Gizem Karabulut (gizem.karabulut@iuc.edu.tr
Downloaded: 10/17/2023 2:41:40 AM
IP Address: 193.255.22.216

Chapter 5
A Review on Multifunctional Silver Nanoparticles Produced With Green Routes for Photocatalysis, Sensing, and Imaging

Gizem Karabulut
https://orcid.org/0000-0003-0930-5380
Istanbul University-Cerrahpasa, Turkey

Nuray Beköz Üllen
Istanbul University-Cerrahpasa, Turkey

ABSTRACT

Metallic nanoparticles (NPs) have great potential for biological and chemical sensor applications because the surface of the NPs has a sensitive spectral response, and the light signal can be easily monitored by their absorption or scattering. In particular, silver nanoparticles (Ag NPs) are used in various applications due to their advanced physicochemical properties such as their excellent antibacterial, catalytic, and conductivity at the nanoscale. Plant-mediated synthesis methods have come to the fore with the green chemistry approach in the synthesis of NPs. The aim of this chapter is to provide a detailed resource by considering the studies in the literature on the use of Ag NPs produced by green routes mainly in the fields of photocatalysis, sensing, and imaging. Additionally, this chapter aims to determine the importance and potential of plant-mediated synthesized Ag NPs in these applications will be determined and to be a guide for industrial and academic personnel working in this field.

DOI: 10.4018/978-1-6684-8743-3.ch005

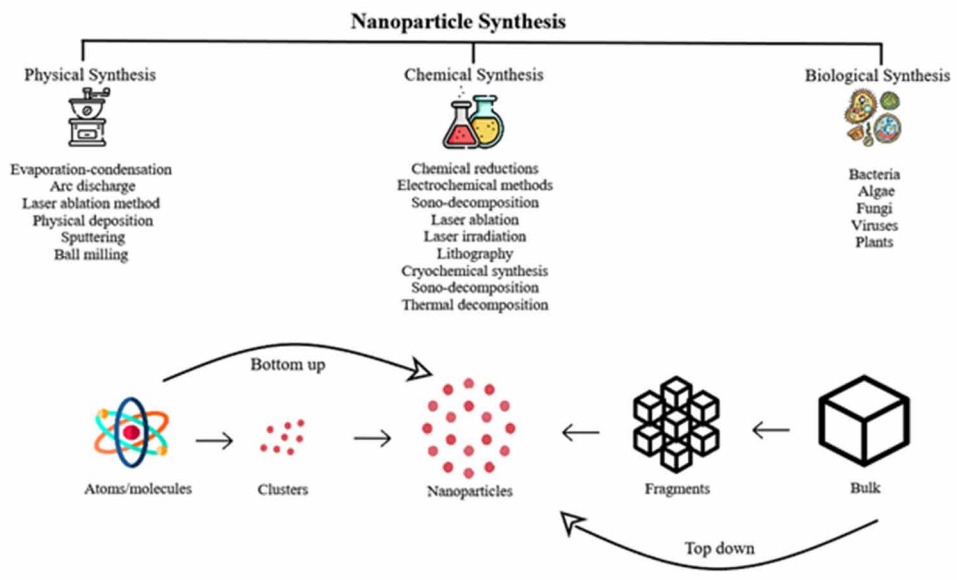
Copyright © 2023, IGI Global. Copying or distributing in print or electronic forms without written permission of IGI Global is prohibited.

Gizem Karabulut (gizem.karabulut@iuc.edu.tr
Downloaded: 10/17/2023 2:41:40 AM
IP Address: 193.255.22.216

INTRODUCTION

Metallic nanoparticles (NPs) have found usage in various fields by showing improved physicochemical and biological properties as a modified nano-engineering materials at the nano-scale compared to their macro-scale structures (Das & Ansari, 2009; Iliger et al., 2021; Yongfei Wang et al., 2019). Metallic NPs recently come to the fore in nanotechnology applications due to reasons such as having less toxicity at the nanoscale compared to the atomic level, free electrons in the conduction bands improve the optical properties of metallic NPs and thus surface plasmon resonance (SPR) can be observed in the UV-Visible regions, allowing photothermal treatment due to their ability to convert light/radio frequencies into heat (Vaid et al., 2020). NPs synthesis methods were classified as bottom-up and top-down synthesis. In this classification, the methods were classified according to their initial size. While the methods that perform synthesis from atomic size to nano size are divided as bottom-up, methods that perform synthesis by reduction from bulk/macro size to nano size are divided as top-down. Another classification of methods is physical, chemical, and biological (Chavali & Nikolova, 2019; Jamkhande et al., 2019; Nasrollahzadeh et al., 2021; Rana et al., 2020; Vaid et al., 2020). A general classification of methods was shown in Figure 1.

Figure 1. Classification of the NPs synthesis methods

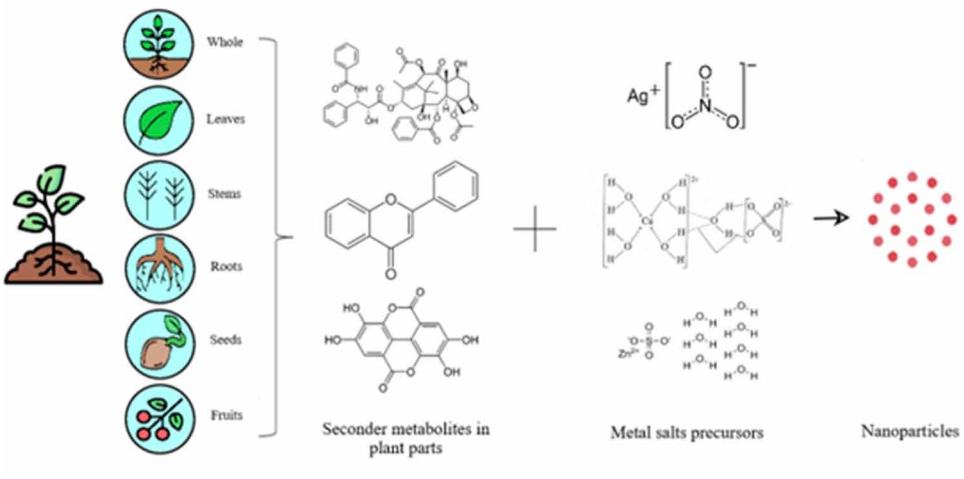


Gizem Karabulut (gizem.karabulut@iuc.edu.tr
Downloaded: 10/17/2023 2:41:40 AM
IP Address: 193.255.22.216

In physical synthesis, the synthesis is carried out with the help of a physical power obtained with the help of equipment. In general, it has disadvantages such as high equipment cost, high energy consumption, and solvent pollution (Nasrollahzadeh et al., 2021). In chemical synthesis methods, the driving force of synthesis is a chemical reaction. Chemical synthesis methods are not preferred due to the use of chemical products and harmful byproducts (Nasrollahzadeh et al., 2021). Nowadays, the world is facing problems such as global warming, pollution, and the depletion of natural resources, which is why the use of more environmentally friendly methods in production processes is coming to the fore in many fields. Biological synthesis have created an alternative to other methods with features such as being more environmentally friendly, being more cost-effective than other methods, and being able to synthesize relatively faster (Ashique et al., 2022; Iravani, 2014; Nasrollahzadeh et al., 2021; Tortella et al., 2022). Recently, biological synthesis methods using eukaryotic and prokaryotic organisms have come to the fore as part of the green chemistry approach to the synthesis of NPs. Biological synthesis can be performed using bacteria, fungi, viruses, and plants. Bacteria, as prokaryotic organism have generally developed resistance to extreme conditions due to their exposure to metal-rich environments and are therefore suitable for synthesis (Habibullah et al., 2021; Iravani, 2014). The mechanism in bacteria-mediated synthesis is the synthesis of metallic NPs through various reactions with metal ions in or around the cell by enzymes or secondary metabolites (Al-Sheddi et al., 2018; Tortella et al., 2022). Bacteria-mediated synthesis of metallic NPs is more environmentally friendly, cost-effective, biodegradable, and less toxic than chemical and physical methods. However, it has disadvantages in terms of health and safety compared to other biological methods (Ashique et al., 2022; Habibullah et al., 2021). Eukaryotic microorganisms are preferred due to their high intracellular metal uptake capacity, ability to synthesize NPs with different chemical compositions, ability to produce large amounts of enzymes per unit biomass, and ease of use under laboratory conditions (Dilshad et al., 2020; Jamkhande et al., 2019). In fungal-mediated synthesis, metal salt solutions are used for the synthesis of metallic NPs. Enzymes and proteins secreted by fungi act as reducing agents (Jamkhande et al., 2019). Since fungi secrete more proteins than bacteria, their production capacity is higher. One of the advantages is that the NPs are easy to scale and their shape can be controlled (Habibullah et al., 2021). However, the synthesis method is risky due to safety factors (Jamkhande et al., 2019). Today, the plant-mediated synthesis of metal NPs with a green approach is one of the most widely used methodologies (Habibullah et al., 2021). Synthesis of metallic NPs from plant sources involves purification of the bio-reducing agent in the plant and controlled mixing with the precursor metal solution. Then, reactions take place at room temperature leading to the formation of the NPs (Vaid et al., 2020). First, the plant to be used is collected and the extract is prepared.

Gizem Karabulut (gizem.karabulut@iuc.edu.tr
Downloaded: 10/17/2023 2:41:40 AM
IP Address: 193.255.22.216

Figure 2. Plant-mediated synthesis mechanism of the metallic NPs



For the plant-mediated synthesis process, the extract of the whole plant or specific parts such as leaves, stems, roots, and seeds are used. The primary and secondary metabolites in the plant content are constantly involved in the metabolic reactions that take place in the plant. These metabolites are used as reducing agents in the plant-mediated synthesis of metallic NPs (Jamkhande et al., 2019). Plant extracts contain secondary metabolites such as phenolic acid, flavonoid, and terpenoid, which are selective for metal ions and provide for the formation of NPs. These secondary metabolites in the prepared extract reduce the metal ions when mixed with the prepared metal precursor solution, providing synthesis and stabilization of the metallic NPs (Jamkhande et al., 2019; Sankar Sana et al., 2022). A schematic diagram of the plant-mediated synthesis of the metallic NPs is given in Figure 2. Plant-mediated synthesis is generally preferred because the source is easy to find, is relatively suitable for high production volumes, and produces environmentally friendly by-products and waste products. Because of these advantages, it has become an alternative to other synthesis methods (Al-Sheddi et al., 2018).

In the literature, there are many studies on the green synthesis and use in various fields of metallic NPs such as copper (Ilgar et al., 2022), gold (Philip et al., 2011), platinum (Konishi et al., 2007), palladium (Bi & Ahmad, 2022), and silver (Arboleda et al., 2018; Karabulut et al., 2023; Karakuş et al., 2021; Zhu et al., 2020). Among of them, silver nanoparticles (Ag NPs) come to the fore in nano-engineered materials due to their electrical conductivity, chemical stability, catalytic properties, and bioactivity (Dilshad et al., 2020; Karabulut et al., 2023). Because of these properties, Ag NPs have found a wide range of applications. Ag

Gizem Karabulut (gizem.karabulut@iuc.edu.tr
Downloaded: 10/17/2023 2:41:40 AM
IP Address: 193.255.22.216

NPs are widely known for their applications in various fields such as photonics, lithography, microelectronics, photocatalysis, and medicine (Alwhibi et al., 2020; Hossain et al., 2022). In this chapter, the role of silver NPs synthesized by green routes in photocatalysis, sensing, and imaging are discussed in detail. A detailed resource has been created to understand the importance of the green method and to determine the role of NPs synthesized in this way in various applications.

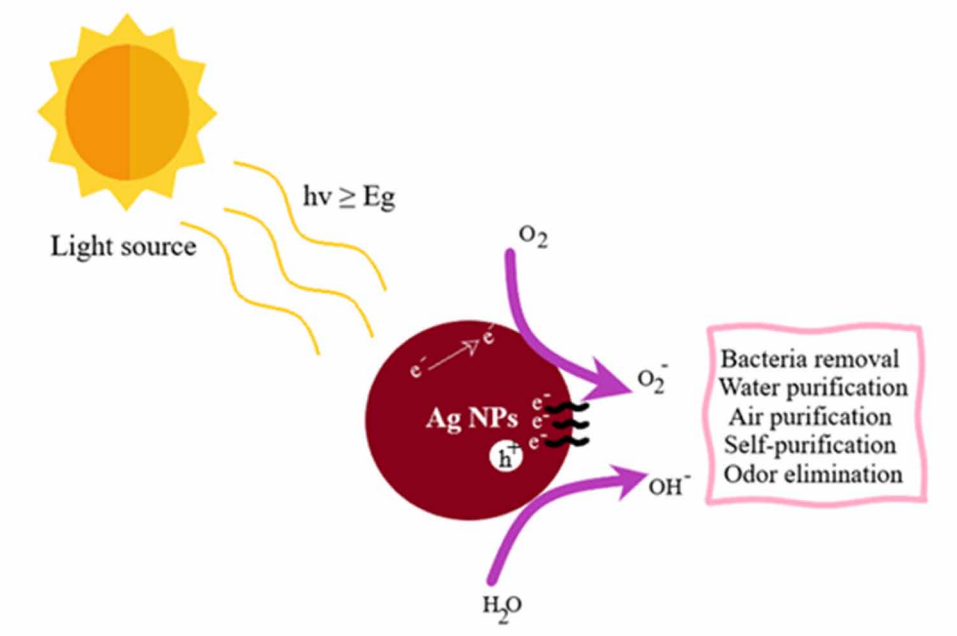
PHOTOCATALYSIS

Photocatalysis is a reaction with a light source. The light incident on the surface of the material acting as a photocatalyst is absorbed by the material and converted into chemical energy. When the band gap of the photocatalyst is equal to or less than the energy of the incident light, the electrons in the valence band of the photocatalyst will absorb the photon and reach the conduction band. The moving electrons' place remain vacant and its play the main role in photocatalysis. Oxidation and redox reactions take place at the vacant points and in the conduction band, resulting in the desired products. The photocatalyst breaks down the components accumulated on the surface of the material and ensures their elimination. Photocatalytic systems are used for purposes such as bacteria removal, water purification, air purification, self-purification, and odor elimination (Mokammel et al., 2022; Sankar Sana et al., 2022; Tahir et al., 2022).

Ag NPs can be activated by a visible light source due to its localized surface plasmon resonance (LSPR) property. It also acts as an electron scavenger that reduces the recombination capacity of e-h+ pairs, thus prolonging the lifetime of charge carriers and increasing photocatalytic efficiency (Aravind et al., 2021; Ha et al., 2021). In addition to these properties, green-mediated synthesized Ag NPs are coming to the forefront for the removal of undesirable substances by photocatalysis because they can be produced in a completely environmentally friendly manner, are inexpensive, and have the potential for many applications (Aravind et al., 2021; Marimuthu et al., 2020). General mechanism of the Ag NPs in photocatalysis is given in Figure 3. The mechanism of green synthesized Ag NPs is explained as follows: The formation of electron-hole pairs occurs in Ag NPs in solution irradiated by a light source. The OH group from the carbon derived from the vegetative structure interacts with the dye molecules and forms the OH free radicals. The larger surface area of the metallic NPs increases the excitation of electrons from the valence band to the conduction band to increase e^- transfer and form free radicals and superoxides. During the oxidation and reduction process takes place, free radicals and superoxides OH and O_2 are formed. The free radicals formed participate in the degradation process (Aravind et al., 2021).

Gizem Karabulut (gizem.karabulut@iuc.edu.tr
Downloaded: 10/17/2023 2:41:40 AM
IP Address: 193.255.22.216

Figure 3. General photocatalysis mechanism of Ag NPs



In a study by Aryan et al., (2021) plant-mediated synthesized Ag NPs were prepared using the *Kalanchoe pinnata*, which is also known as life plant, and the removal of dyes by photocatalytic degradation was investigated. In their study, the removal of the dye rhodamine B ($C_{28}H_{31}ClN_2O_3$) was successfully carried out. The degradation was studied under UV irradiation and in dark environment. It has been stated that the degradation in the presence of UV light was 83% in 45 min with a rate constant (k) of 0.042 min, which was three times higher than in the dark environment. As a result of the study, the authors were stated that plant-mediated synthesized Ag NPs are very useful for dye degradation due to their photocatalytic properties. In the study by Aravind et al. (2021) Ag NPs were synthesized in green way using jasmine flower extract and the degradation of methylene blue dye by photocatalysis was investigated. It was reported that the amount of degradation of green-mediated synthesized Ag NPs with a size of 22 nm increased with time and reached 71% after 2 hours. These Ag NPs are presented as a biodegradable and environmentally friendly solution for dye degradation. Sankareswari et al. (2022) synthesized Ag NPs with *Abrus precatorius* seed extract and then studied the photodegradation of ciprofloxacin (CIP) under visible light. In the examinations, it has been reported that green-mediated synthesized Ag NPs with *Abrus precatorius* seeds, which show a high catalyst effect, provide 90% CIP degradation at the end of 1.5 hours. In the

Gizem Karabulut (gizem.karabulut@iuc.edu.tr
Downloaded: 10/17/2023 2:41:40 AM
IP Address: 193.255.22.216

Table 1. Plant-mediated synthesized Ag NPs used as photocatalysts in various applications

Stabilizer	Application	Activity	References
Kalanchoe pinnata	Degradation of rhodamine B dye	83% after 45 min	(Aryan et al., 2021)
Kalanchoe daigremontiana	Removal of methylene blue	100% after 1 min	(Molina et al., 2019)
Cadiospermum halicacabum and *Moringa oleifera*	Degradation of methylene blue dye	92.7% after 48 h	(Balamurugan et al., 2022)
Tomato, orange, and grapefruit extracts	Environmental remediation of estrone and estrio	27.1, 52.1, and 24.8% after 180 min, respectively	(Weng et al., 2022)
Abrus precatorius	Photodegradation of CIP antibiotic	Above the 90% after 90 min	(Sankareswari et al., 2022)
Antidesma acidum	Methylene blue and congo red dyes degradation	81% and 90% after 18 min and 20 min, respectively	(Basumatary et al., 2023)
Trigonella foenum-graecum	Degradation of rhodamine B dye	~93% after 9 days	(Awad et al., 2021)
Cocos nucifera	Degradation of malachite green dye	75% after 6 h	(Sumi et al., 2016)
Coleus Vettiveroids	Methylene blue, malachite green, and crystal violet	70% after 3h	(Ajay et al., 2022)
Crinum asiaticum	Methylene blue	83.2% after 20 min	(Shukla et al., 2022)

stability and recyclability examinations, it was seen that it was 83% in the result of the 5th repetition, which shows the potential of green-mediated synthesized Ag NPs. Table 1 summarizes the use of plant-mediated synthesized Ag NPs in various pollutant removal applications with their photocatalysis function in recent years. It can be seen that studies on the removal of commercial dyes used in the textile industry from wastewater are widespread.

SENSING

Today, humanity is faced with many problems such as environmental problems and diseases. Early detection, prevention, and elimination of these problems have become very important for the continuity of the ecological system. Thank you to increasing technological developments, rapid, accurate, highly sensitive, and reusable detection of these situations is made possible by biosensors. Biosensors are innovative,

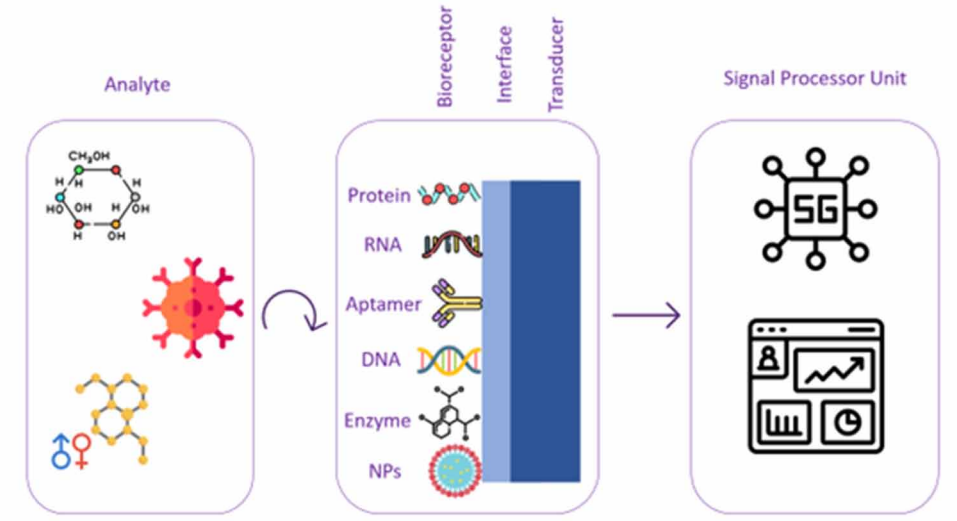
Gizem Karabulut (gizem.karabulut@iuc.edu.tr
Downloaded: 10/17/2023 2:41:40 AM
IP Address: 193.255.22.216

effective, and independent analytical devices that react selectively and reversibly depending on the concentration or activity of the analyte to be detected in the sample (Malhotra et al., 2017; Tetyana et al., 2021; Vigneshvar et al., 2016). The biosensor is a compact device that contains a biological or biomimetic sensing element. It consists of three major components: Bioreceptor, analyte, and transducer (Purohit et al., 2020). The structure of a biosensor and its components is shown schematically in Figure 4. A target analyte is a structure that is detected in a sample. A bioreceptor is a structure that produces a measurable signal due to a physicochemical change that occurs as a result of interaction with an analyte through physical or chemical binding. These include enzymes, tissues, nucleic acids (DNA or RNA), antibodies, organelles, aptamers, etc (Fatima et al., 2022; Tetyana et al., 2021; Thomas et al., 2022). Following the interaction of analytes and bioreceptors, many physicochemical changes can occur, including pH change, mass change, electron or heat transfer, etc (Velasco-Garcia & Mottram, 2003). When at a certain temperature, sound, light, weight, or pressure is produced, the transducer converts it into an electrical signal that can be read or measured (Kumar et al., 2022). The unique sensing performance of nanostructure-based biosensors has enabled various sensing nanoplatforms to be used for enzymatic, non-enzymatic, optical, electrochemical, photoelectrochemical, thermal, acoustic, fluorescence, electrochemiluminescence, chemo resistive, colorimetric, and catalytic sensors. Nano-sized materials can have unique properties compared to bulk structures. They have also proven beneficial and revolutionized biosensor applications. Quickly analyze multiple samples, anytime and anywhere (Dede & Altay, 2018). The selectivity, detection, non-toxicity, biocompatibility, reversibility, rapid response, and sensitivity required of transducer materials can be achieved with nanomaterials (Bose et al., 2022; Karabulut et al., 2022; Thomas et al., 2022). For this reason, plant-mediated synthesized Ag NPs have been widely preferred for sensing applications in recent years due to their bioluminescent and electrochemical properties.

Santhosh et al. (2021) prepared an extract from the peels of *Allium cepa L* (red onion) and synthesized new plant-mediated Ag NPs. The authors tested these Ag NPs for the detection of heavy metals. The plant-mediated synthesized Ag NPs were tested in solutions of various heavy metal salts and a distinct color change was observed in $HgCl_2$ solution. This result paves the way for the detection of mercury in the liquid phase by simple observation and without the need for an instrument. The authors noted that green-produced Ag NPs could be used as a simple and cost-effective sensing partner in biosensor applications. In another study, Zamarchi and Vieira (2021) used the extract of *Araucaria angustifolia* (pine nut) to biologically synthesize Ag NPs through the plant and developed an electrochemical sensor for the detection of paracetamol. The chemical sensor developed with graphite and plant-mediated synthesized Ag NPs on the surface of a glassy carbon electrode

Gizem Karabulut (gizem.karabulut@iuc.edu.tr
Downloaded: 10/17/2023 2:41:40 AM
IP Address: 193.255.22.216

Figure 4. General structure and components of the biosensor



showed good repeatability, reproducibility, low detection limit (8.50×10-8 mol L-1), and sensitivity. The authors stated that these metallic NPs, which have surface properties such as greater surface area and conductivity, offer great advantages and can be developed and used industrially. Table 2 summarizes the studies on sensors modified with plant-mediated synthesized Ag NPs and their applications. In general, it was found that sensors modified with Ag NPs are widely preferred and beneficial in the detection of heavy metals.

Table 2. Plant-mediated synthesized Ag NPs used in sensing

Plant	Applications	References
Allium cepa L	Detection of Hg^{2+}	(Santhosh et al., 2021)
Araucaria angustifolia	Detection of paracetamol	(Zamarchi & Vieira, 2021)
Acacia chundra	Detection of Hg^{2+}	(Ramachandiran & Rajesh, 2022)
Matricaria recutita	Detection of Hg^{2+}	(Uddin et al., 2017)
Cissusquadrangularis	Detection of Cd^{2+}	(Pragathiswaran et al., 2021)
Hyacinth	Detection of Hg^{2+}	(Oluwafemi et al., 2019)
Mangifera indica	Detection of H_2O_2 and Hg^{2+}	(Hai et al., 2022)
Bambusa arundinacea	Detection of glucose	(Jayarambabu et al., 2023)
Allium sativum L.	Detection of cholesterol	(El-Naka et al., 2023)
Camellia sinensis	Detection of H_2O_2	(Tan et al., 2021)

Gizem Karabulut (gizem.karabulut@iuc.edu.tr
Downloaded: 10/17/2023 2:41:40 AM
IP Address: 193.255.22.216

IMAGING

Another area in which Ag NPs are used due to their advanced optical properties caused by the surface plasmon feature is in biological imaging applications (Majeed et al., 2022). Thanks to their small size, NPs exhibit optical scattering properties due to their enhanced surface plasmon property. Optical scattering properties depend on the size, shape, metal content, environment, and surface properties of the NPs (K. J. Lee et al., 2007; K. S. Lee & El-Sayed, 2006). This optical scattering property of metallic NPs makes them useful for imaging systems. Imaging with NPs is widely used in the diagnosis of cancer, one of the most common fatal diseases of mankind today. Here, the main mechanism is the tendency of NPs to accumulate in molecular form in cellular structures. Cancer cells are targeted with various functionalization of the NPs and imaging is sought with their accumulation in the cell and optical scattering (Çetin Uyanıkgil & Selcen Salmanoğlu, 2020; Dağlıoğlu, 2018; K. S. Lee & El-Sayed, 2006). In this field, there are advantages such as easy production and cost-effectiveness of NPs (Çetin Uyanıkgil & Selcen Salmanoğlu, 2020). It has already been said that the use of plant-mediated synthesized Ag NPs for biological applications is more advantageous than other synthesis techniques. Since a toxic material such as Ag NP is still absorbed into the body in applications such as cancer imaging, the fact that it is synthesized in a plant-based manner reduces its toxicity (Mohd Faheem et al., 2022; Yunjian Wang et al., 2021). There are many studies in the literature investigating the anticancer properties of Ag NPs synthesized by plant-based synthesis (Fan et al., 2022; Mohd Faheem et al., 2022; Ossoliński et al., 2023; Wen et al., 2020). The rationale in these studies is the same as the imaging mechanism. Ag NPs targeted to the cancer cell accumulate and destroy the cancer cell with a cytotoxic effect with the reactive oxygen species (ROS) mechanism (Mohd Faheem et al., 2022). For example, Wang et al. (2021) performed the plant-mediated synthesis of Ag NPs using *Zingiber officinale* leaves and studied them in pancreatic cancer cells. In another study, Faheem et al. (2022) synthesized Ag NPs using the whole parts of the *Bergenia ligulata* plant and investigated their breast cancer diagnostic and anticancer properties. It was found that the studies in the literature on plant-mediated synthesized Ag NPs were mainly focused on determining the anticancer property and investigating the cytotoxic properties. It was found in the literature that the studies dealing with imaging were few. This could be due to the fact that magnetic metallic NPs (e.g. iron) have proven properties in this field (Amani et al., 2019; Chavan et al., 2022; Li et al., 2021).

Gizem Karabulut (gizem.karabulut@iuc.edu.tr
Downloaded: 10/17/2023 2:41:40 AM
IP Address: 193.255.22.216

CONCLUSION

Nowadays, NPs are preferred in many fields due to their superior properties at the nanoscale. The synthesis methods of NPs significantly influence their applications. Plant-based synthesized NPs are used in electronics, textile, surface coating, and medicine industries because they are low cost, environmentally friendly, low toxic, and easy to synthesize. In particular, Ag NPs exhibit surface plasmon behavior due to their large surface area. Depending on this behavior, Ag NPs with their optical properties can be used in photocatalysis, sensing and imaging. In this review, Ag NPs and the importance of plant-mediated synthesis, the studies on photocatalysis, sensing, and imaging of Ag NPs synthesized in this manner were examined in detail and a resource was created for researchers working in this field. Plant-mediated synthesized Ag NPs were found to be widely used and suitable for commercial use, particularly in photocatalysis and sensing applications. In imaging applications, it has been found to be particularly useful in cancer diagnosis and treatment, but studies in this field are insufficient for Ag NPs. For this reason, it is recommended that researchers who will work in this area work to develop the properties of Ag NPs synthesized in this way and disseminate their use.

REFERENCES

Ajay, S., Panicker, J. S., Manjumol, K. A., & Subramanian, P. P. (2022). Photocatalytic activity of biogenic silver nanoparticles synthesized using Coleus Vettiveroids. *Inorganic Chemistry Communications*, *144*, 109926. doi:10.1016/j.inoche.2022.109926

Al-Sheddi, E. S., Farshori, N. N., Al-Oqail, M. M., Al-Massarani, S. M., Saquib, Q., Wahab, R., Musarrat, J., Al-Khedhairy, A. A., & Siddiqui, M. A. (2018). Anticancer potential of green synthesized silver nanoparticles using extract of nepeta deflersiana against human cervical cancer cells (HeLA). *Bioinorganic Chemistry and Applications, Nov*(1), 9390784. doi:10.1155/2018/9390784

Alwhibi, M. S., Soliman, D. A., al khaldy, H., Alonaizan, A., Abdulhaq Marraiki, N., El-Zaidy, M., & AlSubeie, M. S. (2020). Green biosynthesis of silver nanoparticle using Commiphora myrrh extract and evaluation of their antimicrobial activity and colon cancer cells viability. *Journal of King Saud University. Science*, *32*(8), 3372–3379. doi:10.1016/j.jksus.2020.09.024

Gizem Karabulut (gizem.karabulut@iuc.edu.tr
Downloaded: 10/17/2023 2:41:40 AM
IP Address: 193.255.22.216

Amani, A., Begdelo, J. M., Yaghoubi, H., & Motallebinia, S. (2019). Multifunctional magnetic nanoparticles for controlled release of anticancer drug, breast cancer cell targeting, MRI/fluorescence imaging, and anticancer drug delivery. *Journal of Drug Delivery Science and Technology*, *49*, 534–546. doi:10.1016/j.jddst.2018.12.034

Aravind, M., Ahmad, A., Ahmad, I., Amalanathan, M., Naseem, K., Mary, S. M. M., Parvathiraja, C., Hussain, S., Algarni, T. S., Pervaiz, M., & Zuber, M. (2021). Critical green routing synthesis of silver NPs using jasmine flower extract for biological activities and photocatalytical degradation of methylene blue. *Journal of Environmental Chemical Engineering*, *9*(1), 104877. doi:10.1016/j.jece.2020.104877

Arboleda, D. M., Santillán, J. M. J., Arce, V. B., Fernández van Raap, M. B., Muraca, D., Fernández, M. A., Torres Sanchez, R. M., Schinca, D. C., & Scaffardi, L. B. (2018). A simple and "green" technique to synthesize long-term stability colloidal Ag nanoparticles: Fs laser ablation in a biocompatible aqueous medium. *Materials Characterization*, *140*, 320–332. doi:10.1016/j.matchar.2018.04.021

Aryan, R., Ruby, & Mehata, M. S. (2021). Green synthesis of silver nanoparticles using Kalanchoe pinnata leaves (life plant) and their antibacterial and photocatalytic activities. *Chemical Physics Letters*, *778*, 138760. doi:10.1016/j.cplett.2021.138760

Ashique, S., Upadhyay, A., Hussain, A., Bag, S., Chaterjee, D., Rihan, M., Mishra, N., Bhatt, S., Puri, V., Sharma, A., Prasher, P., Singh, S. K., Chellappan, D. K., Gupta, G., & Dua, K. (2022). Green biogenic silver nanoparticles, therapeutic uses, recent advances, risk assessment, challenges, and future perspectives. *Journal of Drug Delivery Science and Technology*, *77*, 103876. doi:10.1016/j.jddst.2022.103876

Awad, M. A. A., Hendi, A., Ortashi, K. M., Alzahrani, B., Soliman, D., Alanazi, A., Alenazi, W., Taha, R. M., Ramadan, R., El-Tohamy, M., AlMasoud, N., & Alomar, T. S. (2021). Biogenic synthesis of silver nanoparticles using Trigonella foenum-graecum seed extract: Characterization, photocatalytic and antibacterial activities. *Sensors and Actuators. A, Physical*, *323*, 112670. doi:10.1016/j.sna.2021.112670

Balamurugan, V., Muruganandam, L., & Natarajan, R. (2022). Photocatalytic activity of silver nanoparticles synthesized using cadiospermum halicacabum and moringa oleifera leaf extract. *Materials Today: Proceedings*, *62*, 5365–5370. doi:10.1016/j.matpr.2022.03.540

Basumatary, S., Kumar, K. J., Daimari, J., Mondal, A., Kalita, S., Dey, K. S., & Deka, A. K. (2023). Biosynthesis of silver nanoparticles using Antidesma acidum leaf extract: Its application in textile organic dye degradation. *Environmental Nanotechnology, Monitoring & Management*, *19*, 100769. doi:10.1016/j.enmm.2022.100769

Gizem Karabulut (gizem.karabulut@iuc.edu.tr Downloaded: 10/17/2023 2:41:40 AM
IP Address: 193.255.22.216

Bi, S., & Ahmad, N. (2022). Green synthesis of palladium nanoparticles and their biomedical applications. *Materials Today: Proceedings*, *62*, 3172–3177. doi:10.1016/j.matpr.2022.03.441

Bose, S., Maity, S., & Sarkar, A. (2022). Nano-materials as biosensor for heavy metal detection. *Food, Medical, and Environmental Applications of Nanomaterials*, 493–526. doi:10.1016/B978-0-12-822858-6.00018-2

Çetin Uyanıkgil, E. Ö., & Selcen Salmanoğlu, D. (2020). Metalik nanopartiküllerin hedeflendirilmesi. *Ege Tıp Dergisi*, *59*(1), 71–81. doi:10.19161/etd.698596

Chavali, M. S., & Nikolova, M. P. (2019). Metal oxide nanoparticles and their applications in nanotechnology. *SN Applied Sciences, 1*(6), 1–30. doi:10.1007/s42452-019-0592-3

Chavan, N., Dharmaraj, D., Sarap, S., & Surve, C. (2022). Magnetic nanoparticles – A new era in nanotechnology. *Journal of Drug Delivery Science and Technology*, *77*, 103899. doi:10.1016/j.jddst.2022.103899

Dağlıoğlu, C. (2018). A Comparative Study of Passive and Active Tumor Targeting Using Nanoparticles as Drug Delivery Systems. *Academic Platform - Journal of Engineering and Science, 6*(1), 1–7. doi:10.21541/apjes.349889

Das, I., & Ansari, S. A. (2009). Nanomaterials in science and technology. *Journal of Scientific and Industrial Research*, *68*(8), 657–667.

Dede, S., & Altay, F. (2018). Biosensors from the First Generation to Nano-biosensors. *International Advanced Researches and Engineering Journal*, *02*(02), 200–207.

Dilshad, E., Bibi, M., Sheikh, N. A., Tamrin, K. F., Mansoor, Q., Maqbool, Q., & Nawaz, M. (2020). Synthesis of functional silver nanoparticles and microparticles with modifiers and evaluation of their antimicrobial, anticancer, and antioxidant activity. *Journal of Functional Biomaterials*, *11*(4), 76. doi:10.3390/jfb11040076 PMID:33113975

El-Naka, M. A., El-Dissouky, A., Ali, G. Y., Ebrahim, S., & Shokry, A. (2023). Garlic capped silver nanoparticles for rapid detection of cholesterol. *Talanta*, *253*, 123908. doi:10.1016/j.talanta.2022.123908 PMID:36087411

Fan, N., Li, P., Wang, J., Gongsun, X., Xue, L., Bai, J., Morovvati, H., & Goorani, S. (2022). Novel formulation, characterization, cytotoxicity, antioxidant, and anti-lung cancer activities of silver nanoparticles green-formulated by plant extract. *Inorganic Chemistry Communications*, *143*, 109707. doi:10.1016/j.inoche.2022.109707

Gizem Karabulut (gizem.karabulut@iuc.edu.tr Downloaded: 10/17/2023 2:41:40 AM
IP Address: 193.255.22.216

Fatima, T., Bansal, S., Husain, S., & Khanuja, M. (2022). Biosensors. *Electrochemical Sensors: From Working Electrodes to Functionalization and Miniaturized Devices*, 1–30. doi:10.1016/B978-0-12-823148-7.00001-5

Ha, L. P. P., Vinh, T. H. T., Thuy, N. T. B., Thi, C. M., & Van Viet, P. (2021). Visible-light-driven photocatalysis of anisotropic silver nanoparticles decorated on ZnO nanorods: Synthesis and characterizations. *Journal of Environmental Chemical Engineering*, *9*(2), 105103. doi:10.1016/j.jece.2021.105103

Habibullah, G., Viktorova, J., & Ruml, T. (2021). Current Strategies for Noble Metal Nanoparticle Synthesis. *Nanoscale Research Letters, 16*(1), 1–12. doi:10.1186/s11671-021-03480-8

Hai, N. D., Dat, N. M., Huong, L. M., Tai, L. T., Thinh, D. B., Nam, N. T. H., Dat, N. T., Phong, M. T., & Hieu, N. H. (2022). Phytosynthesis of silver nanoparticles using Mangifera indica leaves extract at room temperature: Formation mechanism, catalytic reduction, colorimetric sensing, and antimicrobial activity. *Colloids and Surfaces. B, Biointerfaces*, *220*, 112974. doi:10.1016/j.colsurfb.2022.112974

Hossain, N., Islam, M. A., & Chowdhury, M. A. (2022). Synthesis and characterization of plant extracted silver nanoparticles and advances in dental implant applications. *Heliyon*, *8*(12), e12313. doi:10.1016/j.heliyon.2022.e12313 PMID:36590472

Ilgar, M., Baytemir, G., Taşaltın, N., Güllülü, S., Yeşilyurt, İ. S., & Karakuş, S. (2022). Multifunctional maca extract coated CuO nanoparticles with antimicrobial and dopamine sensing activities: A dual electrochemical – Smartphone colorimetric detection system. *Journal of Photochemistry and Photobiology A Chemistry*, *431*, 114075. doi:10.1016/j.jphotochem.2022.114075

Iliger, K. S., Sofi, T. A., Bhat, N. A., Ahanger, F. A., Sekhar, J. C., Elhendi, A. Z., Al-Huqail, A. A., & Khan, F. (2021). Copper nanoparticles: Green synthesis and managing fruit rot disease of chilli caused by Colletotrichum capsici. *Saudi Journal of Biological Sciences*, *28*(2), 1477–1486. doi:10.1016/j.sjbs.2020.12.003 PMID:33613075

Iravani, S. (2014). Bacteria in Nanoparticle Synthesis: Current Status and Future Prospects. *International Scholarly Research Notices*, *2014*, 1–18. doi:10.1155/2014/359316 PMID:27355054

Jamkhande, P. G., Ghule, N. W., Bamer, A. H., & Kalaskar, M. G. (2019). Metal nanoparticles synthesis: An overview on methods of preparation, advantages and disadvantages, and applications. *Journal of Drug Delivery Science and Technology*, *53*, 101174. doi:10.1016/j.jddst.2019.101174

Gizem Karabulut (gizem.karabulut@iuc.edu.tr Downloaded: 10/17/2023 2:41:40 AM
IP Address: 193.255.22.216

Jayarambabu, N., Saraswathi, K., Akshaykranth, A., Anitha, N., Venkatappa Rao, T., & Rakesh kumar, R. (2023). Bamboo-mediated silver nanoparticles functionalized with activated carbon and their application for non-enzymatic glucose sensing. *Inorganic Chemistry Communications*, *147*, 110249. doi:10.1016/j.inoche.2022.110249

Karabulut, G., Beköz Üllen, N., Akyüz, E., & Karakuş, S. (2023). Surface modification of 316L stainless steel with multifunctional locust gum/polyethylene glycol-silver nanoparticles using different coating methods. *Progress in Organic Coatings*, *174*, 107291. doi:10.1016/j.porgcoat.2022.107291

Karabulut, G., Üllen, N. B., & Karakuş, S. (2022). *Nanostructures in Biosensors: Development and Applications*. IntechOpen., doi:10.5772/intechopen.108508

Karakuş, S., Taşaltın, N., Taşaltın, C., & Üllen, N. B. (2021). Synthesis and Characterization of Konjac Gum/Polyethylene Glycol-Silver Nanoparticles and their Potential Application as a Colorimetric Sensor for Hydrogen Peroxide. *Journal of Inorganic and Organometallic Polymers and Materials*, *1*(9), 1–14. doi:10.100710904-021-01984-5

Konishi, Y., Ohno, K., Saitoh, N., Nomura, T., Nagamine, S., Hishida, H., Takahashi, Y., & Uruga, T. (2007). Bioreductive deposition of platinum nanoparticles on the bacterium Shewanella algae. *Journal of Biotechnology*, *128*(3), 648–653. doi:10.1016/j.jbiotec.2006.11.014 PMID:17182148

Kumar, R., Chauhan, G., & Martinez-Chapa, S. O. (2022). Metal oxides and their composites as flow-through biosensors for biomonitoring. *Metal Oxides for Biomedical and Biosensor Applications*, 291–319. doi:10.1016/B978-0-12-823033-6.00010-7

Lee, K. J., Nallathamby, P. D., Browning, L. M., Osgood, C. J., & Nancy Xu, X. H. (2007). In vivo imaging of transport and biocompatibility of single silver nanoparticles in early development of zebrafish embryos. *ACS Nano*, *1*(2), 133–143. doi:10.1021/nn700048y PMID:19122772

Lee, K. S., & El-Sayed, M. A. (2006). Gold and silver nanoparticles in sensing and imaging: Sensitivity of plasmon response to size, shape, and metal composition. *The Journal of Physical Chemistry B*, *110*(39), 19220–19225. doi:10.1021/jp062536y PMID:17004772

Li, X., Li, W., Wang, M., & Liao, Z. (2021). Magnetic nanoparticles for cancer theranostics: Advances and prospects. *Journal of Controlled Release*, *335*, 437–448. doi:10.1016/j.jconrel.2021.05.042 PMID:34081996

Gizem Karabulut (gizem.karabulut@iuc.edu.tr
Downloaded: 10/17/2023 2:41:40 AM
IP Address: 193.255.22.216

Majeed, M., Hakeem, K. R., & Rehman, R. U. (2022). Synergistic effect of plant extract coupled silver nanoparticles in various therapeutic applications- present insights and bottlenecks. *Chemosphere*, *288*, 132527. doi:10.1016/j.chemosphere.2021.132527 PMID:34637861

Malhotra, S., Verma, A., Tyagi, N., & Kumar, V. (2017). *BIOSENSORS: PRINCIPLE, TYPES AND APPLICATIONS, 3*(2).

Marimuthu, S., Antonisamy, A. J., Malayandi, S., Rajendran, K., Tsai, P. C., Pugazhendhi, A., & Ponnusamy, V. K. (2020). Silver nanoparticles in dye effluent treatment: A review on synthesis, treatment methods, mechanisms, photocatalytic degradation, toxic effects and mitigation of toxicity. *Journal of Photochemistry and Photobiology. B, Biology*, *205*, 111823. doi:10.1016/j.jphotobiol.2020.111823 PMID:32120184

Mohd Faheem, M., Bhagat, M., Sharma, P., & Anand, R. (2022). Induction of p53 mediated mitochondrial apoptosis and cell cycle arrest in human breast cancer cells by plant mediated synthesis of silver nanoparticles from Bergenia ligulata (Whole plant). *International Journal of Pharmaceutics*, *619*, 121710. doi:10.1016/j.ijpharm.2022.121710 PMID:35367334

Mokammel, M. A., Islam, M. J., Hasanuzzaman, M., & Hashmi, M. S. J. (2022). Nanoscale Materials for Self-Cleaning and Antibacterial Applications. Encyclopedia of Smart Materials, 315–324. doi:10.1016/B978-0-12-815732-9.00015-2

Molina, G. A., Esparza, R., López-Miranda, J. L., Hernández-Martínez, A. R., España-Sánchez, B. L., Elizalde-Peña, E. A., & Estevez, M. (2019). Green synthesis of Ag nanoflowers using Kalanchoe Daigremontiana extract for enhanced photocatalytic and antibacterial activities. *Colloids and Surfaces. B, Biointerfaces*, *180*, 141–149. doi:10.1016/j.colsurfb.2019.04.044 PMID:31039515

Nasrollahzadeh, M., Shafiei, N., & Nezafat, Z. (2021). Synthesis of biopolymer-based metal nanoparticles. *Biopolymer-Based Metal Nanoparticle Chemistry for Sustainable Applications*, 255–316. doi:10.1016/B978-0-12-822108-2.00018-1

Oluwafemi, O. S., Anyik, J. L., Zikalala, N. E., & Sakho, E. H. M. (2019). Biosynthesis of silver nanoparticles from water hyacinth plant leaves extract for colourimetric sensing of heavy metals. *Nano-Structures & Nano-Objects*, *20*, 100387. doi:10.1016/j.nanoso.2019.100387

Gizem Karabulut (gizem.karabulut@iuc.edu.tr
Downloaded: 10/17/2023 2:41:40 AM
IP Address: 193.255.22.216

Ossoliński, K., Ruman, T., Ossoliński, T., Ossolińska, A., Arendowski, A., Kołodziej, A., Płaza-Altamer, A., & Nizioł, J. (2023). Monoisotopic silver nanoparticles-based mass spectrometry imaging of human bladder cancer tissue: Biomarker discovery. *Advances in Medical Sciences*, *68*(1), 38–45. doi:10.1016/j.advms.2022.12.002 PMID:36566601

Philip, D., Unni, C., Aromal, S. A., & Vidhu, V. K. (2011). Murraya Koenigii leaf-assisted rapid green synthesis of silver and gold nanoparticles. *Spectrochimica Acta. Part A: Molecular and Biomolecular Spectroscopy*, *78*(2), 899–904. doi:10.1016/j.saa.2010.12.060 PMID:21215687

Pragathiswaran, C., Violetmary, J., Faritha, A., Selvarani, K., & Nawas, P. M. A. (2021). Photocatalytic degradation, sensing of Cd2+ using silver nanoparticles synthesised from plant extract of cissus quadrangularis and their microbial activity. *Materials Today: Proceedings*, *45*, 3348–3356. doi:10.1016/j.matpr.2020.12.656

Purohit, B., Vernekar, P. R., Shetti, N. P., & Chandra, P. (2020). Biosensor nanoengineering: Design, operation, and implementation for biomolecular analysis. *Sensors International*, *1*, 100040. doi:10.1016/j.sintl.2020.100040

Ramachandiran, D., & Rajesh, K. (2022). Selective colorimetric and fluorimertic sensor of Hg (II) ion from silver nanoparticles using Acacia chundra leaves extract. *Materials Chemistry and Physics*, *287*, 126284. doi:10.1016/j.matchemphys.2022.126284

Rana, A., Yadav, K., & Jagadevan, S. (2020). A comprehensive review on green synthesis of nature-inspired metal nanoparticles: Mechanism, application and toxicity. *Journal of Cleaner Production*, *272*, 122880. doi:10.1016/j.jclepro.2020.122880

Sankar Sana, S., Haldhar, R., Parameswaranpillai, J., Chavali, M., & Kim, S. C. (2022). Silver nanoparticles-based composite for dye removal: A comprehensive review. *Cleaner Materials*, *6*, 100161. doi:10.1016/j.clema.2022.100161

Sankareswari, M., Amutha, C., Vasantha, V. S., Arunpandian, M., & Nagarajan, E. R. (2022). Biosynthesized silver nanoparticles using Rosary Pea seed Extract: Evaluation of Antibacterial, cytotoxic and photocatalytic activity. *Inorganic Chemistry Communications*, *145*, 109977. doi:10.1016/j.inoche.2022.109977

Santhosh, A., Theertha, V., Prakash, P., & Smitha Chandran, S. (2021). From waste to a value added product: Green synthesis of silver nanoparticles from onion peels together with its diverse applications. *Materials Today: Proceedings*, *46*, 4460–4463. doi:10.1016/j.matpr.2020.09.680

Gizem Karabulut (gizem.karabulut@iuc.edu.tr
Downloaded: 10/17/2023 2:41:40 AM
IP Address: 193.255.22.216

Shukla, S., Masih, A., Aryan, & Mehata, M. S. (2022). Catalytic activity of silver nanoparticles synthesized using Crinum asiaticum (Sudarshan) leaf extract. *Materials Today: Proceedings*, *56*, 3714–3720. doi:10.1016/j.matpr.2021.12.468

Sumi, M. B., Devadiga, A., Shetty, K. V., & Saidutta, M. B. (2016). Solar photocatalytically active, engineered silver nanoparticle synthesis using aqueous extract of mesocarp of Cocos nucifera (Red Spicata Dwarf), *12*(1), 14–32. doi:10.1080/17458080.2016.1251622

Tahir, M. B., Sohaib, M., Sagir, M., & Rafique, M. (2022). Role of Nanotechnology in Photocatalysis. Encyclopedia of Smart Materials, 578–589. doi:10.1016/B978-0-12-815732-9.00006-1

Tan, E., Kahyaoğlu, İ. M., & Karakuş, S. (2021). A sensitive and smartphone colorimetric assay for the detection of hydrogen peroxide based on antibacterial and antifungal matcha extract silver nanoparticles enriched with polyphenol. *Polymer Bulletin*, 1–27. doi:10.1007/S00289-021-03857-W/TABLES/5 PMID:34413556

Tetyana, P., Shumbula, P. M., & Njengele-Tetyana, Z. (2021). *Biosensors: Design, Development and Applications*. Nanopores. doi:10.5772/intechopen.97576

Thomas, S., Saji, K. J., & Jayaraj, M. K. (2022). An introduction to biosensors. *Nanomaterials for Sensing and Optoelectronic Applications*, 91–107. doi:10.1016/B978-0-12-824008-3.00013-8

Tortella, G., Rubilar, O., Diez, M. C., Cuozzo, S., Pieretti, J. C., & Seabra, A. B. (2022). Role of bacteria and actinobacteria in the biosynthesis of silver nanoparticles. *Green Synthesis of Silver Nanomaterials*, 493–512. doi:10.1016/B978-0-12-824508-8.00003-4

Uddin, I., Ahmad, K., Khan, A. A., & Kazmi, M. A. (2017). Synthesis of silver nanoparticles using Matricaria recutita (Babunah) plant extract and its study as mercury ions sensor. *Sensing and Bio-Sensing Research*, *16*, 62–67. doi:10.1016/j.sbsr.2017.11.005

Vaid, P., Raizada, P., Saini, A. K., & Saini, R. V. (2020). Biogenic silver, gold and copper nanoparticles - A sustainable green chemistry approach for cancer therapy. *Sustainable Chemistry and Pharmacy, 16*(August 2019). doi:10.1016/j.scp.2020.100247

Velasco-Garcia, M. N., & Mottram, T. (2003). Biosensor Technology addressing Agricultural Problems. *Biosystems Engineering*, *84*(1), 1–12. doi:10.1016/S1537-5110(02)00236-2

Gizem Karabulut (gizem.karabulut@iuc.edu.tr
Downloaded: 10/17/2023 2:41:40 AM
IP Address: 193.255.22.216

Vigneshvar, S., Sudhakumari, C. C., Senthilkumaran, B., & Prakash, H. (2016). Recent advances in biosensor technology for potential applications - an overview. *Frontiers in Bioengineering and Biotechnology*, *4*(FEB), 11. doi:10.3389/fbioe.2016.00011 PMID:26909346

Wang, Y., Chinnathambi, A., Nasif, O., & Alharbi, S. A. (2021). Green synthesis and chemical characterization of a novel anti-human pancreatic cancer supplement by silver nanoparticles containing Zingiber officinale leaf aqueous extract. *Arabian Journal of Chemistry*, *14*(4), 103081. doi:10.1016/j.arabjc.2021.103081

Wang, Y., Chou, S., & Zhang, Z. (2019). Nanomaterials Innovation. *Small*, *15*(32), 15–17. doi:10.1002mll.201902246 PMID:31397544

Wen, X., Wang, Q., Dai, T., Shao, J., Wu, X., Jiang, Z., Jacob, J. A., & Jiang, C. (2020). Identification of possible reductants in the aqueous leaf extract of mangrove plant Rhizophora apiculata for the fabrication and cytotoxicity of silver nanoparticles against human osteosarcoma MG-63 cells. *Materials Science and Engineering C*, *116*, 111252. doi:10.1016/j.msec.2020.111252 PMID:32806252

Weng, X., Yang, K., Owens, G., & Chen, Z. (2022). Biosynthesis of silver nanoparticles using three different fruit extracts: Characterization, formation mechanism and estrogen removal. *Journal of Environmental Management*, *316*, 115224. doi:10.1016/j.jenvman.2022.115224 PMID:35550961

Zamarchi, F., & Vieira, I. C. (2021). Determination of paracetamol using a sensor based on green synthesis of silver nanoparticles in plant extract. *Journal of Pharmaceutical and Biomedical Analysis*, *196*, 113912. doi:10.1016/j.jpba.2021.113912 PMID:33581590

Zhu, M., Li, X., Ge, L., Zi, Y., Qi, M., Li, Y., Li, D., & Mu, C. (2020). Green synthesis of κ-carrageenan@Ag submicron-particles with high aqueous stability, robust antibacterial activity and low cytotoxicity. *Materials Science and Engineering C*, *106*, 110185. doi:10.1016/j.msec.2019.110185 PMID:31753345