistant bacteria and mycotoxigenic fungi. *Journal of Microbiology and Biotechnology*, *30*(2), 226.
[70] Zhang, X., Qu, Y., Shen, W., Wang, J., Li, H., Zhang, Z., ... & Zhou, J. (2016). Biogenic synthesis of gold nanoparticles by yeast Magnusiomyces ingens LH-F1 for catalytic reduction of nitrophenols. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, *497*, 280-285.
[71] Seshadri, S., Saranya, K., & Kowshik, M. (2011). Green synthesis of lead sulfide nanoparticles by the lead resistant marine yeast, Rhodosporidium diobovatum. *Biotechnology progress*, *27*(5).
[72] Salunke, B. K., Sawant, S. S., Lee, S. I., & Kim, B. S. (2015). Comparative study of MnO 2 nanoparticle synthesis by marine bacterium Saccharophagus degradans and yeast Saccharomyces cerevisiae. *Applied microbiology and biotechnology*, *99*, 5419-5427.
[73] Mourato, A., Gadanho, M., Lino, A. R., & Tenreiro, R. (2011). Biosynthesis of crystalline silver and gold nanoparticles by extremophilic yeasts. *Bioinorganic chemistry and applications*, *2011*(1), 546074.
[74] Kowshik, M., Ashtaputre, S., Kharrazi, S., Vogel, W., Urban, J., Kulkarni, S. K., & Paknikar, K. M. (2002). Extracellular synthesis of silver nanoparticles by a silver-tolerant yeast strain MKY3. *Nanotechnology*, *14*(1), 95.
[75] Breierová, E., Vajczikova, I., Sasinková, V., Stratilová, E., Fišera, M., Gregor, T., & Šajbidor, J. (2002). Biosorption of cadmium ions by different yeast species. *Zeitschrift für Naturforschung C*, *57*(7-8), 634-639.
[76] Brayner, R., Coradin, T., Beaunier, P., Grenèche, J. M., Djediat, C., Yéprémian, C., ... & Fiévet, F. (2012). Intracellular biosynthesis of superparamagnetic 2-lines ferri-hydrite nanoparticles using Euglena gracilis microalgae. *Colloids and Surfaces B: Biointerfaces*, *93*, 20-23.
[77] Dahoumane, S. A., Yéprémian, C., Djédiat, C., Couté, A., Fiévet, F., Coradin, T., & Brayner, R. (2014). A global approach of the mechanism involved in the biosynthesis of gold colloids using micro-algae. *Journal of nanoparticle research*, *16*, 1-12.
[78] Priyadharshini, R. I., Prasannaraj, G., Geetha, N., & Venkatachalam, P. (2014). Microwave-mediated extracellular synthesis of metallic silver and zinc oxide nanoparticles using macro-algae (Gracilaria edulis) extracts and its anticancer activity against human PC3 cell lines. *Applied biochemistry and biotechnology*, *174*, 2777-2790.

[79] Naveena, B. E., & Prakash, S. (2013). Biological synthesis of gold nanoparticles using marine algae Gracilaria corticata and its application as a potent antimicrobial and antioxidant agent. *Asian J Pharm Clin Res*, *6*(2), 179-182.

[80] Bhattacharya, P., Swarnakar, S., Ghosh, S., Majumdar, S., & Banerjee, S. (2019). Disinfection of drinking water via algae mediated green synthesized copper oxide nanoparticles and its toxicity evaluation. *Journal of Environmental Chemical Engineering*, *7*(1), 102867.

[81] Kathiraven, T., Sundaramanickam, A., Shanmugam, N., & Balasubramanian, T. (2015). Green synthesis of silver nanoparticles using marine algae Caulerpa racemosa and their antibacterial activity against some human pathogens. *Applied Nanoscience*, *5*, 499-504.

[82] Vigneshwaran, N., Ashtaputre, N. M., Varadarajan, P. V., Nachane, R. P., Paralikar, K. M., & Balasubramanya, R. H. (2007). Biological synthesis of silver nanoparticles using the fungus Aspergillus flavus. *Materials letters*, *61*(6), 1413-1418.

[83] He, S., Guo, Z., Zhang, Y., Zhang, S., Wang, J., & Gu, N. (2007). Biosynthesis of gold nanoparticles using the bacteria Rhodopseudomonas capsulata. *Materials Letters*, *61*(18), 3984-3987.

[84] Durán, N., Marcato, P. D., Alves, O. L., De Souza, G. I., & Esposito, E. (2005). Mechanistic aspects of biosynthesis of silver nanoparticles by several Fusarium oxysporum strains. *Journal of nanobiotechnology*, *3*, 1-7.

[85] Chaudhari, S. P., Damahe, A., & Kumbhar, P. (2016). Silver nanoparticles-A review with focus on green synthesis. *International Journal of Pharma Research & Review*, *5*, 14-28.

[86] Ingle, A., Rai, M., Gade, A., & Bawaskar, M. (2009). Fusarium solani: a novel biological agent for the extracellular synthesis of silver nanoparticles. *Journal of Nanoparticle Research*, *11*, 2079-2085.

[87] Naqvi, S. Z. H., Kiran, U., Ali, M. I., Jamal, A., Hameed, A., Ahmed, S., & Ali, N. (2013). Combined efficacy of biologically synthesized silver nanoparticles and different antibiotics against multidrug-resistant bacteria. *International journal of nanomedicine*, 3187-3195.

[88] Philip, D. (2009). Biosynthesis of Au, Ag and Au–Ag nanoparticles using edible mushroom extract. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, *73*(2), 374-381.

[89] Gade, A. K., Bonde, P., Ingle, A. P., Marcato, P. D., Duran, N., & Rai, M. K. (2008). Exploitation of Aspergillus niger for synthesis of silver nanoparticles. *Journal of Biobased Materials and Bioenergy*, *2*(3), 243-247.

[90] Mukherjee, P., Ahmad, A., Mandal, D., Senapati, S., Sainkar, S. R., Khan, M. I., ... & Sastry, M. (2001). Fungus-mediated synthesis of silver nanoparticles and their immobilization in the mycelial matrix: a novel biological approach to nanoparticle synthesis. *Nano letters*, *1*(10), 515-519.

[91] Shankar, S. S., Ahmad, A., Pasricha, R., & Sastry, M. (2003). Bioreduction of chloroaurate ions by geranium leaves and its endophytic fungus yields gold nanoparticles of different shapes. *Journal of Materials Chemistry*, *13*(7), 1822-1826.

[92] Parikh, R. Y., Singh, S., Prasad, B. L. V., Patole, M. S., Sastry, M., & Shouche, Y. S. (2008). Extracellular synthesis of crystalline silver nanoparticles and molecular evidence of silver resistance from Morganella sp.: towards understanding biochemical synthesis mechanism. *ChemBioChem*, *9*(9), 1415-1422.

[93] Sweeney, R. Y., Mao, C., Gao, X., Burt, J. L., Belcher, A. M., Georgiou, G., & Iverson, B. L. (2004). Bacterial biosynthesis of cadmium sulfide nanocrystals. *Chemistry & biology*, *11*(11), 1553-1559.

[94] Babu, M. G., & Gunasekaran, P. (2009). Production and structural characterization of crystalline silver nanoparticles from Bacillus cereus isolate. *Colloids and surfaces B: Biointerfaces*, *74*(1), 191-195.

[95] Ahmad, A., Senapati, S., Khan, M. I., Kumar, R., & Sastry, M. (2003). Extracellular biosynthesis of monodisperse gold nanoparticles by a novel extremophilic actinomycete, Thermomonospora sp. *Langmuir*, *19*(8), 3550-3553.

[96] Husseiny, M. I., Abd El-Aziz, M., Badr, Y., & Mahmoud, M. A. (2007). Biosynthesis of gold nanoparticles using Pseudomonas aeruginosa. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, *67*(3-4), 1003-1006.

[97] Belliveau, B. H., Starodub, M. E., Cotter, C., & Trevors, J. T. (1987). Metal resistance and accumulation in bacteria. *Biotechnology advances*, *5*(1), 101-127.

[98] Waghmare, S. S., Deshmukh, A. M., Kulkarni, S. W., & Oswaldo, L. A. (2011). Biosynthesis and characterization of manganese and zinc nanoparticles. *Universal Journal of Environmental Research & Technology*, *1*(1).

[99] Gade, A. K., Bonde, P., Ingle, A. P., Marcato, P. D., Duran, N., & Rai, M. K. (2008). Exploitation of Aspergillus niger for synthesis

of silver nanoparticles. *Journal of Biobased Materials and Bioenergy*, *2*(3), 243-247.

[100] Mukherjee, P., Ahmad, A., Mandal, D., Senapati, S., Sainkar, S. R., Khan, M. I., ... & Sastry, M. (2001). Fungus-mediated synthesis of silver nanoparticles and their immobilization in the mycelial matrix: a novel biological approach to nanoparticle synthesis. *Nano letters*, *1*(10), 515-519.

[101] Shankar, S. S., Ahmad, A., Pasricha, R., & Sastry, M. (2003). Bioreduction of chloroaurate ions by geranium leaves and its endophytic fungus yields gold nanoparticles of different shapes. *Journal of Materials Chemistry*, *13*(7), 1822-1826.

[102] Dameron, C. T., Reese, R. N., Mehra, R. K., Kortan, A. R., Carroll, P. J., Steigerwald, M. L., ... & Winge, D. R. (1989). Biosynthesis of cadmium sulphide quantum semiconductor crystallites. *Nature*, *338*(6216), 596-597.

[103] Jha, A. K., Prasad, K., Prasad, K., & Kulkarni, A. R. (2009). Plant system: nature's nanofactory. *Colloids and Surfaces B: Biointerfaces*, *73*(2), 219-223.

[104] Gericke, M., & Pinches, A. (2006). Microbial production of gold nanoparticles. *Gold bulletin*, *39*(1), 22-28.

[105] Kowshik, M., Ashtaputre, S., Kharrazi, S., Vogel, W., Urban, J., Kulkarni, S. K., & Paknikar, K. M. (2002). Extracellular synthesis of silver nanoparticles by a silver-tolerant yeast strain MKY3. *Nanotechnology*, *14*(1), 95.

[106] Nasir, S., Walters, K. F., Pereira, R. M., Waris, M., Chatha, A. A., Hayat, M., & Batool, M. (2022). Larvicidal activity of acetone extract and green synthesized silver nanoparticles from Allium sativum L.(Amaryllidaceae) against the dengue vector Aedes aegypti L.(Diptera: Culicidae). *Journal of Asia-Pacific Entomology*, *25*(3), 101937.

[107] Singaravelu, G., Arockiamary, J. S., Kumar, V. G., & Govindaraju, K. (2007). A novel extracellular synthesis of monodisperse gold nanoparticles using marine alga, Sargassum wightii Greville. *Colloids and surfaces B: Biointerfaces*, *57*(1), 97-101.

[108] Rajesh, S., Raja, D. P., Rathi, J. M., & Sahayaraj, K. (2012). Biosynthesis of silver nanoparticles using Ulva fasciata (Delile) ethyl acetate extract and its activity against Xanthomonas campestris pv. malvacearum. *Journal of Biopesticides*, *5*, 119.

[109] Xie, J., Lee, J. Y., Wang, D. I., & Ting, Y. P. (2007). Identification of active biomolecules in the high-yield synthesis of single-crystalline gold nanoplates in algal solutions. *small*, *3*(4), 672-682.

[110] Kathiraven, T., Sundaramanickam, A., Shanmugam, N., & Balasubramanian, T. (2015). Green synthesis of silver nanoparticles using marine algae Caulerpa racemosa and their antibacterial activity against some human pathogens. *Applied Nanoscience*, *5*, 499-504.

[111] Duhan, J. S., Kumar, R., Kumar, N., Kaur, P., Nehra, K., & Duhan, S. (2017). Nanotechnology: The new perspective in precision agriculture. *Biotechnology reports*, *15*, 11-23.

[112] Rai, M., & Ingle, A. (2012). Role of nanotechnology in agriculture with special reference to management of insect pests. *Applied microbiology and biotechnology*, *94*, 287-293.

[113] Naderi, M. R., & Danesh-Shahraki, A. (2013). Nanofertilizers and their roles in sustainable agriculture.

[114] Guo, H., White, J. C., Wang, Z., & Xing, B. (2018). Nano-enabled fertilizers to control the release and use efficiency of nutrients. *Current Opinion in Environmental Science & Health*, *6*, 77-83.

[115] Subbarao, C. V., Kartheek, G., & Sirisha, D. (2013). Slow release of potash fertilizer through polymer coating. *International Journal of Applied science and engineering*, *11*(1), 25-30.

[116] Bisinoti, M. C., Moreira, A. B., Melo, C. A., Fregolente, L. G., Bento, L. R., dos Santos, J. V., & Ferreira, O. P. (2019). Application of carbon-based nanomaterials as fertilizers in soils. In *Nanomaterials applications for environmental matrices* (pp. 305-333). Elsevier.

[117] Kah, M., & Hofmann, T. (2014). Nanopesticide research: current trends and future priorities. *Environment international*, *63*, 224-235.

[118] Jampílek, J., & Kráľová, K. (2017). Nanopesticides: preparation, targeting, and controlled release. In *New pesticides and soil sensors* (pp. 81-127). Academic Press.

[119] Singh, T., Shukla, S., Kumar, P., Wahla, V., Bajpai, V. K., & Rather, I. A. (2017). Application of nanotechnology in food science: perception and overview. *Frontiers in microbiology*, *8*, 1501.

[120] Graveland-Bikker, J. F., & De Kruif, C. G. (2006). Unique milk protein based nanotubes: food and nanotechnology meet. *Trends in Food Science & Technology*, *17*(5), 196-203.

[121] Fernández, A., Cava, D., Ocio, M. J., & Lagarón, J. M. (2008). Perspectives for biocatalysts in food packaging. *Trends in Food Science & Technology*, *19*(4), 198-206.

[122] Pradhan, N., Singh, S., Ojha, N., Shrivastava, A., Barla, A., Rai, V., & Bose, S. (2015). Facets of nanotechnology as seen in food processing,

packaging, and preservation industry. *BioMed research international*, *2015*(1), 365672.

[123] Weir, A., Westerhoff, P., Fabricius, L., Hristovski, K., & Von Goetz, N. (2012). Titanium dioxide nanoparticles in food and personal care products. *Environmental science & technology*, *46*(4), 2242-2250.

[124] Carbone, M., Donia, D. T., Sabbatella, G., & Antiochia, R. (2016). Silver nanoparticles in polymeric matrices for fresh food packaging. *Journal of King Saud University-Science*, *28*(4), 273-279.

[125] Oberdörster, G., Stone, V., & Donaldson, K. (2007). Toxicology of nanoparticles: a historical perspective. *Nanotoxicology*, *1*(1), 2-25.

[126] Fernández, A., Cava, D., Ocio, M. J., & Lagarón, J. M. (2008). Perspectives for biocatalysts in food packaging. *Trends in Food Science & Technology*, *19*(4), 198-206.

[127] Pradhan, N., Singh, S., Ojha, N., Shrivastava, A., Barla, A., Rai, V., & Bose, S. (2015). Facets of nanotechnology as seen in food processing, packaging, and preservation industry. *BioMed research international*, *2015*(1), 365672.

[128] Weir, A., Westerhoff, P., Fabricius, L., Hristovski, K., & Von Goetz, N. (2012). Titanium dioxide nanoparticles in food and personal care products. *Environmental science & technology*, *46*(4), 2242-2250.

[129] Carbone, M., Donia, D. T., Sabbatella, G., & Antiochia, R. (2016). Silver nanoparticles in polymeric matrices for fresh food packaging. *Journal of King Saud University-Science*, *28*(4), 273-279.

[130] Emamifar, A., Kadivar, M., Shahedi, M., & Soleimanian-Zad, S. (2010). Evaluation of nanocomposite packaging containing Ag and ZnO on shelf life of fresh orange juice. *Innovative Food Science & Emerging Technologies*, *11*(4), 742-748.

[131] Valipoor Motlagh, N., Hamed Mosavian, M. T., & Mortazavi, S. A. (2013). Effect of polyethylene packaging modified with silver particles on the microbial, sensory and appearance of dried barberry. *Packaging Technology and Science*, *26*(1), 39-49.

[132] Yang, F. M., Li, H. M., Li, F., Xin, Z. H., Zhao, L. Y., Zheng, Y. H., & Hu, Q. H. (2010). Effect of nano-packing on preservation quality of fresh strawberry (Fragaria ananassa Duch. cv Fengxiang) during storage at 4 C. *Journal of food science*, *75*(3), C236-C240.

[133] Martínez-Abad, A., Lagaron, J. M., & Ocio, M. J. (2012). Development and characterization of silver-based antimicrobial ethylene–vinyl alcohol copolymer (EVOH) films for food-packaging applications. *Journal of agricultural and food chemistry*, *60*(21), 5350-5359.

[134] Mahdi, S. S., Vadood, R., & Nourdahr, R. (2012). Study on the antimicrobial effect of nanosilver tray packaging of minced beef at refrigerator temperature.

[135] Metak, A. M., & Ajaal, T. T. (2013). Investigation on polymer based nano-silver as food packaging materials. *International Journal of Chemical and Molecular Engineering*, *7*(12), 1103-1109.

[136] Metak, A. M. (2015). Effects of nanocomposite based nano-silver and nano-titanium dioxide on food packaging materials. *International Journal of Applied Science and Technology*, *5*(2), 26-40.

[137] Patel, A., Patra, F., Shah, N., & Khedkar, C. (2018). Application of nanotechnology in the food industry: present status and future prospects. *Impact of nanoscience in the food industry*, 1-27.

[138] Khalaf, H. H., Sharoba, A. M., El-Tanahi, H. H., & Morsy, M. K. (2013). Stability of antimicrobial activity of pullulan edible films incorporated with nanoparticles and essential oils and their impact on turkey deli meat quality. *Journal of Food and Dairy Sciences*, *4*(11), 557-573.

[139] Elsaesser, A., & Howard, C. V. (2012). Toxicology of nanoparticles. *Advanced drug delivery reviews*, *64*(2), 129-137.

[140] Zoroddu, M. A., Medici, S., Ledda, A., Nurchi, V. M., Lachowicz, J. I., & Peana, M. (2014). Toxicity of nanoparticles. *Curr. Med. Chem*, *21*(33), 3837-3853.

[141] Zhang, S. X., Gao, J., Buchholz, T. A., Wang, Z., Salehpour, M. R., Drezek, R. A., & Yu, T. K. (2009). Quantifying tumor-selective radiation dose enhancements using gold nanoparticles: a monte carlo simulation study. *Biomedical microdevices*, *11*, 925-933.

[142] Zhang, X., Xing, J. Z., Chen, J., Ko, L., Amanie, J., Gulavita, S., ... & Roa, W. (2008). Enhanced radiation sensitivity in prostate cancer by gold-nanoparticles. *Clinical and Investigative Medicine*, *31*(3), E160-E167.

[143] Lara-González, J. H., Gomez-Flores, R., Tamez-Guerra, P., Monreal-Cuevas, E., Tamez-Guerra, R., & Rodríguez-Padilla, C. (2013). In vivo antitumor activity of metal silver and silver nanoparticles in the L5178Y-R murine lymphoma model. *British Journal of Medicine and Medical Research*, *3*(4), 1308-1316.

[144] Dhandapani, B., & Iyer, P. R. (2018). Biosynthesis, characterization and application of chitin nanoparticle with Cassia auriculata. *American Journal of Biomedical and Life Sciences*, *6*(5), 96-102.

[145] Ojo, S. A., Lateef, A., Azeez, M. A., Oladejo, S. M., Akinwale, A. S., Asafa, T. B., ... & Beukes, L. S. (2016). Biomedical and catalytic applications of gold and silver-gold alloy nanoparticles biosynthesized using cell-free extract of Bacillus safensis LAU 13: antifungal, dye degradation, anti-coagulant and thrombolytic activities. *Ieee transactions on nanobioscience*, *15*(5), 433-442.

[146] Rai, M., Deshmukh, S. D., Ingle, A. P., Gupta, I. R., Galdiero, M., & Galdiero, S. (2016). Metal nanoparticles: The protective nanoshield against virus infection. *Critical reviews in microbiology*, *42*(1), 46-56.

[147] Sharma, V., Kaushik, S., Pandit, P., Dhull, D., Yadav, J. P., & Kaushik, S. (2019). Green synthesis of silver nanoparticles from medicinal plants and evaluation of their antiviral potential against chikungunya virus. *Applied microbiology and biotechnology*, *103*, 881-891.

[148] Orłowski, P., Kowalczyk, A., Tomaszewska, E., Ranoszek-Soliwoda, K., Węgrzyn, A., Grzesiak, J., ... & Krzyzowska, M. (2018). Antiviral activity of tannic acid modified silver nanoparticles: potential to activate immune response in herpes genitalis. *Viruses*, *10*(10), 524.

[149] Oryan, A., Alemzadeh, E., Tashkhourian, J., & Ana, S. F. N. (2018). Topical delivery of chitosan-capped silver nanoparticles speeds up healing in burn wounds: A preclinical study. *Carbohydrate polymers*, *200*, 82-92.

[150] Ramya, S., Shanmugasundaram, T., & Balagurunathan, R. (2015). Biomedical potential of actinobacterially synthesized selenium nanoparticles with special reference to anti-biofilm, anti-oxidant, wound healing, cytotoxic and anti-viral activities. *Journal of Trace Elements in Medicine and Biology*, *32*, 30-39.

[151] Guo, S. A., & DiPietro, L. A. (2010). Factors affecting wound healing. *Journal of dental research*, *89*(3), 219-229.

[152] Kumar, A., Majumdar, R. S., & Dhewa, T. (2018). In vitro efficacy of biosynthesized AgNPs against Streptococcus mutans causing dental plaque formation.

[153] Thomas, R., Snigdha, S., Bhavitha, K. B., Babu, S., Ajith, A., & Radhakrishnan, E. K. (2018). Biofabricated silver nanoparticles incorporated polymethyl methacrylate as a dental adhesive material with antibacterial and antibiofilm activity against Streptococcus mutans. *3 Biotech*, *8*, 1-10.

[154] Rodrigues, M. C., Rolim, W. R., Viana, M. M., Souza, T. R., Gonçalves, F., Tanaka, C. J., ... & Seabra, A. B. (2020). Biogenic synthesis and antimicrobial activity of silica-coated silver nanoparticles for esthetic dental applications. *Journal of Dentistry*, *96*, 103327.

[155] Eid, A. M., Fouda, A., Niedbała, G., Hassan, S. E. D., Salem, S. S., Abdo, A. M., ... & Shaheen, T. I. (2020). Endophytic Streptomyces laurentii mediated green synthesis of Ag-NPs with antibacterial and anticancer properties for developing functional textile fabric properties. *Antibiotics*, *9*(10), 641.

[156] Fouda, A., Mohamed, A., Elgamal, M. S., EL-Din Hassan, S., Salem Salem, S., & Shaheen, T. I. (2017). Facile approach towards medical textiles via myco-synthesis of silver nanoparticles. *Der Pharma Chemica*, *9*(13), 11-18.

[157] Fouda, A., Saad, E. L., Salem, S. S., & Shaheen, T. I. (2018). In-Vitro cytotoxicity, antibacterial, and UV protection properties of the biosynthesized Zinc oxide nanoparticles for medical textile applications. *Microbial pathogenesis*, *125*, 252-261.

[158] Fernandes, M., Padrão, J., Ribeiro, A. I., Fernandes, R. D., Melro, L., Nicolau, T., ... & Zille, A. (2022). Polysaccharides and metal nanoparticles for functional textiles: A review. *Nanomaterials*, *12*(6), 1006.

[159] Sharma, S., & Bhattacharya, A. J. A. W. S. (2017). Drinking water contamination and treatment techniques. *Applied water science*, *7*(3), 1043-1067.

[160] Goutam, S. P., Saxena, G., Singh, V., Yadav, A. K., Bharagava, R. N., & Thapa, K. B. (2018). Green synthesis of TiO2 nanoparticles using leaf extract of Jatropha curcas L. for photocatalytic degradation of tannery wastewater. *Chemical Engineering Journal*, *336*, 386-396.

[161] Anjum, M., Miandad, R., Waqas, M., Gehany, F., & Barakat, M. A. (2019). Remediation of wastewater using various nano-materials. *Arabian journal of chemistry*, *12*(8), 4897-4919.

[162] Sadegh, H., Ali, G. A., Gupta, V. K., Makhlouf, A. S. H., Shahryari-Ghoshekandi, R., Nadagouda, M. N., ... & Megiel, E. (2017). The role of nanomaterials as effective adsorbents and their applications in wastewater treatment. *Journal of Nanostructure in Chemistry*, *7*, 1-14.