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A Review of Different Synthesis Approaches to Nanoparticles: Bibliometric Profile

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Abstract: Nanomaterials are currently one of the most popular emerging materials used in different applications such as drug delivery, water treatment, cancer treatment, electronic, food preservations, and production of pesticide. This is due to their interesting features including size-dependent properties, lightweight, biocompatibility, amphiphilicity and biodegradability. They offer wide possibilities for modification and are used in multiple functions with enormous possibilities. Some of them are medically suitable which has opened new opportunities for medical improvement especially for human health. These characteristics also make nanomaterials one of the pioneers in green materials for various needs, especially in environmental engineering and energy sectors. In this review, several synthesis approaches for nanoparticles mainly physical, chemical, and biological have been discussed extensively. Furthermore, bibliometric analysis on the synthesis of nanoparticles was evaluated. About 117,162 publications were considered, of which 92% are journal publications. RSC Advances is the most published outlet on the synthesis of nanoparticles and China has the highest number of researchers engaged in the synthesis of nanoparticles. It was noted in the evaluation of synthesis approach that biological approach is the savest method but with a low yield, while the chemical approach offers a high yield with some level of hazardous effect. Also, the bibliometric analysis revealed that the field of nanotechnology is a trending and hot ground for research.

Keywords: Nanoparticle, Chemical, Physical, Biological, Bibliometric analysis.

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1. INTRODUCTION

Nanomaterials are currently one of the most popular emerging materials used in various applications (1). The fascinating optical, structural and morphological properties of materials as they approach the nanometric domain have increased the research attention on these materials. Other properties of note include lightweight, biocomp-atibility, amphiphilicity and biodegradability (2). Nanomaterials are known to be used for multiple functions with enormous possibilities in modification (3). The biocompatibility of some nanomaterials, especially with the human system, has open new opportunities for medical improvement (4). These characteristics also make nanomaterials one of the pioneers in green materials for various needs, especially in environmental engineering and energy sectors.

Application of nanomaterials is mostly medical (5), electronic (6), absorbent (7-13) and membrane technologies (14). Medical application of nanomaterials includes the delivery of drugs, heat, or other substance to a specific targeted cell (15). They are also used in devices such as sensors to provide fast results of disease diagnostic (16), antibacterial compounds (17), purifier in water treatment (7, 18), wound healing treatment (19), as cell reparation agents (20), and in nano-electronic technology. The improved optical and electronic properties has been utilized in display productions, such as organic light-emitting diodes (21), as support in the wireless technology and internet of things (22), as well as in nano-communication in which medical devices could transmit information inside the human body for medical purposes (23). In the membrane sectors, various types of nanomaterials such as carbon, graphene and fullerene are currently widely used (14, 24).

Due to the wide array of benefits and utilization, the current study focuses on highlighting the different synthesis approaches of nanomaterials. Synthesis of nanomaterials can be conducted via various methods including the solid phase (25), liquid phase (26), and thermal methods (27). The solid phase syntheses involve synthesis methods without the use of solvents. The liquid phase syntheses include the solvent dissolution and sol-gel process, while the thermal methods include synthesis at elevated temperatures such as microwave irradiation, plasma, magnesio-thermic reduction, solar energy, and neutron irradiation methods. This paper is aimed to explore and highlight the different synthesis route of nanomaterials via the 3 broad physical, chemical, and biological routes. The bibliometric analysis of these various synthesis approaches is discussed. This review paper will enhance the knowledge on the synthesis route of nanomaterials and the utilization of the synthesized materials for different applications.

2. TECHNIQUES FOR SYNTHESIZING NANOMATERIALS

The two broad categories of synthesis routes are bottom-up and top-down approaches. Physical methods are used in top-down approaches, whereas chemical and biological methods are used in bottom-up approaches. Other synthesis methods falls under these two categories and are discussed in this section.

2.1 Physical Methods of Nanomaterial Synthesis

In this method, electric current is used to generate electron from the initial material to produce the required electron (Ionic Species) which further converted into atomic material and develop into nanoparticle (NPs) (28). Physical methods have the advantages of high speed (29), none use of toxic chemicals (30), uniform size (2), purity (31), and shape (3). Their disadvantages include high cost (32), less productivity (33), radiation exposure (34), high temperature (35), energy intensive (30), high pressure (36), less thermal stability (37), complex shape and size tenability (38), and less stability (39, 40). This synthesis approach could alter the physicochemical and surface chemistry of nanoparticles, making it unsuitable for producing nanoparticles in standard sizes and forms (41). Physical techniques such as ball milling (42), evaporation-condensation (43), sputtering (44), laser ablation (45), and arc discharge methods are examples of this process (46). The use of physical techniques in the synthesis of metal-nanoparticles have recently aroused the interest of researchers, owing to the adjustable parameters utilized in reactions (47). Unlike chemical or biological techniques, physical methods do not require reagents or solvents that can contaminate the samples (48, 49).

In addition, the homogeneity of nanomaterial is potentially high when created via physical techniques (5). However, the requirement for huge and expensive equipment, the long duration of synthesis time are the present challenges (50, 51).

2.1.1 Laser ablation

The laser-induced ablation approach has drawn increased attention among other physical methods because of its eco-friendliness, simplicity and ability to offer nanoparticles with even sizes (52). In synthesizing diverse kinds of NPs by laser ablation, a high-power pulsed laser is a critical and coherent need for ablation on the sample's surface (53). Adjusting parameters such as wavelength, pulse width, repetition rate of the laser source, temperature and ablation time, the production of nanoparticles with chosen morphological characteristics is attainable (54). This is the most prevalent technique for metallic alloy-NPs production among the physical procedures (50). In this approach, a solid substance is irradiate via a laser to produce particles of nano-size (55). This technique involves creating nanoparticle in a liquid environment by obtaining colloidal solution of nanoparticle from solid target material in a variety of solvent (56). A solid target material is abraded using a laser beam as the energy source, resulting in the vaporization to atoms and clusters (57). The NPs are progressively formed in ambient media (58). The settings specified before the experimental setup may impact the final concentration and condition of the nanoparticle solution (39, 59) as it is depicted in Fig 1. The approach offers several notable benefits in particle production. The first is the ability to produce several particles in a single operation, and the second is the laser source's capacity to generate various colloidal solution concentrations in accordance with the chosen parameters (47). The primary issue, despite the solution's promise, continues to be the large, expensive equipment needed (60). The analysis duration is longer than the chemical procedures, and the process is more difficult (49).

Strong laser pulses are centered on metal's target contained in a liquid (61) and NPs might be produced using laser ablation of metallic bulk materials in solution (62). The size of the NPs formed by alcohol based materials depends on its chain length (63). C-3 (Prop-) to C-5 (Pent-) long alcohol chain had more stable particles than short-chains; ethanol and methanol (64). The features of the metal-NPs generated are determined by various factors such as ablation time (65) which increases, as the amount of metal-NPs increase till ablation time optimum value is reached. Increasing surfactant content may also yield smaller metal-NPs (66). According to reported studies, metal-NPs produced by femtosecond laser pulses have a narrower size distribution than those produced by nanosecond laser pulses (67). After the ablation, the liquid environment exclusively includes metal-NPs without other chemicals, and ions.

Laser ablation facilitates the production of nanoparticles with regulated shapes and sizes, resulting in better long-term stability and high yields (55). The *in-situ* conjugation of bio-molecules with gold nanoparticles is one of the biomedical applications of the laser ablation technique, and it is possible since the synthesis is flexible and can be done in both aqueous and organic solvents (64). This strategy has consequently shown to be more successful than traditional procedures through minimizing waste production, manual operation and refining size control of nanoparticle (68).

The studies by Islam, Shohag (47) is a notable example of this technology, ZnO NPs was synthesized via laser ablation in a NaOH solution (particle size from 80.76 - 102.54 nm) and spherical shape which refined size control of the nanoparticles compared to other methods. Singh, Nayak (69), produced ZnO NPs by laser ablation from a mixture of zinc, methanol, and deionized water solution with sizes of the particles range from 1 - 30 nm. Similarly, Mintcheva, Yamaguchi (70) reported the synthesis of laser-ablated rod-shaped ZnO NPs with an average width of 30 nm and a length in the range 40 to 110 nm. Menazea and Ahmed (71), prepared Ag NPs using various liquid media, including distilled water, deionized water, tetrahydrofuran, and dimethylformamide. The study indicated that Ag NPs generated in deionized water had more significant ablation, antibacterial efficiency and stability than other media. Zhang, Gokce (72), employed laser beam irradiation with focused and unfocused laser beams at 12 and 900 mJ/cm^2, respectively. They showed that the diameter of the NP decreased with the reduction in laser wavelength, going from 29 - 12 nm.

The pulsed laser approach may also be utilized for synthesizing metal-organic frameworks (MOF) and inorganic metal complexes or the surface modification of nanomaterials, including nanoparticles coated with organic compounds that can be quickly produced using a single process (73). No by-products and hazardous agents are required for the process. Hence, the pulsed laser synthesis processes are ecologically favourable (54). Fig. 1 depicts this method.

Laser ablation industry is now undergoing fast change. The current advancement in the usage of new lasers with various modes of operation and wavelengths, as well as equipment, are leading to promising outcomes in terms of treatment selectivity, among other developing solutions and advances that are remarkable (74). Laser ablation is evolving into a viable surgical in the medical field (75). Its overarching objectives are to lessen the pain associated with particular cancers and to enhance outcomes (20).

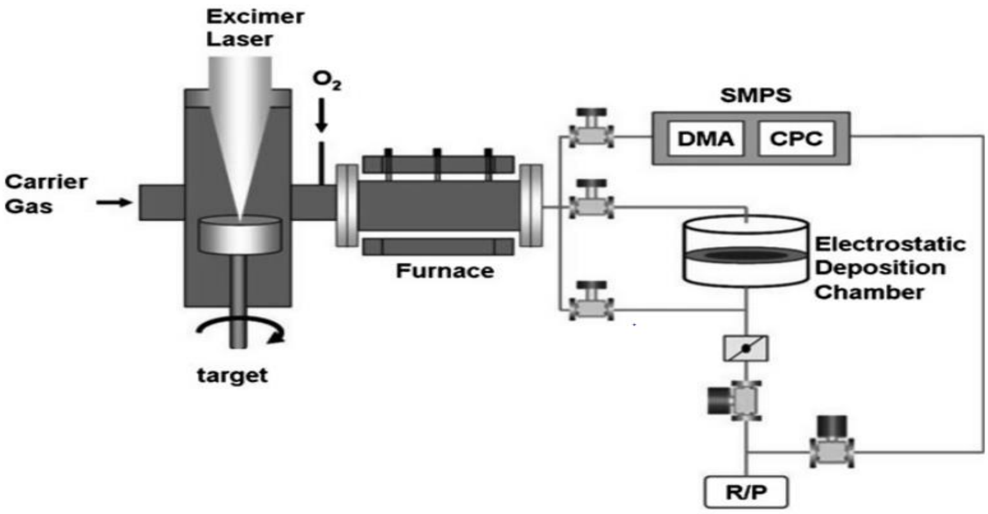

Figure 1: A picture of a laser system connected to a particle analyser (76).

2.1.2. Ball milling

Ball milling is a mechanical process used to generate nanoparticles (77). It started in 1970, and the technology is employed today mainly for ceramic, metallic, and nanoparticles (1). Its key benefits are connected to the cheap cost, the tiny size of particles created, the capacity to handle refractory materials and their purity since no chemical reagents or solvents are required (50). This approach involves the application of a solid force to activate electrons from the material's crystals and electrons from the inner structure (78). High energy is released throughout the operation due to the velocity differential between the rotating balls and the grinding jars (63). The high temperature required to begin chemical synthesis will rise due to the frequent collisions s depicted in Figure 2. This procedure produces nanoparticles or doped nanoparticles as a result of the high temperature's crucial role in atom diffusion (79). The downsides of this approach include the potential for environmental or milling ball contamination and the creation of irregular-shaped NPs (1). Compared with a more significant temperature of 1000 °C, this approach can mill the material better (56). Different variables, including time, milling speed, process control agent, atmosphere, ball-to-powder ratio, temperature, and the size distribution, affect the quality of products produced by ball milling (80).

According to an earlier reported study, ball milling is also suitable for the environmentally friendly synthesis of silver, a process that has been extensively researched in recent years (56, 81). Nicolae-Maranciuc, Chicea (50), used silver nitrate in the presence of two naturally occurring compounds acting as reducing agents while using the ball milling procedure. Eggshell membranes and *Origanumvulgare L*. were added to the silver precursor solution as reducing agents. The results suggested that both biocompatible chemicals, with certain variations, might be employed as reducing agents in this procedure which are used to convert ionic species into atomic material which develops into NPs. The TEM analysis revealed that the particle diameters of *Origanumvulgare L*. are lower. The plant's optical and antibacterial characteristics seem superior to those of the eggshell membrane (82). Fine metal NPs were prepared using the high-energy ball milling approach in an elevated shaker mill (68). Its primary benefit is the capacity to concurrently create enormous volumes of material (47). According to Abdullah, Bakar (83), a high-energy ball milling was employed to produce ZnO NPs with a mean particle size of 0.8 nm. Through milling, particles with ultimate sizes ranging from 200 to 400 nm were produced. Similarly, Raha and Ahmaruzzaman (84) developed a high-energy ball milling method to create rod-shaped ZnO NPs in the 20 – 90 nm range. A high-intensity ball milling process was adopted to generate ZnO NPs from ZnO microcrystalline powder by Prasad, Kumar (85). The samples were processed in a ball mill for 2, 20, and 50 h. According to the findings, the particle size varied over time. The duration of the ball milling process increases with decreasing particle size. Spherical ZnO-NPs with around 30 nm particle sizes were detected in the milled sample. Khayati (86), showed the production of Ag NPs graphite as a reducing agent utilizing a mill. The resulting Ag NPs had a size of 14 nm in the presence of process control agents. Alam and Hossain (87), synthesized rod-shaped ZnO NPs using a high-energy milling technique in the range of 20 to 90 nm. The higher the ball milling duration, the lesser the particle size. After 50 hours of milling, the material revealed spherically formed ZnO-NPs with particle sizes of roughly 30 nm. High-energy ball milling is a handy approach to generating nanosized particles. A typical example of ball mill is shown in Figure 2a & b.

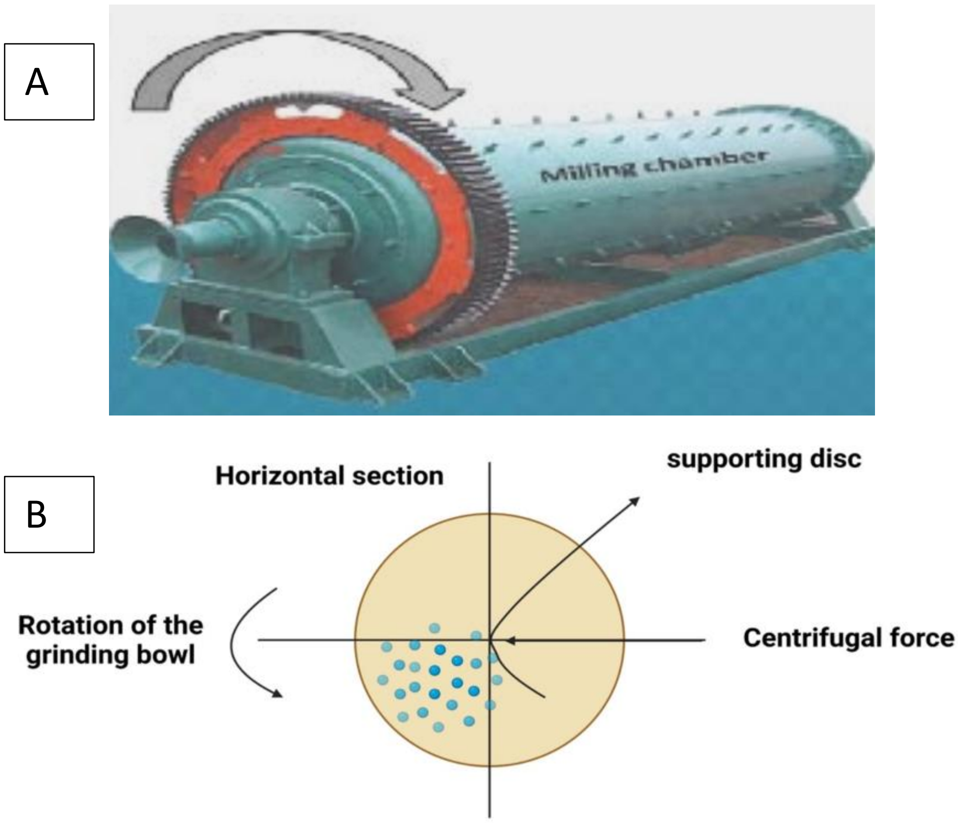

Figure 2: (a) A rock tumbler Ball mills (88), and (b) Illustration of the steps needed to create metallic nanoparticles using high-energy ball milling techniques (47).

2.1.3. Evaporation – Condensation

Evaporation-condensation can be used to synthesize NPs using an air pressure tube furnace/tiny ceramic heater (4). This approach is often used to generate metal-based NPs. There are three primary phases in the evaporation-condensation process: (1) the material is sublimated or evaporated to produce a gaseous phase; (2) the substrate receives material from the source via condensation, and (3) films or particles are generated by nucleation and subsequently followed by growth (89). Rapid cooling of the vapour results in significant concentrations of tiny NPs (90). Additionally, this approach requires a specified kilowatt of electricity from a standard furnace and a given time to attain a steady temperature (91). Radiation was utilized as a reducing agent in this process to produce NPs due to its ability to generate ionic species which further converted to atomic material for the production of NPs (92). This technique was used to assemble nanospheres from different metal components. The downsides of evaporation-condensation are the lengthy process time, and the huge amount of energy needed (93).

Sharma and Kumar (94), Evaporation- condensation process comprises heating of a combination of $AgNO_3$ and CH_3COONa in a tube furnace. This led to the liquid mixture being converted into a gas, which was then condensed into Ag-NPs after cooling. The produced Ag-NPs ranged from 3 - 50 nm. Ong and Nyam (95), used the inert gas helium to demonstrate the evaporation-condensation approach for synthesizing Ag NPs spherical Ag NPs of 9 to 32 nm, with few agglomerations, were formed at a lower inert gas pressure and evaporation temperature. A ceramic heater with a maximum temperature of 1500 °C was used by Lee and Jun (96) to produce Ag-NPs using the evaporation-condensation method. Poly-dispersed Ag-NPs were produced from a heater surface with a constant temperature. The Ag-NPs generated were in the size range of 6.2 - 21.5 nm. Similarly, Hara, Fukuoka (97), produced Ag-NPs using temperatures ranging from 1300 to 1400 °C in a furnace, and the vapour was diluted with N_2 gas. Ag-NPs of 50, 90, and 130 nm were generated at various synthesis temperatures.

However, the synthesis of mainly metallic alloy NPs through evaporation-condensation in a tube furnace has some limitations. The tube furnace has a big volume, uses significant amount of energy to increase the temperature of the metal supply's environment, and has to be maintained for a longer time to retain its thermal stability (98). One of the most appealing nanomaterials for commercial uses is Ag-NPs (99). They have been widely employed in a variety of environmental applications, including textile coatings, food storage, anti-bacterial treatments in the health sector, and electronic goods (100). Ag-NPs were employed as anti-bacterial agents for a variety of purposes, including water treatment, cleaning and disinfection of medical equipment (101).

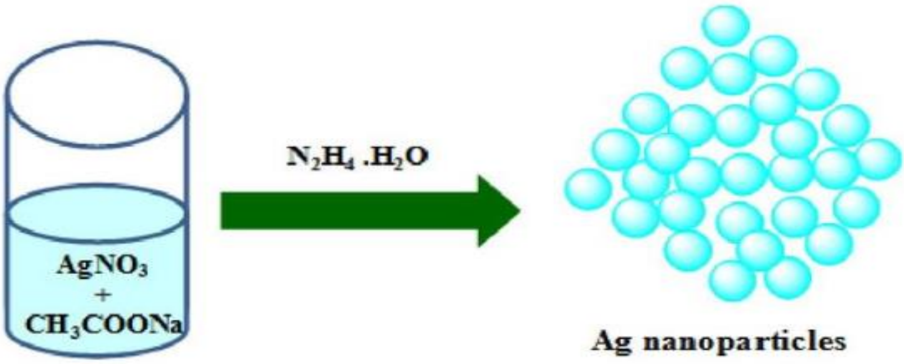

Figure 3: Synthesis of silver nanoparticles by evaporation-condensation method.

2.1.4. Arc discharge method

Due to its ease of apparatus setup and capacity for high production rate, the arc discharge technique has attracted much attention for producing nanoparticles (76). This approach has been used to successfully create a variety of nanoparticles. One of the most studied nanomaterials prepared with this process is carbon nanotubes (CNTs). In this method, a direct current (DC) arc discharge was utilized (102) (Figure 4). The process of producing carbon nano-tubes (CNTs) involves applying a current arc voltage across two graphite electrodes, which causes carbon to evaporate while a catalyst is immersed in an inert gas (103).

The arc discharge approach may be used to synthesize nanoparticles in either continuous or pulsed mode (104). High-purity graphite is employed as an electrode in the production of MWNTs and SWNTs, and arc discharge may be performed in helium or hydrogen gas (105). The arc discharge technique needs vacuum equipment with an effective cooling system. Then the precursor is introduced and heated by the thermal plasma, which creates the ideal environment for the induction of processes that result in super-saturation and particle nucleation (40). It breaks down into radicals, atoms, and ions in the presence of thermal plasma to create an ionized gas at high temperature (106). The plasma arc's high temperatures and dense concentration of species cause a diffusion mechanism that quickly quenches gas species. This condense to form particles during this process after cooling down by combining with a cold gas or being enlarged by a nozzle (107).

Koushika, Shanmugavelayutham (108), created Fe_3O_4-NPs from mild steel scrap via transferred arc plasma approach. Similarly, Si-NPs was created by using a radio-frequency thermal plasma technique to recycle silicon waste (Lee, Kim, (109)). Several metals, alloys, and metal oxides NPs have been synthesized effectively using plasma methods (46). The composition, size, and shape of NPs may be readily adjusted by altering some parameters such as raw material composition, applied voltage and current, gas type and concentration within the reaction chamber, and reaction type (110). Helium, argon, nitrogen, air, and hydrogen are the most common gasses for producing thermal plasma (111).

Typically, experimental factors are changed to improve the arc discharge process, including current/voltage, buffer gas, catalysts, carbon sources, electrode morphologies, external fields, etc. (112). In essence, the experimental parameters determine the plasma characteristics, the spatial distribution, and the nucleation and development of carbon in the space and time domains (113). In most situations, nanoparticles generated via the arc discharge process are exposed to high cooling rates. The homogeneity of the nanoparticles created using this process often degrades due to uneven cooling. Thus, regulating particle nucleation and development requires attention (114).

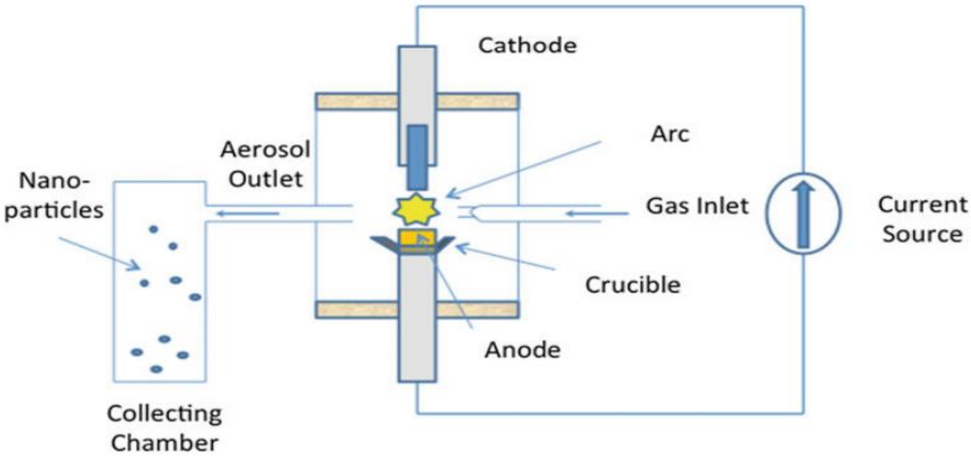

Figure 4: Schematic representation of the experimental configuration for arc discharge in gas chamber (115).

2.1.5. Sputtering

Sputtering involves depositing a thin layer of nanoparticles, which are formed through an annealing process (116). This approach is known as physical vapour deposition, and its efficiency is primarily determined by parameters such as layer thickness, temperature, substrate type, and annealing time (117). All these factors directly impact the nanoparticles' shapes and sizes (118). Ion sputtering is a physical process for depositing substrates that employ high-energy equipment and an ionized plasma (119, 120). The method relies on injecting argon gas, which when exposed to a powerful electric field creates a plasma inside the cavitate and causes the ions to move as an intensely focused ion beam from the anode to the cathode (49). In most circumstances, the concentrated ion beams are sputtered on a selected substance as an adhering film. Since this is a top-down method, a high vacuum is necessary in order to accelerate the gas ions and finish the deposition (121).

In order to better monitor the changes in single molecule analysis techniques like surface-enhanced Raman spectroscopy, López-Lorente, Picca (122), utilized ion beam sputtering to deposit nanocomposites using variable proportions of Ag and TiO_x/ZnO on silica surfaces (SERS). Three samples were created: an Ag-TiO_x composite made with two co-sputtering targets, Ag-NPs deposited on ZnO, and Ag-NPs deposited on TiO_x. The results of the study showed that the substrate's sensitivity can be increased by adding silver and ceramics, allowing for the collection of more detailed information via vibrational spectroscopy. The samples made of Ag/TiOx increased the SERS while also functioning as photocatalytic materials. The study showed that, in addition to their antibacterial effects, Ag-NPs also possess exceptional chemistry and surface functionalization abilities; hence, using Ag-NPs as spectroscopic substrates is a feasible strategy for further research (50). Also, Zhao, Zhang (123), reported the preparation of Sn-NiO films via simple one-step magnetron sputtering process for a superior electrochromic performance. The amount of Sn in the Sn-NiO films was controlled by adjusting the sputtering power of the SnO_2 target. The optimized Sn-NiO film was used as an anodic electrochromic layer to prepare inorganic all solid-state electrochromic device (ECD) and the ECD displayed excellent electrochromic perfor-mance. The strategy of preparing NiO modified by Sn^{4+} ion presents an innovative direction to obtain high performance electrochromic materials for energy saving smart windows. Wang, Qu (124), reported the preparation of Cu-doped Ag thin films via magnetron co-sputtering method which was successfully fabricated on SiO_2 substrate. He discovered that the peak value of 36.8 dB is the highest shielding effectiveness at an optimal concentration of 2 mol%. This exceptional property make Cu-doped Ag films highly valuable and applicable for electromagnetic shielding in transparent windows which is as a result of Co-sputtering method.

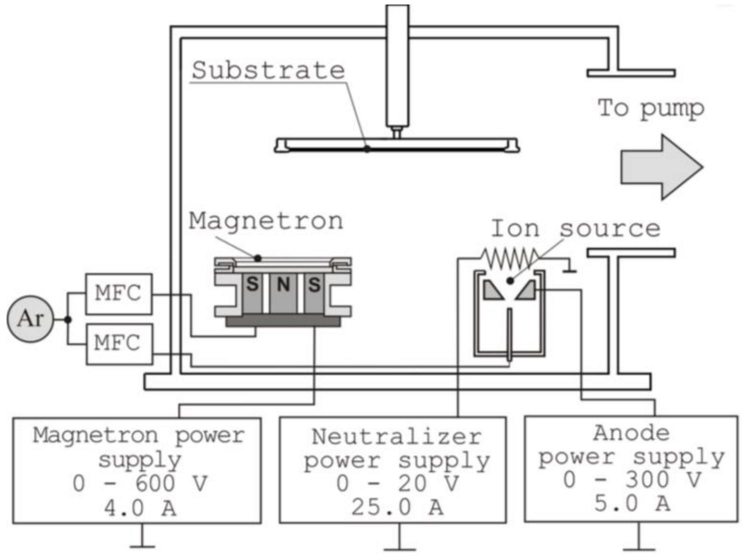

Figure 5: Schematic representation of the experimental configuration for sputtering (124).

2.2. Biological Methods of Synthesizing Nanomaterials

Green synthesis of nanoparticles by various physiochemical processes necessitates considerable energy consumption, harsh reaction conditions, costs, and the usage of harmful substances (125). Synthetic ways of producing nanoparticles also generates some hazardous by-products that are harmful to the environment and living things (126). Biological synthesis commonly referred to as "green synthesis", is an alternative route to the production of nanoparticles. Green synthesis of nanoparticles is a new topic in nanoscience that includes the efficient preparation of functional nanoparticles utilizing plant extracts, bacteria, and fungi (127). Biological pathways are beneficial in various fields since they are simple, safe, biocompatible, and harmless to living things and the environment (128, 129). The green synthesis process is not only dependable, economical, and time-saving, but it also reduces the creation of hazardous waste (130, 131). The green strategy for the synthesis of nanoparticles is the preferable technology since it does not involve significant energy consumption, such as high pressure or temperature. In contrast to the other synthesis methods, it employs moderate reaction conditions and nontoxic precursors (132).

The use of plants and microorganisms to synthesize metal nanoparticles has excited lots of research interests (133, 134). Numerous metallic nanoparticles have recently been created using a green method and are widely employed in the pharmaceutical and biological industries (135). However, biologically synthesized nanoparticles play an essential role in the environmental and biomedical domains due to their high yield, enhanced stability, excellent biocompatibility, and lower bio-toxicity (136). Furthermore, as interest in sustainable development grows, so does interest in biological synthesis, since it conserves raw resources and decreases the use of dangerous chemicals (137). Plant components such as seeds, leaves, peels, fruits, and flowers are high in phytochemicals including terpenoids, phenols, etc which function as reducing agents (137-140). The production of NPs by microorganisms and plants has several benefits, including mono-dispersity, the absence of harmful compounds, effective, fast, and eco-friendly process (1). The synthesis of NPs depends critically on factors like pH, incubation period, and temperature (141). Metal-alloy NPs (MNP), which were generated biologically, showed superior biocompatibility than metal alloy NPs manufactured using diverse physicochemical approaches (142). Biologically produced MNPs have been widely employed to address difficulties or to boost process efficiency in industries and biomedical sciences (143-145).

2.2.1. Green synthesis using microorganism

Microbes offer enormous potentials for producing ecologically friendly metallic nanoparticles (MNPs) without the need for traditional physical or chemical methods (146). Microbes are everywhere, and they may swiftly adapt to their surroundings and develop tolerance to hazardous metals (147). Enzymes in physiological and biological functions enable microorganisms to create metallic alloy NPs. The proteins, enzymes, and functional groups are all known for their ability to decrease ions (148). Two fundamental strategies underlie microbial resistance to hazardous metals. Nanoparticles (NPs) may be produced by microbes both intracellularly and extracellularly. Microbes may generate materials of various sizes and morphologies at the nanoscale by bio-mineralizing inorganic minerals intracellularly or extracellularly (147, 149). The transfer of metal ions into the microorganism causes the intracellular synthesis of metallic alloy NPs (137). In contrast, the extracellular approach also involves the metal ion concentration at the cell surface (150). In a nutshell, for the extracellular approach, the specific microorganism is cultivated for 1–2 days in a rotary shaker, the biomass is separated through centrifugation, while the supernatant is collected (50). MNPs are created by combining a specific ratio of cell-free culture supernatant and filter-sterilized metallic salt solution, then incubating the mixture at the ideal temperature (151, 152).

In contrast to generated intracellular MNPs, the microbial biomass is centrifuged and thoroughly washed with sterile water (125). The biomass is then dissolved in a metallic salt solution that has been asterilized. The combination is incubated as a visible colour change is monitored (153). The biomass is removed by centrifugation after several cycles of sonication, and the produced MNPs are then quantified using a UV spectrophotometer (145, 154). The microbial cell wall/membrane is broken down by ultrasonication, allowing the MNPs to exit the cell (142). Because it does not need the same processing steps as intracellular production and recovery of MNPs, such as centrifugation, sonication, and washing, extracellular synthesis of MNPs is regarded as a low-cost, fast, and scalable technique (155). Diverse fungal metabolites with improved oxidation/reduction potential and increased bioaccumulation potential have been used to study the mycosynthesis of MNPs using simple, environmentally safe methods (156). Three different phenomena, including electron shuttle quinones, nitrate reductase activity, and their interactions, have been characterized for the myco-mediated generation of MNPs (157). For the production of various MNPs, many enzymes have been identified, including NADPH-dependent reductases in the case of *Fusariumoxysporum* and nitrate reductase in the case of *Penicillium sp* (59). Few studies have demonstrated how *actinomycetes* contribute to the development of MNPs (158). *Actinomycetes* have the potential to be used in the synthesis of stable, mono-dispersed MNPs, but further studies are needed (159).

Kalpana and Devi Rajeswari (149), synthesized ZnO NPs from Vitexnegundo plant extract using zinc nitrate hexahydrate as a precursor. Bio-synthesised ZnO nanoparticles with size of 40.5-20.8 nm exhibited antibacterial properties against *Staphylococcus aureus* and *Escherichia coli*. Undabarrena, Ugalde (160) reported that the reductase enzyme from *Streptomyces sp*. has been used to synthesize zinc with 11.84-24.82 nm size, copper with 6.93 nm size, and silver NPs with 5.62 nm size and MNPs. Yeast has been utilized to synthesize MNPs by downstream techniques AbdelRahim, Mahmoud (161). Capsids of genetically modified viruses has also been utilized as bio-templates to create titanium nanostructures and quantum dot nano-wires (156, 157). Semiconductor nanoparticles have also been synthesized by using some biological molecules including polyphosphates, amino acids, and fatty acids as templates. Other biological techniques for green nanostructure synthesis include protein cages (162), DNA (163), bio-lipid cylinders (164), multi-cellular superstructures (165), and viroid capsules (166), which have been used for template-mediated MNP production (167). This process is represented in Fig. 6.

Figure 6: Green synthesis of nanoparticles by various microorganisms (168).

2.2.2. Green synthesis using plants

Plants contain a variety of molecular functions, naturally occurring compounds, secondary metabolites, or phytochemicals, which may be exploited as efficient biological factories to deal with environmental toxins caused by industrial wastes (169). Synthesis via the use of plant extracts allow a considerably easier approach to creating nanoparticles in more significant quantities than microbe-mediated synthesis (15). The solvent, pressure, temperature, and pH conditions in green synthesis approaches are all essential considerations (150). Numerous plant extracts, particularly those from the leaves, have been thoroughly studied for NPs production because they contain a variety of useful phyto-chemicals like flavones, terpenoids, ketones, phenols, amides, aldehydes, carboxylic acids, and ascorbic acids (1). These bio-molecules can transform metal salts into metal nanoparticles, which have been explored for diagnostic and anti-microbial applications (170).

Plants also offer several potential uses in biomedicine due to the presence of biologically active substances such as flavonoids, alkaloids, terpenoids, saponins, polyphenols, co-enzymes, carbohydrates, vitamins and proteins (171). In Ayurvedic, Thai, and Chinese traditional medicine, plants have been extensively used to treat various illnesses, including skin conditions, rheumatism, venereal infections, and beriberi (169). The biological effects of plants have been found to include antimycotic, antibacterial, antiviral, free radical scavenging, anticancer, and anti-inflammatory properties (172).

Therefore, a replacement option for producing nanoparticles is by employing plants and their components. Because they are non-toxic, naturally capable of capping ends, reduce metal ions, and can accumulate heavy metals in their cells. Synthesis of nanoparticles with plants involves a simple, energy-free, quick, and affordable approach (173). Nanoparticles produced from plants or their components have the requisite size and form, are non-toxic, biocompatible, stable, have enhanced activity, and have a solid capacity to penetrate (174). Plant and its component include numerous biochemicals that play a vital role in reducing, capping and stabilizing metal ions to nanoparticles (135, 175). Recently, scientists have been focusing on plants to biosynthesize biocompatible nanoparticles. Secondary plant metabolites may play a vital and critical function as reducers, and stabilizing agents for biosynthesizing nanoparticles (150).

Additionally, phytochemicals' surface adsorption results in biocompatible nanoparticles' formation (176). Instead of using nanoparticles that are produced routinely, they might additionally improve the biological properties of nanoparticles. The use of plants in the synthesis of nanoparticles offers a number of advantages since it are dependable, simple, economical, easy to scale up, and ecologically friendly (177). Plants are also preferable to microbial synthesis methods for the green production of nanoparticles since they need less time, are safe, and do not require complex laboratory infrastructure (178).

Ijaz, Shahid (179), reported the fabrication of CuO-NPs using *Abutilon indicum* leaves aqueous extract and described A one-port synthesis of ZnO and Cu-doped ZnO nanoparticles using aqueous leaf extracts of *Abutilon indicum* and *Clerodendrum infortunatum* has been described Khan and Lee (180). Several components, including fruits, leaves, fruit peels, roots, and seeds, have been used to prepare Au nanoparticle, Ag nanoparticle, Pd nanoparticle, Pd/Fe_3O_4 nanoparticle, and Pd/CuO nanoparticle, respectively (127). The initial stage in producing nanoparticles by plants is collecting desirable plant parts, such as leaves, fruits, and roots followed by cleaning and drying as shown in Figure 7. The dried material is then grinded and heated for an extended period at the ideal temperature. Plant solid waste is filtered using plant extract. Metal salt solution and aqueous plant extract are heated at optimal temperature conditions. The nanoparticle synthesis production may be determined by visual examination (130, 181). Plants produce nanoparticles by reducing metal ions into NPs through redox reactions such as the enol-to-keto-transformation, which are electron-rich phytochemical molecular functions found in sugars, polyphenols, and flavonoids in plant extract (182, 183). Saponins, alkaloids, terpenoids, co-enzymes, and proteins in plant extracts capped and stabilized the nanoparticles (180).

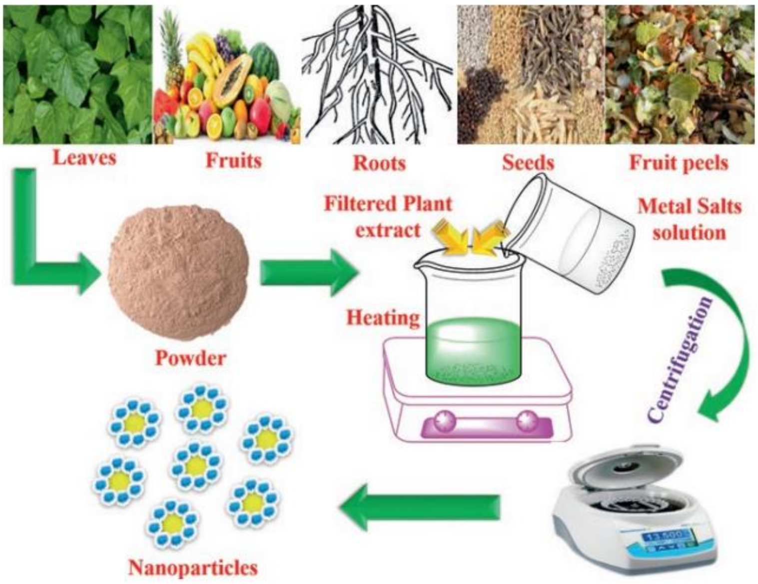

Figure 7: Green nanoparticle synthesis using various plant components, such as leaves, fruits peel, fruits, roots, and seeds (180).

2.3. Chemical Methods of Synthesis of Various Nanoparticles

This section detailed numerous chemical techniques for the preparation of various nanomaterials. This highlights the significance and comparative merit of one strategy over the others.

2.3.1. Hydrothermal method

This method involves preparing nanoparticles in an aqueous medium under high temperature and pressure. Different studies have examined the use of hydrothermal method to prepare various nanoparticles, including titanium oxide and graphene oxide among others (184). Even while hydrothermal technology is regarded as cost-effective and environmentally beneficial, it frequently involves high temperatures (185). An autoclave has a temperature range of 160 to 180 °C (87). However, there are several limitations, such as the inability to clearly see the crystal material growing in autoclave and the expensive nature of the equipment. When the temperature in the autoclave exceeds the boiling point of water, the pressure reaches saturation with vapour. The autoclave's temperature and the volume of solution supplied directly affect how much internal pressure is generated (186). Synthesis of zinc oxide was reported by Bulcha, Leta Tesfaye (187) which was been synthesized using hydrothermal method. He reported successful production of zinc oxide synthesis. Jubeer, Manthrammel (188), also reported the synthesis of ZnS nanoparticle through the hydrothermal method which was found successful. Chen, Liu (189) and Khan, Usman (190) synthesis Ce-doped SnO_2 hollow spheres and $CuAl_2O_4$/rGO nanocomposites respectively using one-pot hydrothermal method and from there finding the synthesis was successful. Figure 8 is an example of hydrothermal synthesis method of nan- oparticle showing the synthesis of GO nanoparticle.

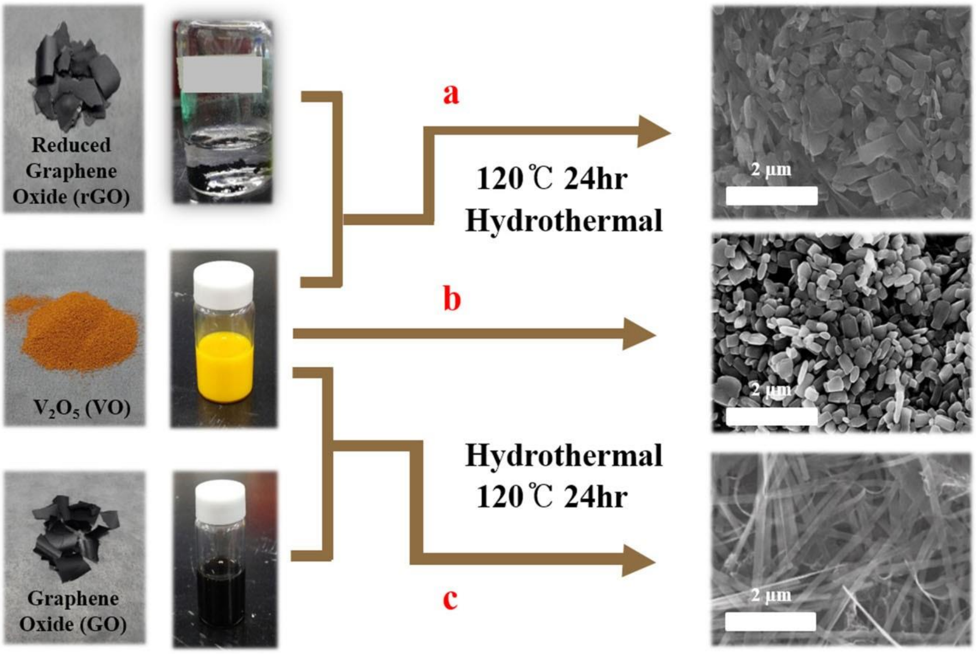

Figure 8: Synthesis of GO nanoparticle using Hydrothermal Method (24).

2.3.2. Solvothermal method

This method involves the application of non-aqueous solution (precursor and non-aqueous solvent) at high temperature and pressure to produce various nanoparticles. Both synthesis in alkaline environments and in the presence of organic molecule precursors fall under the solvo-thermal technology which involves the reaction between precursor(s) in a solvent in a close system (191). The use of a solvothermal method to create nanoparticles offers a number of benefits, including economical, and releasing nearly no by-products throughout the reaction (192). For instance, Perumal, MonikandaPrabu (193), demonstrated a solvothermal method for producing TiO_2 nanop- articles, using toluene and titanium tetra isopropoxide as the solvent. The solution underwent thermal treatment in a stainless steel autoclave at 250 °C for 5 hours at a rate of 20 °C/min, followed by two hours of calcinations at 550 °C. The XRD measurement showed the synthesis of pure anatase TiO_2 nanoparticles with a particle size of 20 nm, in contrast to the SEM images that showed particles with irregular shapes and an average size in the range of 7–14 nm. Similarly, ammonium citratoperotitanate and polyvinyl alcohol (PVA) were used to create anatase TiO_2 nanoparticles Uematsu, Baba (194). The PVA was mixed with the titanium precursor, which was then micro-waved to evaporation. Kløve, Philippot (195), reported the synthesis of pure-phase tetragonal ZrO_2 nanoparticle via simple solvothermal synthesis. Different types of Alcohol were used for condition variation as solvent and studies using in-situ scattering. The variation of tetragonal or monoclinic phase ratios within the produced powders was directly correlated with the amount of in-situ generated water from solvent dehydration during the syntheses. Zhang, Feng (196), reported the synthesis of hollow CoSx@CdS polyhedron constructed by ZIF-67 via one-pot solvothermal route. It was discovered that the photocurrent responses of the CoS_x@CdS-modified ITO electrodes could be specifically turned on by Hg^{2+}, in contrast to these of the CoS_x or CdS-modified ones showing no significant Hg^{2+} induced photocurrent. Under visible light irradiation, herein, the synergetic combination of CoS_x and CdS components could improve the carriers transferring of photoelectrochemical system. Figure 9 summarized solvothermal synthesis method of nanoparticles.

Figure 9: Synthesis of Nanoparticle using Solvothermal Method (24).

2.3.3. Co-precipitation Method

This entails the co-precipitation of metal cations from several sources, including hydroxides, citrates, carbonates, and oxalates (197). At the suitable temperature, these precipitates are transformed into powders because the demerit of this method is that product co-precipitates with unwanted contaminants as well as the analyte (198). By producing inclusion and occlusion (when a contaminant generates a frame site in the transporter's crystal structure, which is about a crystallographic fault), re-precipitating the analyte can correct this imperfection (when an adsorbed contamination becomes physically surrounded inside the crystal) Priyadharshini, Shobika (199), Nickel ferrite nanoparticles was prepared using the co-precipitation process with starting materials such as; $Ni(NO_3)_2.6H_2O$ and $Fe(NO_3)_3.9H_2O$ before annealing the samples at various temperatures (500 °C, 700 °C, and 900 °C). According to the XRD study, a highly crystalline ferrite phase was formed, with average crystallite sizes ranging from 9 to 21 nm, depending on the annealing temperature. Priyadharshini, Shobika (199), also used a co-precipitation technique to create $NiFe_2O_4$ nanoparticles. The creation of the cubic spinal phase of $NiFe_2O_4$ was confirmed by XRD analysis, and SEM analysis revealed the formation of spherical particles with an average particle size of 28 nm. Although this approach is difficult and expensive, co-precipitation produces nanoparticles whose shapes are unpredictable, necessitating more deliberate efforts to achieve the desired particle size and form. Figure 10 presents the synthesis procedure.

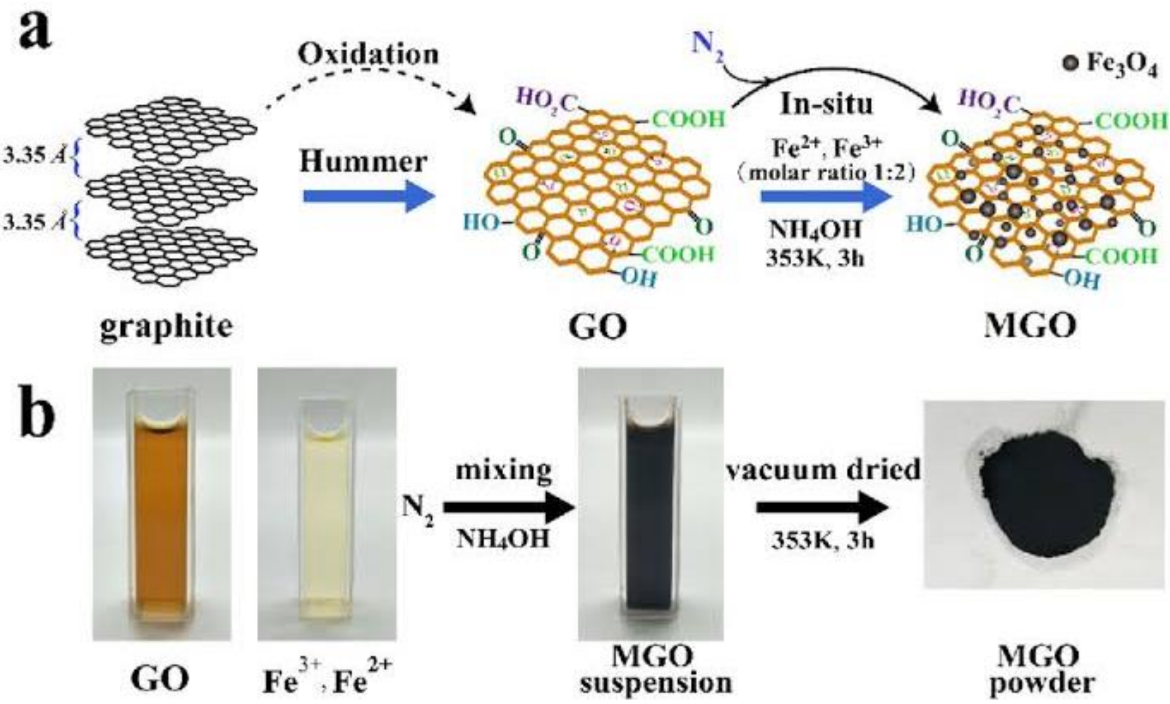

Figure 10: Synthesis of Nanoparticle using Co-precipitation Method (197).

2.3.4. Sol-gel method

This is a straightforward and affordable wet-chemical approach used to create composite materials with exceptional control over size. With this method, the solution (sol) progressively develops into a gel-like substance that is composed of both liquid and solid phase (18, 200). Non-aqueous and aqueous sol-gel syntheses are the two types of sol-gel methods. The initial stage in creating a rational synthesis for non-aqueous sol-gel creation of metal oxide nanoparticles is to elaborate the chemical formation mechanism alongside investigations on the crystallization process (201). However, in order to verify that this technique yields comprehensive results, it is necessary to explore many characterizations qualities, including crystallographic and microscopy.

In contrast, the hydrolysis of metal alkoxides occurs very fast in aqueous conditions when using the sol-gel method, complicating the ability to control reaction rate. When using the non-aqueous sol-gel approach, the carbon-oxygen bond may be applied with moderate reactivity at a low reaction temperature, which causes the nanoparticle to have a high crystallinity. The right solvent must be selected because it has a significant impact on how nanoparticles develop. For instance, Ahmed, Aly (202), used the sol gel approach to create titanium dioxide (TiO_2) nanoparticles by combining ethanol and titanium chloride ($TiCl_4$). The created TiO_2 nanoparticles were calcined for two hours at various temperatures between 200 and 800 °C. Up to 400 °C, these materials demonstrated good thermal resilience.

Polyacrylic acid (PAA) was used as a chelating agent in the sol-gel process to create spinel nickel ferrite nanoparticles. $NiFe_2O_4$ nanoparticles' size, specific surface area, and crystallinity were all influenced by the molar ratios of PAA to total metal ions and the calcination temperature (203). Using glycine gels made from metal nitrate and glycine solutions, Liu, Guo (204), adapted the sol-gel combustion process to create ultrafine barium ferrite ($BaFe_{12}O_{19}$) nanoparticles with sizes ranging from 55 to 110 nm. Furthermore, Zakir, Iqbal (205), used the sol-gel auto combustion approach to create spinel nickel ferrite ($NiFe_2O_4$) nanoparticles. Figure 11 summarized sol-gel synthesis method of nanoparticle.

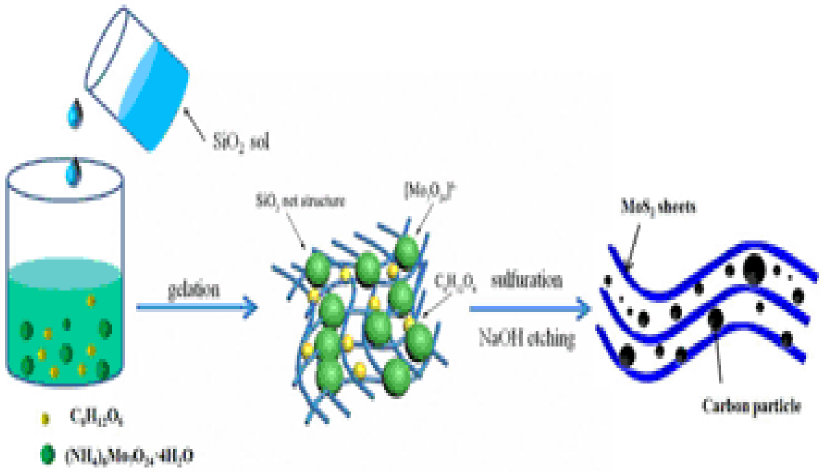

Figure 11: Synthesis of nanoparticles using Sol-gel Method (200).

2.3.5. Solution mixing method

The fundamental method for mixing solutions is in a solvent system. This method uses electrospinning to combine two distinct nanoparticles in a solution. Since there is no chemical connection between the new substance and the base, the main disadvantage is the potential leaching of the added material. For instance, the synthesis of Zinc doped Iron oxide/GO/Polymer ternary nanocomposites using solution mixing approach was explored by Suneetha, Selvi (206). The impedance study showed that the modified electrode made of nanoparticle had an excellent capacitance with a bond phase angle of 87° and was a promising candidate for use in super capacitors. Zeng, Teng (207), used ultrasonic techniques to create Al-graphene oxide composites, and they discovered that the materials had a 255 MPa tensile strength. The creation of graphene oxide metal oxide/metal nanocomposites has been shown to improve mechanical qualities and address a variety of energy and environmental-related problems. An effective method for producing graphene-TiO_2 nanomaterials by photocatalyzing the reduction of graphene oxide in solution has been reported Nawaz, Moztahida (208), Figure 12 depicts a simplified solution mixing synthesis process for nanoparticles.

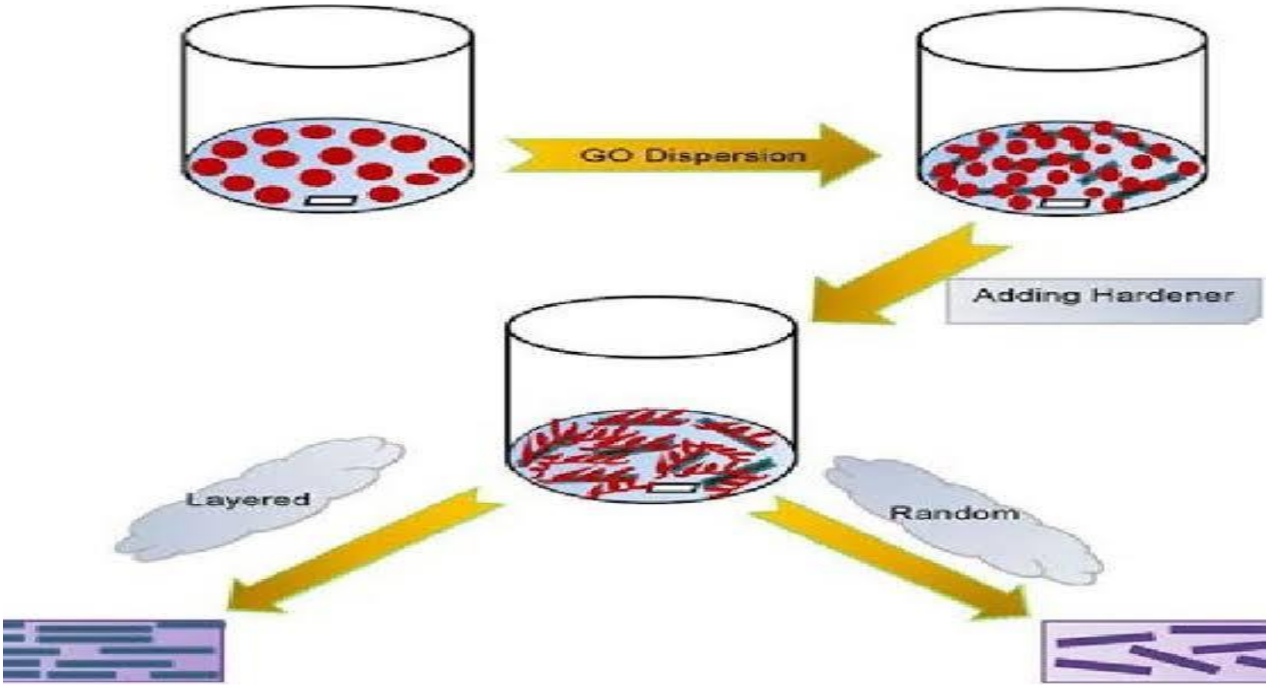

Figure 12: Synthesis of GO nanoparticles using Solution Mixing Method (208).

2.3.6. Chemical vapour deposition (CVD)

Chemical vapour deposition (CVD) is method which involves the deposition of solid materials from a chemical reaction through the production of vapour or vicinity of a normally heated substrate surface. This is an example of vapour-solid reaction which normally used in the production of thin films in semiconductor industry. In this method, vapour phase precursors are brought into a hot wall reactor under conditions that favour nucleation of particles in the vapour phase rather than deposition of a film on the wall. It is called chemical vapour synthesis or chemical vapour condensation in analogy to the chemical vapour deposition processes used to deposit thin solid films on surfaces. This method has tremendous flexibility in producing a wide range of materials. Hong, Liu (209), reported the synthesis of layered two-dimensional $MoSi_2N_4$ material via chemical vapour deposition. The monolayer was built up by septuple atomic layers of N-Si-N-Mo-N-Si-N which can be viewed as a MoN_2 layer sandwiched between two Si-N bilayers. Xu, Zhang (210), reported the synthesis of graphene on thin metal films using chemical vapour deposition which was successfully produced. Thin metal films are usually made by depositing metals on various substrates such as single-crystal sapphire which serves as catalytic substrates for high quality graphene growth. Table 1 is the summary of different synthesis routes to nanoparticles such as chemical, physical, and biological for different applications such as optical communication, membrane, adsorbents sensor, electronic, and antimicrobial.

Table 1: Overview on the synthesis of different nanomaterials.

Nanomaterials	**Synthesis routes**	**Synthesis methods**	**Applications**	**Ref.**
Aramid	Chemical	In-situ	Membrane	(211)
Rubidium chloride doped magnesium oxide	Chemical	Green	Optical communication	(212)
Polyacrylamide hydrogels	Physical	Thermal	Membrane	(213)
Hyperbranchedpolyethyleneimine	Chemical	Facile	Adsorbent	(214)
Ru–poly(amindoamine)	Chemical	Ionic liquid	Electronic	(215)
MXenes	Chemical	Triple carbides and nitrides MAX	Membrane	(216)
Amine functionalized mesoporous silica	Chemical	Etching and polymerization	Adsorbent	(217)
Carbon dots-based covalent	Chemical	Schiff-base reaction	Food additive and adsorbent	(218)
ZnO	Physical Chemical	Carbon microspheres	Sensor and adsorbent	(219)
Graphite flakes and carbon-based nanomaterials	Physical	Thermal	-	(220)
In_2O_3	Physical	Hydrothermal and calcination	Sensor	(221)
TiO_2/WO_{3-x} hybrid	Chemical	Ethanoic acid	Nanowire	(222)

Nanomaterials	Synthesis routes	Synthesis methods	Applications	Ref.
Tungsten oxide	Physical Chemical	Hydrothermal and Dissolution	Electronic	(223)
One-dimensional α-MoO_3	Physical	Hydrothermal	Sensor	(224)
$BaLa_2ZnO_5:Dy^{3+}$	Physical	Dissolution and thermal processes	Solar cell	(225)
Nano-Fe_3O_4@TiO_2-Pr-2AB@Cu	Chemical	Coprecipitation	Cosmetic	(226)
Ag/ZnO	Chemical	Facile	Antibacterial	(227)
$CoNi_2S_4$	Physical Chemical	Dissolution and calcination	Adsorbent	(228)
$MgFe_2O_4$	Physical	Microwave solution combustion	Dye degrader	(229)
Pd-dopedCeO_2	Physical	Hydrothermal	Sensor	(230)
$Ba_2YAlO_5:Dy^{3+}$	Physical	Propellant combustion	Electronic	(231)
AgNPs	Biological Chemical	Plant extraction	Antimicrobial	(232)
CNMs	Physical Chemical	Surface activation and heating	Membrane	(233)
Sn–SnO_2–C	Physical	Monte-Carlo reaction	Electronic	(234)
MoO_x/Nb_2O_5	Physical	Calcination	Medical	(235)
GO-MgO	Biological	Plant extraction	Adsorbent	(236)
Silica nanoparticles, graphene nanosheets and graphene oxide nanosheets	Physical	Ambient fiery and furnace	Medical	(237)
TiO_2/Ag	Chemical	Sterilization and purification	Electronic	(238)
$Mg(OH)_2$	Biological	Seaweed extraction	Anti-mycobacterial	(239)
Tris(selenobenzoato)antimony(III), tris(selenobenzoato)bismuth(III) and bis(selenobenzoato)dibutyltin(IV)	Chemical	One pot process	Electronic	(240)
$NaBH_4$ and $FeCl_3{\cdot}6H_2O$	Chemical	In-situ	Algae harvesting	(241)
Metal ion dopedZnO	Physical	Combustion	Adsorbent	(242)
Porous TiO_2	Biological	Biomass assistance	Electronic	(243)
CaO	Biological Physical	Fruit extraction and furnace	Antimicrobial	(244)
Bimetallic Cu-Ni hybrid	Biological Chemical	Plant extraction and dissolution	Antimicrobial	(245)
α-MnS	Chemical	Dissolution	Electronic	(246)
$Ca_3MgAl_{10}O_{17}$	Chemical	Facile	Sensor	(247)
SWCNT-hybrid	Chemical	Subphthalocyanine substitution	Electronic	(248)
$FeFe_2O_4$	Chemical	Facile	Adsorbent	(249)
Biogenicgold	Chemical	Dissolution	Electronic	(250)
Zn–F co-dopedTiO_2	Physical	Sol-gel and coprecipitation	Electronic	(251)
2-methyl-6-nitroquinoline	Chemical	Cyclization reaction	Medical	(252)
$CuFe_2O_4$	Biological	Waste eggshell extraction	Adsorbent and antibacterial	(253)
ZnO_xS_{1-x}	Chemical	Facile	Adsorbent	(254)
$Zn_xFe_{3-x}O_4$ redox	Chemical	Dissolution	Adsorbent	(255)
Gd doped α-Sb_2O_4	Physical	Washing and calcinations	Electronic	(256)

3. METHODOLOGY

Scopus Database was chosen for data collection of the current study primarily due to the broad range of data covered, in-depth coverage of various publications (especially with regard to citation by source), and the system that ensures rigorous peer review(257). The data were searched and collated on the 30th December, 2022, with the search scope being inclusive of all sorts of articles available in the WoS database to ensure that the current study covered all potentially relevant publications. Important search terms were encapsulated in double quote marks to produce the best results, and related terms were split using the OR operator to produce a wider range of results. Examples of keywords include Title-ABS-KEY [synthesis AND nanoparticle] and Title-ABS-KEY [synthesis AND nanoparticle]. As an alternative, TITLE-ABS-KEY [nanomaterial] and TITLE-ABS-KEY [synthesis] were chosen to search for recent papers between 2010 and 2023, which will ultimately help recognize and study various research topics with a higher number of publications.

The WoS website also generated citation statistics so users could see the year-by-year trend of documents published and the frequency with which they were cited. In order to determine the quantity of publications relative to various authors, nations, affiliations, research areas, publishers, and journals, the WoS website was also examined. Lastly, the downloaded data were imported into the VOSviewer 1.6.18.0 programme to plot co-occurrence maps of author keywords used in the articles as well as network maps showing relationships between authors and nations.

In order to create network maps with respect to various parameters such as author, citation, organization, country, and keyword co-occurrence, Ludo Waltman and Nees Jan van Eck created the free-to-use scientometric programme VOS viewer (Visualisation of Similarities). The dataset was also sorted using the three metrics of total link strength, document count, and citation count using the VOSviewer software. According to the data, a frame's dominance in network maps increases with frame size, and a frame's networking power increases with the number of lines that originate from it (a line serves as a connection between two frames). When it comes to keyword co-occurrence maps, the larger the frame size, the more frequently a keyword is used. Various applications were assessed by examining the most recent, pertinent, and highly referenced publications found on the WoS website, in addition to the various network mapping and trend studies, and mechanistic insights were presented for each nanoparticle synthesis.

4. RESULTS AND DISCUSSION

4.1. Primary Details and Publication Patterns

117,162 publications of the total documents from more than 15,568 sources had more than 19000 keywords in addition to the author's own keywords with an average of 15 citations per document and more than 2000 authors. In Figure 13, the analyzed papers span the period of January 2010 to December 2022, indicating that research is progressing to improve synthesis of different nanoparticles.

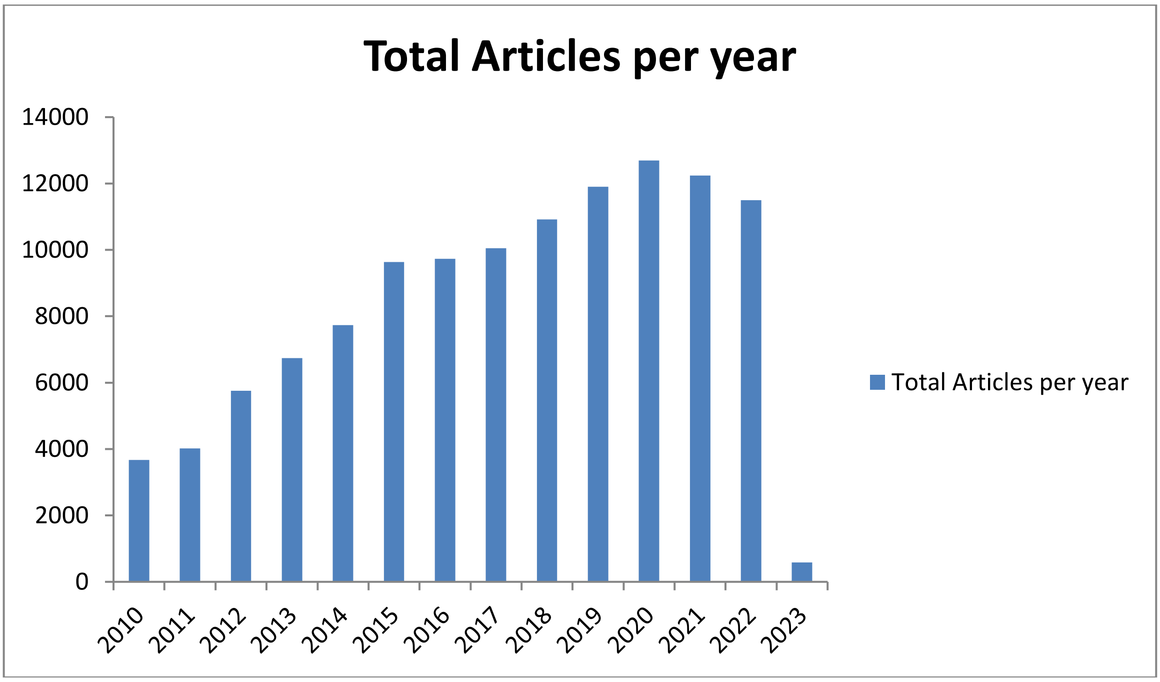

Figure 13: General patterns of the publications per year.

Between 2007 and 2020, the overall number of annual publications grew gradually. The chart, however, demonstrates that following the available information on Scopus whereby there was low publication between 1985 and 2009. The lack of research papers during those years can be linked to a lack of understanding of the application of nanotechnology which ultimately led to an increase in publication output starting in 2010. With 12,691 and 12,237 documents for 2020 and 2021 respectively reported the largest publication production. The reason why 2020 was the largest yearly publication was because researchers concentrate much on research due to Covid-19 pandemics lockdown.

4.2. Performance of Various Journals

About 111,553 journals in total have published studies on the synthesis of nanoparticles. Table 2 highlights the h-index and other performance metrics-based lists of the 20 most relevant journals. The top 20 journals generated more than 25 % of the total papers related to synthesis of nanoparticles over the course of the 13 years, indicating both a widespread distribution of these publications and a general interest in these devices. 2638, 2138, 1712, 1599 and 1577 articles are the five most prominent journals by total number of publications (TNP) are RSC Advances, Journal of Colloid and Interface Science, Journal of Nanoparticle Research, ACS Applied Materials and Interfaces and chemical Communication respectively.

Table 2: Top 20 most published Journals.

Rank	Sources	Documents	IF
1	RSC Advances	2628	4.036
2	Journal of Colloid and Interface Science	2138	9.965
3	Journal of Nanoparticle Research	1712	2.533
4	ACS Applied Materials and Interfaces	1599	10.383
5	Chemical Communications	1577	6.065
6	New Journal of Chemistry	1574	3.925
7	Journal of Alloys and Compounds	1551	6.371
8	Colloids and Surfaces A Physicochemical And Engineering Aspects	1507	5.518
9	Journal of Materials Science Materials in Electronics	1359	2.779
10	Materials Letters	1357	3.574
11	Applied Surface Science	1282	7.392
12	Ceramics International	1242	5.532
13	Nanoscale	1214	8.307
14	Materials Today Proceedings	1213	-
15	Journal of The American Chemical Society	1123	16.383
16	Colloids and Surfaces B Biointerfaces	1122	5.999
17	International Journal of Biological Macromolecules	1040	8.025
18	Materials Chemistry and Physics	923	4.094
19	Journal of Nanoscience and Nanotechnology	872	4.849
20	Langmuir	848	4.331

4.3. Authors' Characteristics

4.3.1. Performances of authors

The research on synthesis of nanoparticles was written by more than 1650 authors. Table 3 depicts the top ten most prolific authors in terms of publication, together with their total number of publications. The first author in the top ten most productive authors has the most articles published (196), while the tenth author has the fewest (85). More than half of these writers are from the top ten most productive countries, implying that they are more productive in the field of research. Prof. Salavati-Niasari has the most published articles (196), indicating that he has a good academic performance with scientific quality and that the majority of his works are well known. Prof.Rajeshkumar is the second-most prolific author in terms of publication, with 137 papers.

Table 3: Top 20 most published authors.

Ranks	Authors	Documents
1	Salavati-Niasari, M	196
2	Rajeshkumar, S	137
3	Asiri, A.M	129
4	Baykal, A.	112
5	Chen, S.M	105
6	Nasrollahzadeh, M	99
7	Ghaedi, M	89
8	Maaza, M	87
9	Darroudi, M	86
10	Morsali, A	85

4.3.2. Most cited articles

The top most cited publications for the examined period (2010–2023) were also concerned about the first authors' countries, the journal's name, and the number of TCs. Differences in the number of citations or references received in a given year can be used to quantify the impact of publications and the authors' influence. As shown in Figure 13, most prolific authors are from China, India, United States, and Iran. The article, titled "porphyrin-sensitized solar cells with cobalt (II/III)-based redox electrolyte exceed 12 percent efficiency" was published in science in 2011 with 5475 total citations. The article, titled "MoS_2 nanoparticles grown on graphene: an advanced catalyst for the hydrogen evolution reaction" which appeared in journal of the American chemical society in 2011 and received 4150 total citations, is the second-most referenced article overall. This article provides a general overview of nanostructures, discusses their significance, and reviews current develop-ments in nanostructured on graphene while the article, titled "principles of nanoparticle design for overcoming biological barriers to drug delivery" is the third most cited article. It had 3737 TCs when it was published in Nature Biotechnology in 2015. The research described the principles of nanoparticle design for overcoming biological barriers to drug delivery.

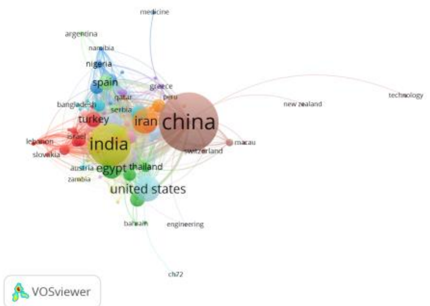

Figure 14: The Map of top 20 countries in terms of academic cooperation for Nanoparticle synthesis.
Colour caption: The colour size indicate the percentage quantities of nanoparticle synthesized countries with their collaborator.

5. CONCLUSION

In this review, different synthesis methods of several nanoparticles such as chemical, physical and biological techniques were discussed. The co-precipitation approach is a chemical synthesis route and it is the simplest of all techniques while green synthesis produces non-toxic compounds but it has very low yields compared to other techniques. There are many other factors that are associated with these synthesis approaches which are very important such as cost, simplicity, and percentage yield. The character of the products is largely influenced by the specifics of the preparation. The huge specific surface area, quick charge transfers, and the shape of the materials are features that determine the performance of the nanoparticles.

Since various applications of nanoparticles have emerged, bibliometric examination of the evolution of literary works connected to synthesis of nanoparticles has been examined. Between 2010 and December 2022, about 117,162 publications on synthesis of nanoparticles were identified using bibliometric analysis in the Scopus database, and 92% of them were journal articles. The study demonstrates that in the period under evaluation, the literature on synthesis of nanoparticles has advanced significantly. Research publications about synthesis of nanoparticles were published in over 139 sources. The top five journals with more than 30% contributions to the subject field are RSC Advances, Journal of Colloid and Interface Science, Journal of Nanoparticle Research, ACS Applied Materials and Interfaces, and Chemical Communication. The top five most productive nations are as follows: South Korea, China, India, and the United States, with China being the most prolific across all references, indicating its leadership position in nanoparticle synthesis research. The most productive institution is Ministry of Education China with 5,356 articles, followed by Chinese Academy of Sciences with 4,472 articles and CNRS Centre National de la Recherche Scientifique with 1419 articles. The top 10 institutions all have positive international inter-institutional relationships. The bibliometric analysis also identifies the most popular terms, which point to the most popular subject areas. The future of synthesis of nanoparticles lies in the basic development of composite materials from various types of preparations in order to overcome their drawbacks. The bibliometric studies, in our opinion, will motivate academics to further investigate the previously highlighted areas and promote future cooperation.

6. ACKNOWLEDGMENT

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