The Applications of Green Synthesized Silver Nanoparticles: A Review

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Abstract: Nanoscience is a fascinating field of study that has made unique outputs and applications both cost-effective and efficient. Significant and outstanding Nano-based applications have been applied in various sectors such as agricultural, food processing, and pharmaceutical sectors. Nanoparticles with sizes ranging from 1 to 100 nm have a significant measure of the relationship between surface area and volume. Because nanomaterials have a higher bioavailability than bigger particles, they can be used as individual cells; organs, and tissues are all examples of this. Silver is considered as the most researched and used material to prepare nanoparticle. Because of their vast range of prospective uses, silver nanoparticles have sparked a lot of attention. Silver nanoparticles are less hazardous to humans, but they are extremely harmful to bacteria. In biomedical applications, silver nanoparticles have been discovered to be useful in antimicrobial, catalysis, human health, and the environment cleanup. Silver nanoparticles are attractive catalytic materials for a variety of applications due to their outstanding optical and electrical characteristics. This article reviewed the synthesis of silver nanoparticles via green approach and important applications such as antimicrobial activity, insecticidal activity, anticancer activity, nano-biosensors, human health applications, environmental applications, painting application and many others.

Keywords: Nano Silver, Green Synthesis, Plant Extract, Applications, Antimicrobial, Anticancer, Sensors, Paint

1. Introduction

Nanotechnology is a relatively new area of knowledge that is focused with the mathematical nano-size particles of diverse materials (Robinson & Batt, 2014). Nanomaterial is defined as "a matter that has dimensions between 1 to 100 nm (NNI, 2020). Nanoparticles (NPs) are the fundamental structure in nanotechnology. Metal NPs are particularly desired depending on the size of NP because of their physical and chemical properties. (Pfleger et al., 2003). Among noble metal NPs, there are several uses for silver NPs, including nonlinear optics, bio-labelling, spectrally selective covering for solar energy panels absorb, photoreceptors in electrical battery sandwich materials, chemical-reaction catalysts, and antimicrobial activities (Vidhu et al., 2011). Silver NPs have excellent chemical stability (Novikov et al., 2017). Sustainable nanotechnology is a growing field in science and engineering, and has proven to be successful in solving problems in a variety of fields including medical, catalysis, industrial, and agricultural operations (Mata et al., 2012).

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Nanostructures are central to all Nanotechnology applications in nature, and the size of nanoparticles determines their characteristic features (Elemike et al., 2016). In the context of nanoscience and nanotechnologies, it is widely agreed that the focus should be on rather than any other unit of scientific measurement, units of size are used instead. NPs are fascinating because of their incredibly small size and large surface to volume measurable relationship, which when comparing to bulks of equal chemical composition. There are chemical and physical variances in their characteristics including mechanical, biological, and satirical characteristics, chemical action activity, thermal and electrical conductivity, optical absorption, and freezing point (Daniel and Astruc, 2004). NPs are being employed commercially in a range of coating applications, including electronics, energy contact activities, and pharmaceuticals. Such NPs are being used commercially in the pharmaceutical and other medical fields disciplines rely heavily on Ag NPs. (Fig. 1). Because of their appealing physicochemical features, Ag NPs play a significant role in biology and medical research. Silver compounds have long been recognized for their powerful inhibitory and bactericidal effects, and also their ability to suppress a wide spectrum of microorganisms (Nam et al., 2016), It has been used for ages to prevent and treat a variety of ailments, the most common of which include illnesses (Ahmed et al., 2016). Silver NPs have been developed for a variety of physical, biological, and pharmaceutical applications. Several procedures, such as spark discharge, electrochemical reduction, solution irradiation, and cryochemical manufacture may be used to control the amount of silver atoms present in the crystals. Fields, particles, rods, square blocks, wires, films, and coats are some of the materials which some of the numerous shapes that they can take (Nam et al., 2016; Firdhouse & Lalitha, 2015; Nasrollahzadeh, 2014). Different sorts of textile industries, such as dyeing, polishing, tanning, and weaving are all require a variety of various chemicals and colours for manufacturing in order to meet the need for clothes and fashion changes. Because of their greater biocompatibility, biosynthesized Ag NPs are preferred for medicinal applications over chemically synthesized Ag NPs. Green chemistry, which uses extracts from various plant components such as leaves, roots, flowers, seeds, and microorganisms for a variety of applications, is environmentally friendly, non-toxic, and inexpensive (Abdelghany et al., 2018). Many attempts have been made in the last 5 years to create new greener and less expensive nanoparticle production technologies (Ankamwar et al., 2005). In comparison to chemical and physical approaches, biosynthesis of nanoparticles was already recommended as a more cost-effective and ecologically friendly option for producing nanoparticles (Varghese et al., 2015). A variety of microorganisms (such as fungi, bacteria, yeasts, and plants, both intracellular and extracellular) have been used to producing nanoparticles, resulting in increased agricultural yields and cheaper costs (Kathiravan, 2015). This research aims to explore novel avenues for nanomaterial biogenesis as antibacterial agents in the future, as well as potential applications.

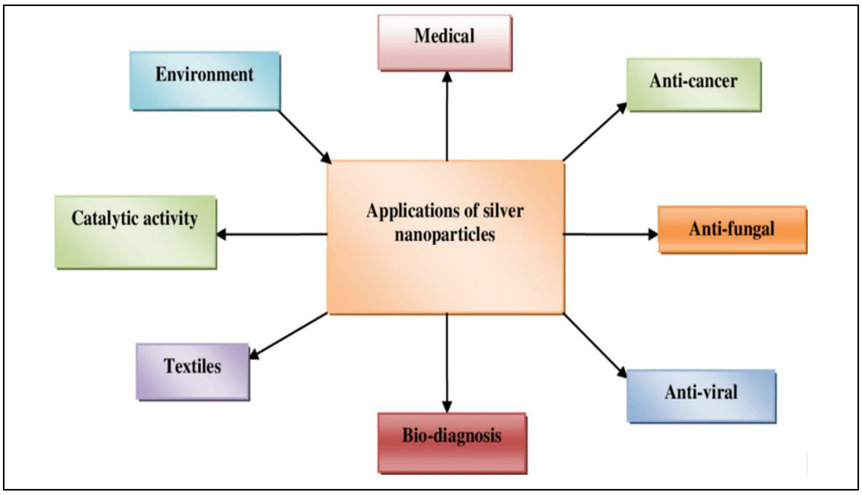

Figure 1: Main applications area of silver nanoparticles

2. Applications of Silver Nanoparticles

2.1 Green Synthesis of Silver Nanoparticles (Ag NPs)

In addition to having good electrical and thermal conductivity, silver has attractive applications that makes it stand out among transition metals. Prior to the discovery that bacteria are infection agents, this had been known for far longer than recorded history because of its medicinal and therapeutic capabilities. It's employed in a variety of ways, including coins, containers, solutions, foils, sutures, and colloids like lotions and ointments. In medicine, it is the most effective treatment for catching disorders and surgical infections. Ag has a greater number of benefits than it has negatives (Alexander, 2009). Nanoscience is a relatively recent multidisciplinary field that is based on the basic characteristics of nanoscale things (Abou El-Nour et al., 2010; Mohanpuria et al., 2008). Their high surface-to-volume ratio makes them very efficient. Nanoparticles have more amazing optical, electrical, magnetic, and catalytic capabilities than bulk materials (Poulose et al., 2014; Vijayakumar et al., 2013). Because of the Surface Plasmon Resonance (SPR) phenomenon, metal nanoparticles such as silver and gold exhibit unique colours when seen under ultraviolet light. Owing to a collective oscillation of free electrons of metal nanoparticles in resonance with the frequency of light wave contacts, the SPR band arises in the visible and infrared spectrums in the visible and infrared ranges (Parsons et al., 2007).

Developing silver nanoparticles and controlling their size is a challenging task that is dedicated as unique eco-friendly methods (Mori et al., 2011). Because of their metallic properties, such as conductivity performance, and their antibacterial effects in the medical sector, Ag NPs are widely used in industrial applications (Alexander, 2009). Ag NPs have antibacterial properties against a variety of species in the human body, and this impact may be noticed at low concentrations of Ag NPs (Ip et al., 2006). Nano-sized silver particles provide scientific hurdles due to their distinct characteristics as compared to major component metal or bulk metal (Zielińska et al., 2009). Green synthesis of Ag NPs is a straightforward and cost-effective method that addresses the needs of the scientific community while excluding the possibilities of environmental concerns (Rogach, 2000). Metallic nanoparticles are synthesized in two ways: top-down and bottom-up, utilizing chemical, physical, and biological methods. Physical and chemical techniques are used in the typical synthesis of nanoparticles. Both procedures may be used to make Ag NPs. The top-down process includes mechanical grinding of bulk metals and subsequent stabilization of the resultant nanosized metal particles by adding colloidal protective agents. Metal reduction, electrochemical techniques, and decomposition are also options in addition to the bottom-up strategy (Prabhu & Poulose, 2012; Firdhouse & Lalitha, 2015).

Chemical procedures are regarded unpleasant and energy-intensive, whereas traditional physical procedures often provide a small amount of Ag NPs. As a result, in the field of nanotechnology, the proliferation of an ecologically friendly approach for producing metallic nanoparticles is an unavoidable practice (Prabu & Johnson, 2015; Gurunathan, 2019). In the least biological microorganisms such as bacteria, fungus (yeast), and plant extracts can be used in green synthetic systems (Prabhu & Poulose, 2012; Al-Mubaddel et al., 2017; Veerasamy et al., 2011). Even though chemical and physical approaches may be efficient in producing crystalline nanoparticles with a distinct shape and purity, these techniques have been both costly and hypothetically dangerous to the environment.

2.1.1. Green Synthesis of Silver Nanoparticles (AgNPs) using plant extracts

Today, the production of nanoparticles is concentrated on green synthesis, which involves the use of extracts from diverse plant parts. Green chemistry is implemented using multifunctional agents for reducing and stabilizing plant extracts for biological production of NPs (Pantidos & Horsfall, 2014, Krithiga et al., 2015). A growing number of researchers are interested in using plants as the generating test of Ag NPs because of their rapidity, environmental friendliness, lack of pathogen toxicity, and affordability. Additionally, plants reveal useful phytochemicals which are used as reducing agents for Ag NP synthesis, which makes them a viable option as an Ag NP synthesis assembly (Figure 2).

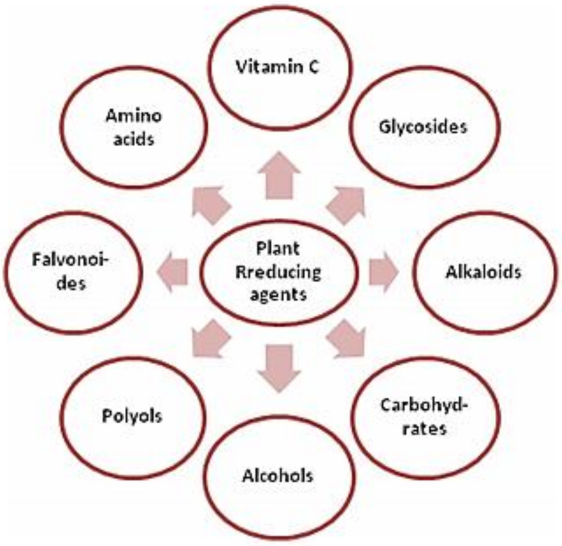

Figure 2: Bioreducing phytochemicals in plant extracts

A significant variety of plants have been documented to assist Ag NP syntheses of various sizes in Table 1, which were briefly described in this review.

The sonication approach was used to achieve biogenic production of Ag NPs utilizing extracts from sixteen commercially accessible plants (Firdhouse & Lalitha, 2016). Ag NPs were made using the green approach, with using Momordica charantia leaf extract, that may reduce the amount of cholesterol in your bloodstream while also stabilizing it (Ajitha et al., 2015). This mechanism of utilizing plant extract for producing Ag NPs has been described by numerous authors (Abbasi et al., 2016; Abd El-Aziz et al., 2015; Abdel-Aziz et al., 2014; Abdelghany et al., 2018; Ahmad & Sharma, 2012; Ahmad et al., 2010; Sajadi et al., 2018; Talabani et al., 2021). Using an atomic force microscope, plant extracts from Ag NPs with average diameters of 28, 26.5, 65, 22.3, and 28.4 nm were synthesized using the plants Ocimum tenuiflorum, Solanum trilobatum, Syzygium cumini, Centella asiatica, and Citrus sinensis, respectively (Logeswari et al., 2015); S. aureus, P. aeruginosa, E. coli, and K. pneumonia were tested for antibacterial activity. Ag NPs produced by S. trilobatum and O. tenuiflorum extracts had the best antibacterial efficacy against S. aureus (30 mm) and E. coli (30 mm), respectively. Ag NPs were effectively produced from banana leaf extract, neem leaf extract; and bioreduction procedures are all examples of natural remedies. Ag NPs were produced in varying sizes across the three plants, and modest extraction yields have been also obtained from banana leaves. The extract of polysaccharide from red marine algae (Gracilaria birdiae) was used as reducing and stabilizing agent in the synthesis of Ag NPs (de Aragao et al., 2019). To make Ag NPs, researchers used three concentrations of polysaccharide (0.02, 0.03, and 0.05 percent v/v) and two pHs (10 and 11) while stirring for 30 minutes at 900°C. Some researchers have reported on synthesizing Ag NPs synthesized from pepper leaf extract and their structure and chemical composition were investigated using XRD and EDS, with typical nanoparticle sizes ranging from 5-60 nm as measured via transmission electron microscopy (Mallikarjuna et al., 2014). Banana peel extract (BPE) as reducer and caper was employed in synthesizing nanoparticles within optimal terms also including silver nitrate (1.75 mM). Silver nitrate (20.4 mg dry weight) being employed as just a pH (4.5) and incubation period (72 h) (Ibrahim, 2015). Ag NPs have a tremendous influence on both the environment and the economy.

Table 1: Different Plant green synthesis (Ag-NPs) of various sizes

Plant	Ag NPs Size (nm)	Reference
Ocimum tenuiflorum	28	(Logeswari et al., 2015)
Solanum trilobatum	26.5	(Logeswari et al., 2015)
Syzygium cumin	65	(Logeswari et al., 2015)
Centella asiatica	22.3	(Logeswari et al., 2015)
Justicia glauca	10-24	(Emmanuel et al., 2015)
Pepper leaf broth	5-60	(Mallikarjuna et al., 2014)
Banana peel extract	23.7	(Ibrahim, 2015)
Catharanthus roseus leaf extract	35-55	(Ponarulselvam et al., 2012)

2.2 General Applications of Ag NPs

Silver nanoparticles (Ag NPs) possess a broad variety of antibacterial and antifungal activities. Ag NPs are often used as antibacterial in therapeutic applications such as cardiovascular implants, wound dressings, catheters, orthopedic implants, dental composites, nano-biosensing or agricultural engineering covering (He et al., 2016). A more extensive summary of the number of applications follows. Nanotechnology has helped to long-term competitiveness and growth in a variety of industries (Parisi et al., 2015). Nanoparticles' chemical and physical features enable them to perform beneficial tasks (Gogos et al., 2012) that are quickly utilized in a variety of fields, including medical, biology, materials science, and energy. Biotechnology, however, on the flip side, works with molecular, genetic, and cellular processes to generate medications for agricultural use (Fakruddin et al., 2012). Despite the fact that Ag NPs are employed in a wide range of applications, counting thin films (Yeo et al., 2014), surface coatings (Jo et al., 2014), batteries (Bindumadhavan et al., 2017), energy harvesting (Guo et al., 2014) and conductors (Gerardo et al., 2017).

Due to the rise in life-threatening illnesses throughout the world and the issues of non-specific medication delivery posed by multidrug resistance, medical applications have gotten a lot of attention. Unfortunately, the economic viability of using Ag NPs is quite restricted. The flexibility of Ag NPs on a various variety of toxicities, on the other hand, is widely recognized. Ag NPs are important antimicrobial agents because they modify the proteins and enzymes of the host/pathogenic cells, finally causing cell death. Because Ag NPs are converted to Ag+ ions, which produce reactive oxygen species, they are believed to have antimicrobial properties. They are also likely to disrupt the bacterial cell's growth signaling system by changing the tyrosine phosphorylation of proteins required for cell survival (Shrivastava et al., 2007). Silver is thought to have a function in bacterial growth inhibition by adhering covalently to cell surfaces and eventually breaking cell tissues (Shankar et al., 2016; Saratale et al., 2017). Ag NPs have been used in a variety of investigations for their biological qualities, including insecticidal, antilarval, antibiofilm, and anticancer activities (Pugazhendhi et al., 2018; Rajakumar & Rahuman, 2011). Nanotechnology has the potential to help regulate, detect, and improve the ability of plants to absorb nutrients, among other things. Nanotechnology can help us better comprehend the potential of different crops and boost yields and nutritional benefits. The use of environmental monitoring systems to improve the capacity of plants to absorb nutrients or insecticides (Gogos et al., 2012; Tarafdar et al., 2013). Nanoparticles and nonmaterial uses are quickly expanding on a variety of fronts because of their size, dispersion, and form. Green nanotechnology is pushing the boundaries of science and technology, and it is being dubbed "the marvel of science" at the same time (Mata et al., 2012). The rapid advancement of nanotechnologies has ushered in new fundamental advances for a variety of applications. This encompasses nanoscale material production, physicochemical characteristics, and optoelectronic characteristics (Gogos et al., 2012; Tarafdar et al., 2013).

2.3 Antimicrobial Activity

Antimicrobial agents known as Ag NPs have been reported to inhibit microorganisms including Staphylococcus aureus, Escherichia coli, and yeasts. In the pharmaceutical business, Ag NPs offer substantial benefits in the treatment of different bacterial and viral infections (Song & Kim, 2008). Ag NPs are especially effective against clinical infections such as multidrug-resistant (MDR) and extended-spectrum betalactamase (ESBL) infections. Ag NPs have been discovered for having stronger antibacterial activity than silver such, which might be due to the fact that Ag NPs had larger surface areas and greater surface atom fractions. Silver nanoparticles made from Abutilon indicum leaf extract had a strong antibacterial effect against Staphylococcus aureus (16.8 mm), Bacillus subtilis (18.3 mm), Salmonella typhi (14.5 mm), and Escherichia coli (17.2 mm) (Ashokkumar et al., 2015). The impregnation of Ipomea carnea-Ag Nps with a cellulose acetate membrane to form an organized antimycobacterial wall on Mycobacterium smegmatis produced in a 14 mm zone of antimycobacterial activity mostly on bacteria suppression (Daniel et al., 2014). Ag NPs produced using lemon peel extract have antidermatophytic action was found to be 12 0.3 SD and 11 0.5 SD against T. mentagrophytes and Candida albicans, respectively, with no action against T. rubrum (Nisha et al., 2014). Lineweaver-Burk plots revealed that Ag NPs generated using methanol extract of Solanum xanthocarpum berries had a greater anti-H. pylori activity and a noncompetitive inhibition (Amin et al., 2012). The characteristics of Ag NPs would make it easier for the nanoparticles to enter bacterial cells and cause cell death. Furthermore, the introduction of Ag NPs into bacterial cells causes DNA damage and changes the activities of the cells. The interaction of Ag+ ions with sulphur-incorporated proteins causes the bacterial cell walls to break down and disrupts the protein production machinery (Sondi & Salopek-Sondi, 2004).

Antibacterial activity was shown in Ag NPs made from the fungus Fusarium oxysporum. In hospitals, nanoparticle-enhanced clothing can be utilized to reduce the incidence of Staphylococcus aureus infections (Gade et al., 2008). The antibacterial properties of Ag NPs produced employing various organisms against various harmful bacteria are shown in Table 2. Furthermore, Ag NPs' size, shape, and surface charge all have a role in antibacterial activity. Antibacterial activity differs across Ag NPs with the same surface area but different geometries.

Table 2: Ag NPs and antibacterial activity

Organisms used for Ag NPs Synthesis	Pathogenic Bacteria	References
Plant Capparis spinosa leaves	Escherichia coli, Salmonella typhimurium, Staphylococcus aureus and Bacillus cereus	(Benakashani et al., 2016)
Corn leaf waste of Zea mays	Bacillus cereus, Listeria monocytogenes, Staphylococcus aureus, Escherichia coli, and Salmonella Typhimurium	(Patra and Baek, 2017)
Root extract of Helicteres isora	Bacillus subtilis and Micrococcus luteus	(Bhakya et al., 2016)

Microbiological resistance to metals ions and antibiotics is on the rise, and resistant bacteria are becoming more common, researchers are focusing on metallic nanoparticles (Gogos et al., 2012). Because of its unique characteristic, Ag NPs have gotten too much attention in the world of nanotechnology. Silver NPs have a chemical stability and catalytic action that set them apart from other metallic nanoparticles (Elemike et al., 2016; Banerjee et al., 2014). Silver has long been known to have an inhibiting impact on microorganisms found in medical and industrial environments (Shankar et al., 2005; Wiley et al., 2006).

2.4 Insecticidal Activity

Insects and diseases affecting food-producing and commercial crops pose a hazard to the agriculture industry. Pests are insects that rely on plants for their meals. Young leaves, fruits, and grains are all harmed by pests. Increased usage of chemical pesticides might have negative and serious repercussions for ecosystems, including harming the state of one's health (Gavrilescu, 2005), Biodiversity is disappearing, and nitrogen fixation is disappearing as well (Lin et al., 2013) and the loss of natural environments. Insecticidal activity of Ag NPs mediated by Euphorbia prostrate aqueous leaf extract against Sitophilus oryzae, a pest that mostly affects rice, wheat, and maize crops, was shown in Figure 3 (Zahir et al., 2012). The insecticidal properties of Ag NPs and sulfur nanoparticles (S NPs) from varied sources were investigated in the larval, pupal, and adult stages of the fruit fly (Araj et al., 2015).

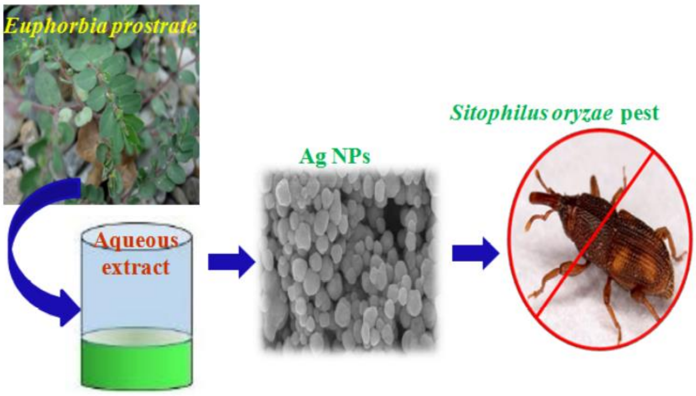

Figure 3: Ag NPs have insecticidal properties. Euphorbia prostrate aqueous leaf extract mediated Ag NPs possess insecticidal activity against Sitophilus oryzae pest

2.5 Anticancer Activity

In addition to diagnostic and cancer therapy, silver NPs have been used in anti-inflammatory medications, contact lenses, and medication administration (Koziara et al., 2003; Tien et al., 2008; Skirtach et al., 2004). Only 40% of human breast cancer cells are inhibited by silver NPs produced from Acalypha indica Linn (MDA-MB-231) (Krishnaraj et al., 2014). In the presence of Ag NPs generated by Dendrophthoe falcata (L. f.) Ettingsh, MCF-7 cells decrease 50% of their activity at 5 mg/mL (Sathishkumar et al., 2014). The Ag NPs produced utilizing cutaneous melanoma cells were incubated with several ethanolic extracts of plants including Phytolacca decandra, Gelsemium sempervirens, Hydrastis canadensis, and Thuja occidentalis, all of which showed varying degrees of anticancer properties (Das et al., 2013). Piper nigrum has shown to be an effective use of greenly produced silver nanoparticles in one study. The study also showed that these nanoparticles may be used as a cancer treatment (Venugopal et al., 2017b). Another current work attempted to develop a phyto-synthetic approach for creating size-controlled silver nanoparticles as an environmentally sustainable way to enhanced manufacturing with an attractive calm form. The plasmon resonance band rose steadily as the temperature of the reaction mixture fluctuated from 25 to 80 °C, which had an influence on the size and form of Ag NPs, as demonstrated by UV–visible spectroscopy and TEM data. The results of the staining revealed that Ag NP-induced cell death was caused by apoptosis in cancer cells. These findings suggest that silver nanoparticles might be used as anticancer agents in the treatment of a variety of cancers. However, in vivo research of these nanoparticles is required to determine their role and function inside the human body (Venugopal et al., 2017a). As a result, according to our extensive evaluation of several studies on silver nanoparticles, cancer can be cured with them.

2.6 Nano-biosensors

Nanoparticles are unusual in biosensors because they can be sensed in a lot of reasons, like optical absorption, fluorescence, and electric conductivity. This makes them particularly useful in drug discovery. When it comes to sensitivity and measurements, Ag NPs outperform the competition by using SPR (Doria et al., 2012). Nanobiosensors for illness detection, monitoring malady development or therapy monitoring, cell tracking, and nanoprobes in vivo detecting/imaging, as well as new nanotechnology-based gadgets, have all benefited from the new physicochemical features of metals at the nanoscale (Marchiol, 2012).

In a study, at a reflective localized surface plasmon resonance (LSPR) optical fiber sensor has been developed using silver nanoparticles (Talabani et al., 2021). Two essential parameters, both the sensing area's length and the coating's thickness are critical duration of the Ag NPs, were tuned to improve the sensitivity of the LSPR optical sensor. A sensing length of (1.5 cm) and a coating period of (1) hour were found to be ideal for producing very sensitive biosensing sensors. With a refractive index sensitivity of 387 nm, the upgraded sensor outperforms its predecessor significantly greater than any reported individual silver nanoparticles in liquids. Furthermore, the sensor has been antigen-modified to function as a biosensor. After each surface modification phase, distinct wavelength changes were discovered. The reflecting LSPR optical fiber sensor also provides a high level of repeatability and stability (Chen et al., 2015).

2.7 Human Health Applications

Nanotechnology is quickly advancing, with nanoparticles being manufactured and used across a broad variety of business situations all around the world. Silver nanoparticles are employed in a variety of applications such as electronics, biosensing, clothes, food industry, paints, sunscreens, cosmetics, and medical equipment. These widespread uses, on the other hand, increase the human exposure and, as a result, the danger of short- and long-term harm. In vitro studies on mammalian cells from the skin, liver, lung, brain, vascular system and reproductive organs have shown that Ag NPs are toxic to these cells systems according to a vast number of in vitro investigations (Ahamed et al., 2010). Nanoparticles have a variety of health impacts as compared to the bulk substance from which they are made (Khan, 2013). Increasing nanoparticle biological activity can be useful, harmful, or both. Many nanoparticles are tiny enough to pass through the skin into the lungs and brain (Koziara et al., 2003; Oberdörster et al., 2005). In vitro studies on mammalian cells from the skin, liver, lung, brain, vascular system and ovaries have shown that Ag NPs are toxic to these cells were produced, causing oxidative stress and cell damage (Limbach et al., 2007; Xi et al., 2006). In the cosmetics business, nanomaterials are utilized the use of UV protection ointment and creams, sunscreen, lipsticks, skin moisturizers, and toothpaste.

2.8 Environmental Applications

The recent major improvements in creating nanocomposites centered on specific materials that have been treated with Ag to boost their photocatalytic activities have been highlighted by researchers (Huang et al., 2020). The rational methodologies for advanced nanocomposites with Ag modification were brief, including nanostructure design, heterojunction assembly, and band gap adjustment. Furthermore, researchers believe that the SPR effect of Ag nanoparticles, which shifts the Fermi level, is responsible for the enhanced catalytic efficiency (Talabani et al., 2021). The researchers also found that the enhanced high catalytic capacity was due to the creation of a schottky barrior, which allowed for efficient electron-hole secession at the interaction (Patnaik et al., 2018).

Nanomaterials can be employed as catalysts in automotive catalytic converters and power production equipment to respond with unpleasant and poisonous gases such as carbon monoxide and nitrogen oxide, preventing pollution from gasoline and coal combustion (Sharma & Bhargava, 2013). Wastewater treatment plants and biological systems are also concerned about silver nanoparticles (Jalandoni-Buan et al., 2015). These are the most common silver nanoparticle uses in the environment (Figure 4).

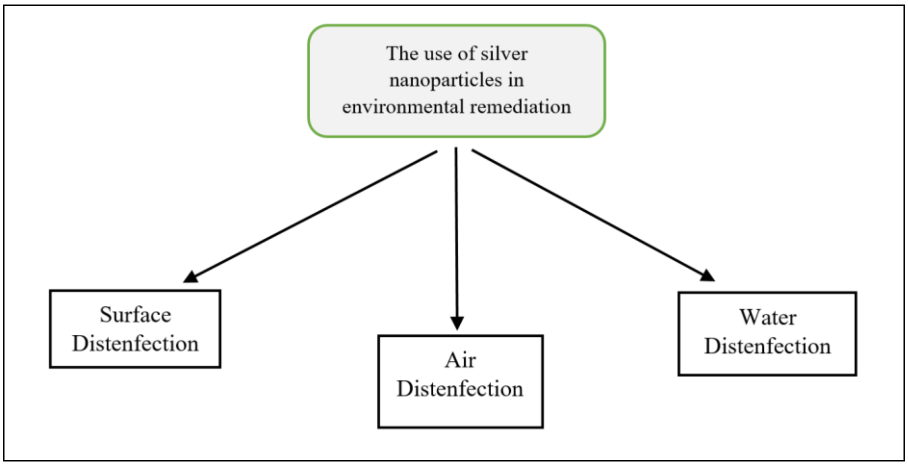

Figure 4: Applications of silver nanoparticles in environment treatment

2.9 Paint Application Using Silver Nanoparticles

Metallic silver nanoparticles are released when they meet aqueous solutions. In a study (Kaegi et al., 2010), investigated the release of silver nanoparticles from outdoor facades. Over the course of a year, a facade panel put based on a model home was showing to the elements. Individual rain events' runoff volumes were calculated, and the silver and titanium concentrations of 36 out of 65 runoff events were measured. Electron microscopic investigation was performed on a few samples. During the early runoff episodes, a substantial leaching of Ag NP was recorded, with a maximum concentration of 145 m Ag/l. Ag NP constitutes over than 30% of the total was unrestricted into the environment after a one-year period. Particles were primarily 15 nm in size, and they were discharged as composite colloids connected to the paint's organic binders. According to microscopic findings, Ag NP is most likely converted into less hazardous forms such as Ag2S (Kaegi et al., 2010). Silver's antibacterial properties have been known for ages (Blaser et al., 2008). Because of Ag's high toxicity to a varied spectrum of microbes paired with its low toxicity to humans, silver-based solutions have been developed for a variety of bactericidal uses (Monteiro et al., 2009). Upwards of 1000 consumer products nanoscale are currently included in inventory, according to the latest figures, with a sharp upward trend.

Painting with Ag NP was already reported, and it is believed to be one of the most key contributors of Ag NP released into the marine ecosystems (Mueller & Nowack, 2008). Because of a complete absence of experimental data on the release of Ag NP from exterior coatings, there's still currently no way to determine how much Ag NP is released from an external coating (Blaser et al., 2008). This region of application was just not taken into consideration in the risk assessment of Ag to freshwater ecosystems. Researchers have shown that the nano-fraction of the whitening pigment (TiO2) released under real-world weather circumstances from facade coatings is carried via segregated stormwater sewers and immediately dumped into natural surface waterways. In this way, it is possible to predict a comparable effect for Ag NP that is released from external coatings (Kägi et al., 2008). Even though the precautionary principle was already established proclaimed for items that may release engineered nanoparticles (ENP), there is yet to be a study of Ag NP leaching from external coatings. Only a little amount of Ag was present and then tested in a few runoff samples at the conclusion of the experiment. Within 372 days, 65 runoff events occurred, of which 36 have been utilized for Ag determination, accounting for 56 percent of the total number of occurrences. During the rest of the process, the surface normalized runoff volume (l/m2) is presented in Figure 5. All the runoff events that occurred during the time when the Ag concentration was measured are indicated by the colored symbols. The exposed squares reflect runoff occurrences that have been solely biased to calculate an amount of runoff. These samples were not subjected to any elemental analysis.

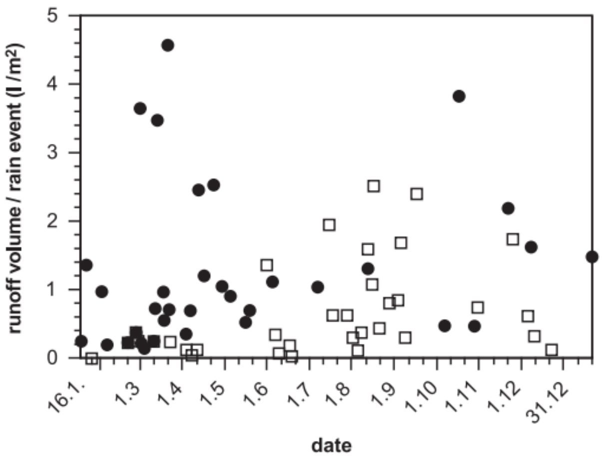

Figure 5: Runoff events with filled circles have had their Ag content calculated

2.10 Other Applications

Silver nanoparticles are also found in a variety of consumer items, such as water filters and sanitization systems, deodorants, soaps and socks, food preservation, and room sprays, so extending the economic potential of Ag NPs even more (Manjumeena et al., 2014). Silver nanoparticles and their composites exhibit much more catalytic activity than all the other materials throughout the dye reduction and removal process (Sharma et al., 2015). A variety of various industries in which Ag NPs may be beneficial are summarized in Table 3.

Table 3: Potential uses of Ag-NPs

Medical applications	Skin therapy and crucial in cosmetics Medical devices and plastic catheters Target drug delivery Gowns, coating of breath mask patent and ultrasonic detection Cancer therapy Coating of hospital textiles such as face mask surgical	(Shankar et al., 2003) (Roe et al., 2008) (Ahamed et al., 2010) (Tran and Le, 2013) (Boca et al., 2011) (Van Duyne et al., 2003)
Antibacterial activity	Nano wires and high energy batteries. Ag NPs exhibits inhibitory activity against Gram positive, Gram negative, Pseudomonas aeruginoss, Bacillus cereus	(Jana et al., 2001) (Praba et al., 2014) (Paulkumar et al., 2014)
Consumer goods and personal care products	Textiles, paints and sunscreen cosmetics. Toys and humidifiers, filters	(Kotthaus et al., 1997)
Electronic components and transportation	Biosensors for food analysis Sensors, electrodes and integrated circuits	(Pérez-López and Merkoçi, 2011) (Kotthaus et al., 1997)
Antimicrobial activity	Ag NPs have antimicrobial activity against S. epidermidis, P. fluorescens, Klebsiella Pneumonia, Pseudomonas aeruginosa, Pseudomonous sp., Gram positive, Gram negative, Salmonella typhi, R. arrhizus, and Proteus vulgaris, and multidrug resistant bacteria.	(Hussain et al., 2014) (Govarthanan et al., 2016)

3. Conclusion

The current study investigates the broad uses of silver nanoparticles in depth. Ag NPs' physicochemical properties, including as shape, size, adhesion, and SPR make them appropriate for a diverse variety of potential uses. With a variety of applications, green synthesized Ag NPs have essential characteristics of nanotechnology. Ag NPs offer a varied kind of uses in the present and future, including cardiovascular implants, dentistry, medicine, therapeutics, biosensors, agriculture, and many more. Silver nanoparticles have a broad range of applications, including usage in modern portable devices as well as the creation of linens, leather goods, and other textile. Silver nanoparticles and coatings can protect these products from dangerous germs. In conclusion, the use of green synthesized silver nanoparticles is a cost-effective and time-saving solution for a variety of applications.

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