

## SYNTHESIS, CHARACTERIZATION AND BIOLOGICAL APPLICATIONS OF GREEN SYNTHESIZED IRON OXIDE NANOSTRUCTURES USING *ZINGIBER OFFICINALE*

B. S. Ali<sup>1</sup>, S. M. Hassan<sup>2</sup>, G. Abbas<sup>3</sup>, T. Aslam<sup>1</sup>, R. Tanveer<sup>4</sup>, M. A. Ibrahim<sup>5</sup>, M. Arshad<sup>3</sup>, M. A. Naveed<sup>3</sup>, M. Imran<sup>6</sup>, K. Imran<sup>7</sup>

<sup>1</sup>Department of Chemistry, Lahore Garrison University, Lahore.

<sup>2</sup>Department of Criminology and Forensic Sciences, Lahore Garrison University, Lahore.

<sup>3</sup>Department of Animal Production, Riphah International University, Lahore, Pakistan.

<sup>4</sup>Department of Chemistry, University of Education, Lahore.

<sup>5</sup>Department of Mathematics, the University of Lahore, Lahore

<sup>6</sup>Department of Pathology, University of Veterinary and Animal Sciences, Lahore Pakistan

<sup>7</sup>Pet Centre, University of Veterinary and Animal Sciences, Lahore Pakistan

<sup>8</sup>Department of Food Science and Human Nutrition, University of Veterinary and Animal Sciences, Lahore, Pakistan

Corresponding author: [s.monahassan@lgu.edu.pk](mailto:s.monahassan@lgu.edu.pk); [ghulamabbas\\_hashmi@yahoo.com](mailto:ghulamabbas_hashmi@yahoo.com)

**ABSTRACT:** Nanotechnology plays a vital role in the field of science. It acts as a bridge between bulk material and atomic level. Nanoparticles (NPs) are defined as materials with a size range from 1 to 100 nm. Nanostructures can be synthesized by three methods which include chemical, biological, and physical approaches. In chemical methods chemicals and solvents are harmful and poisonous to the biosystem and environment. However, in the biosynthesis method, the use of living organisms is involved. Plant extracts and microbes act as biological agents in the biosynthesis method. Comparatively biosynthesis method is preferable method the rest of the two approaches because of its non-toxicity, eco-friendliness, high stability, and reproducibility. Green synthesis is a bottom-up process that is similar to chemical reduction. However, in green synthesis, a natural product extracts an expensive chemical that works as a reducing agent in the manufacture of metal and its oxide nanostructures. Biomolecules (such carbohydrates, proteins, and coenzyme) found in plants have the exceptional ability to convert salts of metal into nanostructures. In the present study, *Zingiber officinale* was used to prepare iron oxide nanoparticles because of its polyphenols, which have significant antioxidant activity and other therapeutic characteristics. Phytochemically *Z. officinale* possesses steroids, glycosides, phenolic compounds, tannins, amino acids, carbohydrates, proteins, triterpenoids, and saponins. Iron nanostructures prepared from *Z. officinale* have enhanced antioxidant, anti-inflammatory, and antimicrobial properties.

**Keywords:** Nanostructures, Green synthesis, antioxidant, anti-inflammatory, *Zingiber officinale*.

(Received 06.07.2024

Accepted 04.09.2024)

## INTRODUCTION

Nanotechnology is involved in the characterization, synthesis, and modification of living and non-living structures that are typically smaller than 100 nanometers in size. This scale of structures has been proven to have distinct and unique functional characteristics. (Weiss, Takhistov, & McClements, 2006). Nano-particles research acts as a bridge between bulk materials and atomic level materials. Different methods and various precursors are used to create nanoparticles. Iron, nickel, zinc, copper, silver, and gold nanoparticles have recently become popular due to their widespread use and numerous benefits (Fazlzadeh et al., 2017; Abbas et al., 2022). Nanoparticles compact size, surface tailorability, multifunctionality and optimized solubility open many new research avenues for biologists. Unique features of nanoparticles allow them to engage with

complicated biological functions in a variety of ways at the molecular level. (McNeil, 2005). Nanotechnology is an area of science and engineering concerned with the manufacture, classification, and utilization of biomaterials with at least one dimension on the nanoscale scale, or one billionth of a meter, as the smallest functional unit (G. A. Silva, 2004).

The demand for more food has led scientists and engineers to find novel strategies to increase agricultural productivity as the world's population grows. Excessive use of long-acting pesticides has poisoned groundwater and soil over the previous six decades, causing a slew of chronic diseases and challenges in non-target creatures like humans and animals. The accurate detection of disease-causing bacteria in food products or toxic contaminants in soil and groundwater is the first step in eliminating such harmful substances. By exploiting well properties of nanomaterials. In pollution sensing and

prevention nanotechnology has promising inventions. Nanosensors can detect microbes, moisture content, and hazardous air pollutants at relatively low levels (Baruah & Dutta, 2009). Nanoparticles (Ns) are defined as materials with a size range from 1 to 100 nm. They have greater surface areas than the comparable bulk forms, relatively high reactivity, and a tunable nature of several characteristics due to their tiny size. These remarkable properties have the application of nanoparticles in biomedicine, aesthetics, electronic, food, environmental analysis and remediation or paints (Martínez-Cabanas, López-García, Barriada, Herrero, & de Vicente, 2016). In many sectors of the economy metal nanoparticles are used. A lot of interest in biological and environmental safety is growing in their production. Mainly nanoparticles can be synthesized by chemical and physical methods but they are mostly expensive and strongly harm the environment (Makarov et al., 2014). Nanostructures can be synthesized by three methods which include chemical, biological, and physical approaches. In chemical methods chemicals and solvents are harmful and poisonous to the biosystem and environment. However, in the biosynthesis method, the use of living organisms is involved. Plant extracts and microbes act as biological agents in the biosynthesis method. Comparatively biosynthesis method is a preferable method to the rest of the two approaches because of its non-toxicity, eco-friendliness, high stability, and reproducibility. Many inorganic metal nanoparticles can be prepared using a biosynthetic approach which includes the synthesis of silver, copper, gold, iron, titanium, palladium, lead, etc. (Renugadevi, Kumar, & Nachiyar, 2017). The use of plant extracts in the biosynthesis of nanometals has brought a new phase in nanoparticle creation that is both efficient and non-toxic (Iravani, 2011). Because of their special and distinctive chemical, photochemical, optical, and electronic properties, the “green synthesis” of metal nanostructures gains a lot of recognition in the field of nanotechnology (Mohanpuria, Rana, & Yadav, 2008). Green synthesis is a bottom-up process that is similar to chemical reduction. However, in green synthesis, a natural product extract such as plant leaves, vegetables, or fruits replaces an expensive chemical that works as a reducing agent in the manufacture of metal and its oxide nanostructures (Hussain, Singh, Singh, Singh, & Singh, 2016). Conventional chemical synthesis or green synthesis method is used to produce metal nanoparticles (MNPs). A multitude of progressing methods is involved in green synthesis which leads to the production of metal nanoparticles of the desired properties. The most investigated group of living organisms are plants which are used for the green synthesis of MNPs. Several plant species have been studied until now. Few of the factors are still unnoticed and uninvestigated yet during the production of MNPs by green synthesis (L. P. Silva, Reis,

& Bonatto, 2015). The use of various biomaterials in the production of nanomaterials is considered an important strategy in green nanotechnology. Nanostructured materials made from environmentally safe, energy-efficient, and eco-friendly natural resources, such as bacteria, algae, and fungi, have been developed at low cost (Saif, Tahir, & Chen, 2016; Pervez et al., 2022). The most common magnetic nanoparticles are iron oxide nanoparticles. The co-precipitation method or thermal decomposition approach is used to prepare these iron oxide nanoparticles, (Chiou, Lai, Hsu, & Chen, 2013). At room temperature, iron nanoparticles offer an order of magnitude greater susceptibility. This equates to lower magnetic fields required to manipulate the particles or enhanced localization of the particles. In leading to enhanced magnetic qualities, gold-coated iron nanostructures have expanded features and functions as a consequence of the very diversified chemistry attributed to gold. (M. Chen, Yamamuro, Farrell, & Majetich, 2003). Conventional methods cannot produce magnetic nanoparticles that can be used in biomedical applications that involve nonpolar organic solvents. The magnetism and dispersibility of iron oxide nanoparticles as synthesized are lost in the presence of air due to the chemical approach (Herlekar, Barve, & Kumar, 2014). Diagnostic applications of NPs include liver, body fluid node, inflammatory processes, and tube-shaped structures scanning, all of which use highly resonant imaging techniques, although they have recently begun to include additional magnetic organ imaging techniques. Medications cover the use of iron supplementation in anemia and advanced cannula treatments, which are comparable to modulating phagocytic cell polarization, magnetohydrodynamic physiologic state, and magnetic drug targeting. Due to their unique properties, iron-compound nanoparticles are an excellent tool for therapeutic purposes. (Dadfar et al., 2019). New approaches to growing nanoparticles are utilizing biological processes (Hassan et al., 2022). Iron oxide nanoparticles can surely be made by using alfalfa biomass, as previously reported. Magnetic cores were designed by mistreating a casting method consisting of the coexistence of  $\text{Fe}^{2+}$  and  $\text{Fe}^{3+}$  in a chemical reaction (Nnemeka et al., 2016).

The *Zingiber officinale* used in the experiment was treated, and as a result, the iron sulfide nanostructures were ready. Ginger, the rhizome of *Zingiber officinale* Roscoe (Zingiberaceae), may have originated in the Indo-Malayanian zone and is presently a crop that is grown throughout Asia, Africa, Europe, and the Americas, with most of it being distributed in Asia (Kizhakkayil & Sasikumar, 2011). With the pharmacological effects, *Zingiber officinale* has been known to be an excellent herbal medicinal product. *Zingiber officinale* aids in the formation of prostaglandins by suppressing cyclooxygenase-1 and cyclooxygenase-2,

two enzymes involved in prostaglandin synthesis. Ancient Chinese and Indian medicine use *Zingiber officinale* to address a wide variety of disorders, including stomach ulcers, diarrhea, nausea, asthma, and respiratory problems (Grzanna, Lindmark, & Frondoza, 2005). For over 2000 years, people have utilized *Zingiber officinale* as a spice and herbal seasoning (Bartley and Jacobs, 2000). *Zingiber officinale*, on the other hand, has a wide range of medicinal benefits. Research has also shown that long-term dietary consumption of *Zingiber officinale* has hypoglycaemic and hypolipidic consequences (Ahmed & Sharma, 1997).

In addition to immunomodulatory, anti-tumorigenic, anti-inflammatory, hypoglycemic, anti-lipidemic, anti-emetic, and anti-emetic properties, *Zingiber officinale* and its synthetic derivatives have some other medicinal properties. *Zingiber officinale* is a potent anti-oxidant and may either reduce or eliminate the production of free radicals (Table 2). It is regarded as a safe herbal medicine with only a few and minimal detrimental reactions (Ali, Blunden, Tanira, & Nemmar, 2008). According to the phytochemical data, *Z. officinale* powder has relatively high levels of saponin (4.01

g/100g) and cyanogenic glycoside (2.81 mg HN), but low levels of phytic, tannin, and oxalate. Proximate biochemical analysis showed the presence of crude fiber (10,36%), ash (6,57%), ether extract (6,48%), nitrogen-free extract (64,82%), and crude protein (64,82%). Major minerals include zinc (Zn), copper (Cu), sodium (Na), calcium (Ca), phosphorus (Pb), and iron (Fe) (Ogbuewu et al., 2014).

**Table 1: Nomenclature of *Zingiber officinale*.**

| Scientific classification |                            |
|---------------------------|----------------------------|
| Kingdom                   | Plantae                    |
| Clade                     | Tracheophytes              |
| Clade                     | Angiosperms                |
| Clade                     | Monocots                   |
| Clade                     | Commelinids                |
| Order                     | Zingiberales               |
| Family                    | Zingiberaceae              |
| Genus                     | Zingiber                   |
| Species                   | <i>Z.officinale</i>        |
| Binomial name             | <i>Zingiber officinale</i> |

**Table 2: The synthesis, characterization, and biological applications of green synthesized iron oxide nanostructures using *Zingiber officinale* (ginger).**

| Aspect                                   | References                      | Details                                                                                                                                  |
|------------------------------------------|---------------------------------|------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Synthesis</b>                         |                                 |                                                                                                                                          |
| <b>Materials</b>                         | Shanmugam et al. (2014)         | Iron salts like $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$ , deionized water, and <i>Zingiber officinale</i> extract.                     |
| <b>Method</b>                            | Gupta and Gupta (2005)          | Green synthesis using ginger extract, act as a reducing/stabilizing agent for iron salts to synthesize iron oxide NPs.                   |
| <b>Advantages</b>                        | Haq et al. (2017)               | These are cost-effective, eco-friendly, and avoids toxic chemicals which provide additional biological characteristics from ginger.      |
| <b>Process Conditions</b>                | Khatoon et al. (2015)           | Typically involves mixing ginger extract with an iron salt solution at room temperature or slightly elevated temperatures.               |
| <b>Characterization, Techniques Used</b> |                                 |                                                                                                                                          |
| <b>XRD</b>                               | Ahmad et al. (2013)             | Determines the crystalline structure and phase composition of the synthesized iron oxide nanostructures.                                 |
| <b>TEM/SEM</b>                           | Kumar et al. (2012)             | Visualizes the morphology, size, and distribution of nanoparticles.                                                                      |
| <b>FTIR</b>                              | Iravani (2011)                  | Identifies functional groups involved in the synthesis and capping of nanoparticles.                                                     |
| <b>UV-Vis Spectroscopy</b>               | Khan et al. (2016)              | Confirms the formation and optical properties of iron oxide nanoparticles.                                                               |
| <b>Antibacterial Activity</b>            | Bhattacharya & Mukherjee (2008) | Iron oxide nanoparticles exhibit antibacterial properties against a range of pathogens, enhanced by ginger's natural compounds.          |
| <b>Biological Applications</b>           |                                 |                                                                                                                                          |
| <b>Anti-inflammatory</b>                 | Sulaiman et al. (2018)          | Potential to reduce inflammation, leveraging both the properties of iron oxide and the bioactive compounds in ginger.                    |
| <b>Antioxidant Activity</b>              | Shukla et al. (2015)            | The antioxidant properties of ginger combined with iron oxide nanoparticles can scavenge free radicals effectively.                      |
| <b>Cancer Therapy</b>                    | Rajiv et al. (2013)             | Exhibits potential in targeting and killing cancer cells, due to the synergistic effects of iron oxide and ginger's bioactive compounds. |
| <b>Drug Delivery</b>                     | Prajapati et al. (2014)         | Nanoparticles can be used as carriers for targeted drug delivery, benefiting from ginger's therapeutic properties.                       |

Table 3: Applications of nanotechnology in various production fields.

| Field                | Applications                      | References                          | Description                                                                                                                                                            |
|----------------------|-----------------------------------|-------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Energy               | Solar Cells                       | Green (2012).                       | Nanomaterials are used to lessen the cost and increase the efficiency of solar cells, i.e. quantum dot and dye-sensitized solar cells.                                 |
|                      | Energy Storage                    | Arico et al. (2005).                | Nanomaterials improve battery and performance of supercapacitor, offering faster charging and higher energy density.                                                   |
| Medicine             | Drug Delivery                     | Peer et al. (2007).                 | Nanoparticles help to deliver drugs to targeted cells/tissues, increasing treatment efficacy and minimizing side effects.                                              |
|                      | Diagnostics                       | Rosi & Mirkin (2005).               | Nanoparticles are used to develop highly sensitive diagnostic tools like nanosensors (help early detection of diseases).                                               |
|                      | Cancer Therapy                    | Brannon-Peppas & Blanchette (2004). | Nanoparticles help to target/destroy cancer cells and spare healthy cells by methods e.g hyperthermia hence target drug distribution.                                  |
| Food and Agriculture | Food Packaging                    | Duncan (2011).                      | Use of nanomaterials in packing to increase barrier properties, thus prolonging the shelf life of foodstuffs.                                                          |
|                      | Pesticides and Nutrients Delivery | Rai & Ingle (2012).                 | Nanoparticles are used to provide pesticides/nutrients more efficiently, decreasing environmental effect.                                                              |
| Textiles             | Smart Fabrics                     | Tang et al. (2006).                 | Incorporation of nanoparticles into textiles and give functions including stain resistance, UV safety, and antimicrobial action.                                       |
|                      | Wearable Electronics              | Tao (2005).                         | Development of fabrics linked with electric works for health monitoring and connectivity features.                                                                     |
| Environment          | Water Treatment                   | Savage & Diallo (2005).             | Application of nanoparticles to remove contaminants/pollutants from water i.e. heavy metals as well as organic pollutants, by adsorption and/or catalytic degradation. |
|                      | Air Purification                  | Dufour et al. (2011).               | Titanium dioxide are used in air filters and coatings to remove pollutants, hence help to improve the air quality.                                                     |
| Electronics          | Transistors and Semiconductors    | Sordan (2008).                      | Nanotechnology allows the production of transistors (crucial components in modern electronics), which are more efficient, smaller, and faster.                         |
|                      | Displays                          | Shirasaki et al. (2013).            | Quantum dots and other nanomaterials are employed in displays to create brighter, more vibrant colors with lower energy consumption.                                   |
| Cosmetics            | Sunscreens                        | Nohynek et al. (2007).              | Titanium dioxide and zinc oxide nanoparticles used in sunscreens provide translucent sun protection.                                                                   |
|                      | Anti-Aging Products               | Ge et al. (2010).                   | Nanotmaterials permit deeper supply of active ingredients in skincare products to improve efficiency of anti-aging treatments.                                         |

The findings of phytochemical screening revealed the presence of saponins, polyphenols, flavonoids, reducing sugar, and alkaloids in the aqueous and petroleum ether extracts. However, tannins, anthracoids, phlorotannins, anthraquinones, and hydroxyl anthroquinones were missing from both aqueous and petroleum ether extracts. The findings of the approximate test indicated that *Zingiber officinale* rhizome includes ash, protein, lipid, and carbohydrate. According to the proximate analysis, it is stated the rhizome of *Zingiber officinale* has a high amount of carbohydrate but low protein contents (Nasef, 2018).

**Nanotechnology and Nanoscience:** Nanotechnology is the area of science and engineering that includes designing, production, analysis, and use of materials and technologies with at least one functional unit in one

dimension is one billionth of a meter or in nanoscale (Silva, 2004).

Nanoscience and nanotechnology are the novel boundaries of this era. Nanotechnology is utilized in many fields such as agriculture, the food sector, and pharmaceuticals. A lot of interesting topics of nanotechnology related to food and agriculture such as bioseparation of protein, fast sampling of biological and chemical pollutants, nanoencapsulation of nutraceuticals, and smart delivery of nutrients are studied in this field (Sozer & Kokini, 2009).

National nanotechnology initiation stated in 2006 that the understanding and control of matter between 1 to 100 nanometers due to which unique and distinctive applications are shown in them is called nanotechnology. Nanotechnology encompasses nanoscale research, engineering, and technology, as well as the

evaluation, sculpting, and alteration of matter on this scale (Weiss, Takhistov, & McClements, 2006).

**History of Nanotechnology:** The concept of a "nanometer" was first proposed by Nobel Prize-winning chemist Richard Zsigmondy in 1925. He was the first to use a microscope to measure the size of particles such as gold colloids, inventing the name "nanometer" to describe it. (Fanfair, Desai, & Kelty, 2007)

Richard Feynman, the physicist who won the Nobel Prize in 1965, is widely credited with developing modern nanotechnology. Richard Feynman delivered a lecture titled "There's Plenty of Room at the Bottom" at the 1959 American Physical Society meeting in Pasadena, California, where he came up with the concept of controlling matter at the atomic scale. (Hulla, Sahu, & Hayes, 2015). In the early 2000s, the public became increasingly aware of and concerned about this field, which led to the emergence of marketing applications of nanotechnology (Hassan *et al.*, 2022). In almost every branch of science, nanotechnologies have a positive impact, from physics and materials science to chemistry and biology (Bayda, Adeel, Tuccinardi, Cordani, & Rizzolio, 2020)

**Applications of Nanotechnology:** The use of zero-valent iron nanoparticles for the cleanup of water and soil polluted with chlorinated compounds and heavy metals is important (Ali Mansoori, Bastami, Ahmadpour, & Eshaghi, 2008).

It is possible to label specific molecules, structures, or microorganisms using magnetic nanoparticles attached to a specific antibody (Mushtaq *et al.*, 2022; Lashari *et al.*, 2022). The magnetic field produced by magnetically labeled targets can be detected directly with a sensitive magnetometer utilizing magnetic immunoassay techniques. It is possible to detect genetic sequences using gold nanoparticles labeled with short DNA segments (Jain, 2003).

Nanoparticles are also used as ultraviolet (UV) filters, such as insoluble mineral nanoparticles of titanium dioxide (TiO<sub>2</sub>) and zinc oxide (ZnO). There are several benefits to using nanoparticle formulas in cosmetic products, including:

- i) Enhancing the efficiency of many cosmetic ingredients encapsulated within the nanoparticles like unsaturated fatty acids, vitamins, or antioxidants;
- ii) Boosting the absorption of some constituents, such as vitamins and other antioxidants
- iii) Improving the effectiveness and sensitivity of UV filters on the skin surface (Mu & Sprando, 2010)

Nanoparticles are being used in diagnostic and therapeutic insights to help recognize, diagnose, and treat illnesses, especially in the medical field (Lewinski, Colvin, & Dreze, 2008). Food nanostructured

ingredients and food nanosensing are two broad categories of food nanotechnology applications. Because of their high essential element content and absence of toxicity, nanoparticle-based materials are in high demand in the food industry (Mughal, *et al.*, 2022). They also discovered that it remained stable at elevated temperatures and pressures. The use of nanotechnology in the food industry provides end-to-end solutions, from food production and processing to packaging (see table 3). Food quality and safety have improved with the use of nanomaterials, and many other health benefits that these foods provide (T. Singh *et al.*, 2017).

**Nanoparticles:** Nanoparticles (NPs) are materials with a diameter between one and one hundred nanometers. Because of their small size, they have larger surface areas than the bulk forms, relatively high reactivity, and an infinitely adjustable essence to numerous sites (Hassan *et al.*, 2022). These specialized properties have accelerated the development of nanoelectronics and the application of NPs in a broad variety of fields like biomedicine, cosmetics, electronics, food, environmental analysis, and remediation, or paints. The broad range of available core components, in conjunction with the tuneable surface chemistry, make nanoparticles a superb forum for a wide variety of biological and biological research (De, Ghosh, & Rotello, 2008).

Nanoparticles are also used in fluorescent biological labels. delivery of drugs and genes. Due to the detection of pyrogens, proteomic detection, DNA structure probing. The use of genetic engineering to create new tissue, destruction of the tumor by heating. Purification of biological molecules and cells through separation and purification increased MRI field of view, Phagokinetic research (Salata, 2004). Nanoparticles are complex mixtures. They interact in two ways differently. Even though they may absorb light like a dye and appear to disintegrate like any other tiny molecule, their real behavior is frequently different, which is mainly owing to the material's various components (Khushi *et al.*, 2022). They may appear to dissolve because they are small molecules. One of the reasons for some of the nanoparticles' unique properties is that they have a very high surface area to volume ratio (Christian, Von der Kammer, Baalousha, & Hofmann, 2008)

In nanocomposites, the greater surface area of nanoparticles brings a lot of interaction among the materials which results in distinctive properties such as enhanced strength, resistance, and chemical reactivity. The dimension of nanoparticles is below the critical wavelength of light which makes them transparent. This property of being transparent makes them valuable as they are useful in packaging, cosmetics, and coating (Holister, Weener, Roman, & Harper, 2003)

Because of their high surface area and nanoscale size, NPs show extraordinary properties. They possess

optical properties that are based on their size, which gives them different colors because of absorption in the visual spectrum. The novelty of their size, shape, and structure affects their reactivity, durability, and other characteristics (Oktaviani, 2021).

**Why Nanoparticles are Important?:** Nanoparticles' unique chemical and physical characteristics make them ideal for creating newly updated various sensors, particularly electrochemical sensors, and biological sensors. Many types of nanoparticles like metal, oxide, and semiconductor nanoparticles, have been used in the construction of electrochemical sensors and biological sensors, and these nanoparticles perform role in various sensing applications (Luo, Morrin, Killard, & Smyth, 2006)

Nanotechnology gives the chance for an effective elimination of contaminants and microbes in the water treatment area. Even now, nanopowder, nanomembrane, and nanoparticles are used to identify and eliminate chemical and biological substances, including metals (such as cadmium and copper), nutrients, cyanobacteria (such as cyanobacterial toxins), bacteria, viruses, pathogens, and antibiotics (Tiwari, Behari, & Sen, 2008).

With their unique physiochemical properties and growth inhibition capabilities against microbes, nanoparticles are studied for their potential use as antimicrobials (Ravishankar Rai, 2011). For lessening energy consumption nanomaterials are also used in the manufacturing of household electronics such as refrigerators (Bi, Shi, & Zhang, 2008).

The blood-brain barrier (BBB) is a significant barrier to drug delivery to the brain and spinal cord (CNS). Nanoparticles are used to deliver to the brain (Kreuter, 2005). Researchers are experimenting with nanoparticles in biofuel production in the hopes of improving the efficiency of bioprocesses (Sekoai *et al.*, 2019).

**Classification of Nanoparticles:** NPs are classified into different categories based on their size, morphology, and chemical characteristics. Based on chemical and physical properties nanoparticles are classified (Khan, Saeed, & Khan, 2019)

- Carbon-based nanoparticles
- Metal nanoparticles
- Ceramic nanoparticles

**Carbon-Based Nanoparticles:** Fullerenes, carbon nanocones, carbon nanofibers, graphene, nanodiamonds, and nano horns are all carbon nanoparticles (Zhang, Zheng, Li, & Lin, 2013). Because of its unique combined effect of chemical and physical properties, functional carbon-based nanomaterials (CBNs) have grown in importance, and vast research is being conducted to use these materials for a variety of industrial applications like

electronic devices and high-strength materials (Cha, Shin, Annabi, Dokmeci, & Khademhosseini, 2013). Nanomaterial that are composed of the globular hollow cage are said to be fullerenes. It is an allotropic form of carbon. It acts as an efficient gas absorbent and a supporting medium for many inorganic catalysts (Khan *et al.*, 2019)

**Metal Nanoparticles:** Metal NPs are solely constructed from metal precursors (Khan *et al.*, 2019). Novel noble metal nanostructures Au-Pt bimetallic nano complexes, Pt-Au heterostructures, a series of Pd nanocatalysts, and Au nanowires are synthesised (Bibi, *et al.*, 2023). Additional study indicates that these materials have greater catalytic potency in organic processes than previously described nanocrystal catalysts. Metal nanoparticles display an advanced electro-catalytic interaction for the oxidation of methanol (Wang & Gu, 2015). Because of their quantum size effects and high surface-to-volume ratio, MNPs have properties that differ significantly from those of their atomic constituents and bulk substances when operating at the nanoscale scale. Dimensions like configuration, crystalline nature, structures, and formation influence the MNPs' physical and chemical properties (Jingguo Li *et al.*, 2015).

**Ceramic Nanoparticles:** It is a nonmetallic inorganic solid made by heating and cooling. Ceramic NPs are inorganic nonmetallic solids. They come in amorphous, polycrystalline, tightly packed, porous, and hollow varieties (Khan *et al.*, 2019). Many years have passed since ceramic nanomaterials (both as single-component systems and as multi-component systems) have been used in many engineering applications. Polishing agents (cerium oxide and -alumina), insulators (silica aerogels), and cutting tools are all examples in this context. Stiffening fillers (nanosize carbon and titania), transducers, and dielectrics are some further examples. (Traykova, Aparicio, Ginebra, & Planell, 2006).

Material with particle size less than 100 nanometers, such as metallic and ceramic nanocrystalline materials, have exceptionally high values of strength and/or hardness, which are required in many applications (Ovid'ko & Sheinerman, 2007)

**Semiconductor Nanoparticles:** The materials that have the properties of metal and non-metal are said to be semiconductors. Semiconductor NPs have a band gap and with bandgap tuning, they show alteration in their properties (Khan *et al.*, 2019). Low-dimensional semiconductor materials have a lot of potential in electronic and optoelectronic because of their distinctive structure and functionality (including 2D, 1D, and 0D). Numerous 1D (such as black phosphorus and transition metal dichalcogenides) and 2D (for example, nanowires) components have shown greater efficiency in field effect transistors and photodiodes (Fang *et al.*, 2020).

**Polymer Nanoparticles:** Conducting polymers are a significant new category of functional organic materials for electronic and optical devices. Different sensor devices have made use of nanostructured conducting polymers with large surface areas, compact size, and specific physical characteristics (Yoon, 2013). Photoactivatable Near-Infrared Protherapeutics can be done by Using semiconducting Polymer Nanomaterials for Cancer Treatment (Jingchao Li & Pu, 2020) and also used as solar water splitting (Dai, Pan, & Liu, 2020).

**Lipid-based nanoparticles:** Lipid-based nanoparticle (LBNP) systems are among the most favorable colloidal transporters for bioactive organic compounds. Their current use in oncology has transformed cancer treatment by enhancing the antitumor effect of many anticancer drugs. The advantages of LBNPs involve their temporal resolution and thermal stability, maximum loading capabilities, easy preparation, low cost, and massive commercial production because they can be prepared from biological compounds (García-Pinel *et al.*, 2019). Due to their non-toxicity in living systems, lipid-based nanoparticles have made considerable advancement concerning DNA/RNA and drug delivery, especially when combined with nanoassemblies (Puri *et al.*, 2009).

**Iron and its Oxide:** Iron is a metal in group 8 of the periodic table of elements and ductile, hard material. Although it is the most common metal, its pure form corrodes quickly when exposed to humid air or high temperatures. On top of that, iron makes up a significant portion of the Earth's crust by weight and is thought to be the fourth most common element on Earth (Tandara & Salamunić, 2012).

Iron (Fe) can be found in nearly all of the earth's rock layers. Soil Fe oxide formation pathways can be explained by looking at the environmental settings under which a specific phase or group of phases occurs in a specific environment or soil sequence. Fe oxides can be reduced by a wide range of microorganisms, primarily anaerobic bacteria (Schwertmann & Taylor, 1989). Iron oxides such as hematite and goethite ( $\alpha\text{FeOOH}$ ) dominate the mineral world. Hematite and goethite are both iron sources for newly synthesized iron oxides but hematite dissolves in reducing conditions. Hematite concentration in the red soil layer conceals the existence of many other iron oxides (Costantini, Lessovaia, & Vodyanitskii, 2006).

**Iron Nanoparticles:** Iron oxide nanoparticles are the most extensively employed magnetic nanoparticles in biomedical applications because of their inexpensive cost, minimal toxicity, and strong magnetic properties. Maghemite ( $\gamma\text{-Fe}_2\text{O}_3$ ) and magnetite ( $\gamma\text{-Fe}_3\text{O}_4$ ) which shows supermagnetic behaviours are two examples of magnetic iron oxide nanoparticles that typically show excellent saturation magnetization (Aisida *et al.*, 2020).

The synthetic FeONPs demonstrated potential antibacterial properties against Gram-negative and positive pathogens as an individual and as an embedded material over cotton fabrics. On the other hand, FeONPs had a less antibacterial effect when tested against *Escherichia coli* and *Klebsiella pneumonia*. For the bioleaching of sewage from industrial and domestic source materials, FeONPs synthesized with *Ruella tuberosa* could be critical in killing pathogenic bacteria and degrading pigment (Vasantharaj, Sathiyavimal, Senthikumar, LewisOscar, & Pugazhendhi, 2019). In the field of groundwater and hazardous waste treatment, nZVI (nanoscale zero-valent iron) is one of the most used nanoparticles (Yan, Lien, Koel, & Zhang, 2013).



Figure 1. Prepared iron oxide nanoparticles

**Preparation of Nanoparticles:** Top-down and bottom-up approaches can both be used to make nanoparticles. The top-down method utilizes macro-sized materials to synthesize nanoparticles, while the bottom-up approach provides atoms to make nanoparticles. Comparing the two techniques, the bottom-up approach is the most widely used and established, and it is primarily based on synthesis routes that fall into two categories: simultaneous methods or successive methods. Precursor materials can be bimetallic or trimetallic alloy clusters are required in the same reaction by the simultaneous techniques. The succeeding method entails the development of particles by reducing metal ions on another metal core's surface (Huynh *et al.*, 2020).

For manufacturing nanoparticles gas particles and liquid/solid-to-solid pathways can be adopted by using aerosol methods (Backman, 2005).

**Gas to Particle Conversion:** Particle generation in gas-to-particle conversion involves cooling a superheated vapor using methods such as physical vapor deposition (PVD) or "evaporation–condensation method" and chemical vapor deposition (CVD). In PVD, the source of vapor is generated by evaporating solid or liquid. The nucleation and condensation of the saturated vapor, as well as the formation of solid particles, take place during the cooling stage. The vapor emitted from solution precursors is decomposed by heating or chemically in

CVD by adding another precursor vapor or neighboring gas. Eventually, nucleation, condensation, and coagulation are the processes involved in the formation of solid particles (Okuyama, Huang, Seinfeld, Tani, & Kousaka, 1991).

**Liquid-to-Particle Conversion:** Liquid-to-particle conversion is a breakdown process. It is called spray pyrolysis. In the spray method solutions and sols are utilized which is why it is called the liquid phase method. Many functional nanoparticles are generated through this process (Okuyama & Lenggoro, 2003).

**Microemulsion:** In 1943 Schulman and his colleagues gave the concept of microemulsion. It is impulsively created with the uptake of oil and water as they possess negative transient tension between their surfaces. As the total oil-water interfacial tension enhances the free energy goes on decreasing (Pillai, Kumar, Hou, Ayyub, & Shah, 1995).

**Sputtering:** The process in which nanoparticles are synthesized by bombarding high-energy beams on targeted metal is termed sputtering. This process involves three steps

- I. Atoms are migrated from a metal surface
- II. Nucleation and nanoparticle growth take place
- III. Absorption on metal in the presence of an electric field takes place (Huynh et al., 2020).

**Chemical precipitation method:** In this method on supersaturated conditions solids are formed by using a solution. In which soluble material is converted into insoluble form by changing pH, and oxidation potential, by adding precipitation reagent (Huynh et al., 2020).

**Green Synthesis:** Keeping in view the dependable, stable, and environmentally friendly manufacturing approaches green synthesis is the best approach through which undesired and hazardous products do not form. At large scale using plant extract is the simple way for producing nanoparticles. Biomolecules (such as carbohydrates, proteins, and coenzyme) found in plants have the exceptional ability to convert salts of metal into nanostructures. Gold and silver metal nanoparticles were originally studied in plant extract-assisted biosynthesis. To manufacture silver and gold nanoparticles, several plants have been used, including Oat (*Avena sativa*), aloe vera (*Aloe barbadensis* Miller), Tulsi (*Osimum sanctum*), alfalfa (*Medicago sativa*), Neem (*Azadirachta indica*), Lemon (*Citrus limon*), Coriander (*Coriandrum sativum*), lemon grass (*Cymbopogon*) and Mustard (*Brassica juncea*) (J. Singh et al., 2018)

Different macroscopic or microscopic organisms, such as plant extracts, bacteria, fungi, seaweeds, yeast, and microalgae, can successfully

manage numerous epidemic illnesses with fewer side effects by generating biological nanoparticles (Nurbas, Ghorbanpoor, & Avci, 2017).

In all biological species plants are the most suitable option for the synthesis of nanostructures on a commercial scale. The nanomaterial that is composed of plants has more stability and it is synthesized more rapidly than the synthesis of microorganisms (Iravani, 2011).

Nanomaterials that are prepared through green synthesis can produce bioinspired nanoparticles that have with range of biofunctionality. This is the reason green synthesis is preferred over chemical synthesis (Yuvakkumar & Hong, 2014).

Green synthesis is termed biological reduction in which plants act as reducing agents. It is a “bottom-up” approach which is close to the chemical reduction method. The major difference is of reducing agent as in green synthesis an extract of a plant that can have stability and growth terminating and protecting properties is substituted instead of a chemical (Hussain, Singh, Singh, Singh, & Singh, 2016).

**Why green synthesis method is effective in nanotechnology?:** When iron oxide nanoparticles are exposed to air, they oxidize and aggregate. To prevent this, nanoparticles must be encased or blended with supporting materials such as organic manures and carbon. Plant biomass is a cost-effective, renewable, and carbon-rich energy source. It can be utilized to make nanoparticles with minimal or no chemical treatment. Plant biomass is used in the synthesis as a reducing agent (Herlekar et al., 2014)

**Zingiber officinale:** *Zingiber officinale* Roscoe belongs to the family of Zingiberaceae and is known as conventional medicine that is also used as spices, food flavoring, and remedies to cure women during childbirth, cure stomach illness, and diarrhea (Norhidayah, Noriham, & Rusop, 2013) *Zingiber officinale* is a popular and frequently used spice with a long history in India. Polyphenolic substances with high antioxidant activity include gingerol and its derivatives isolated from ginger root. It has gotten increased interest from researchers because of its polyphenols, which have significant antioxidant activity and other therapeutic characteristics (Mukherjee, Mandal, Dey, & Mondal, 2014).

*Zingiber officinale* can cure several illnesses which include arthritis and rheumatism (degenerative problems), related to digestive health such as constipation, ulcers, and cardiovascular and indigestion problems such as vomiting, hypertension, cancer, and diabetes. For controlling the aging process ginger also possesses anti-inflammatory and anti-oxidative characteristics. Its antimicrobial quality can take part in curing infectious diseases (Mashhadi et al., 2013).

**Naming of *Zingiber Officinale*:** In different parts of the world, *Z. officinale* is known by different names (Kumar, Karthik, & Rao, 2011).

**Table 2.1: Name of *Z.officinale* in different languages.**

| <i>Z.officinale</i> names | Language   |
|---------------------------|------------|
| Ginger                    | English    |
| Sheng jiang               | Chinese    |
| Aduwa, sutho              | Nepali     |
| Gingembre                 | French     |
| Jahe                      | Indonesian |
| Khing                     | Thai       |
| Saenggang                 | Korean     |
| Adarakha                  | Hindi      |
| Ada                       | Bengali    |
| Adi, Adrak                | Punjabi    |
| Allamu, Allam             | Telugu     |
| Adrak                     | Urdu       |

**Structure and Morphology of *Zingiber officinale*:** *Zingiber officinale* Roscoe or ginger which contains leaf structure, stem, and rhizomes. *Zingiber officinale* is a monocotyledon that belongs to the family Zingiberaceae (Abdullah, Kamaruddin, & Harun, 2018).

The *Zingiber officinale* plant's leaf is made up of mesophyll cells, vascular bundles, and epidermal cells. Oil and crystal cells are found throughout the parenchyma in scattered form (Liu, Specht, Zhao, & Liao, 2020).

*Zingiber officinale* having thick tuberous rhizome is a crawling perennial plant that produces an upright tall stem of 30-100cm (1-3 ft). They have lobed-shaped leaves that are green in color. They are 15-20 cm long. They have a distinctive longitudinal rib that surrounds conical clusters of tiny yellow-green flowers with purple patches. It is grown from rhizome grafting and grown in fertile soil (Adebawale, Gbenga, & Yewande, 2014).



**Figure 2. *Z.officinale*'s Plant**

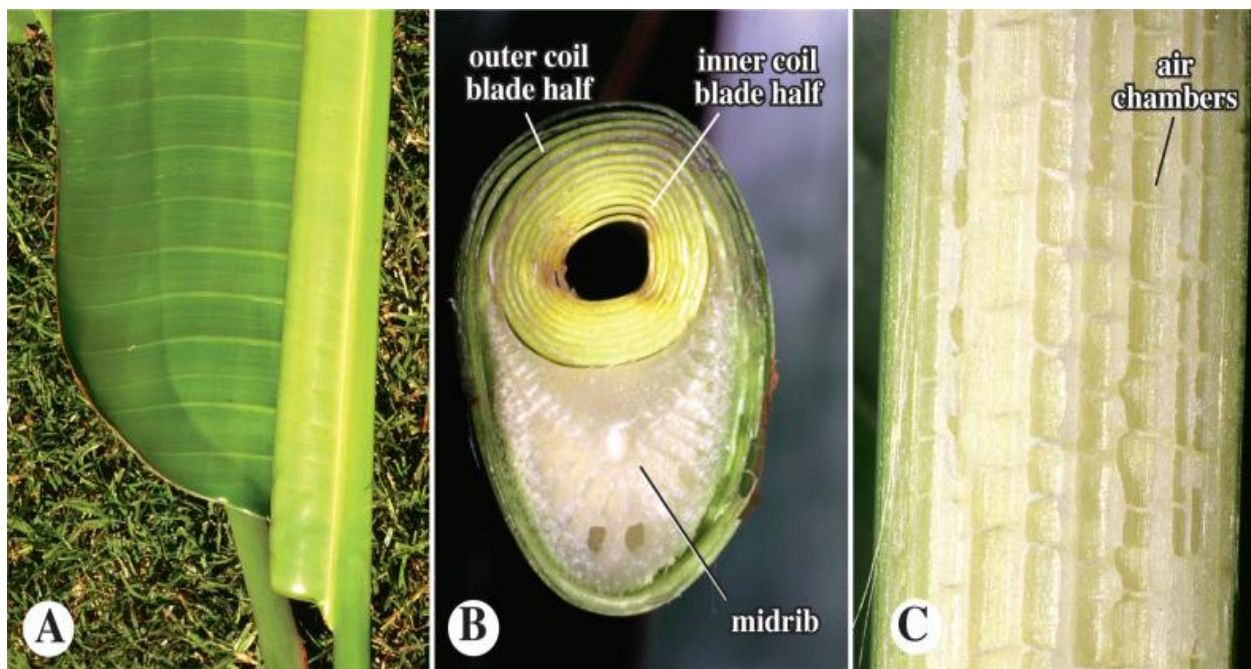


**Figure 3. A: Young leaf B: Immature leaf cross-section C: Diaphragm air chamber in a leaf petiole**

*Zingiber officinale* reproductive phase began when the inflorescence stalk appeared from the rhizome, and its phenological characteristics were peduncle elongation, inflorescence appearance, dropping, and aging (Martinsyah, 2021). *Zingiber officinale* have ebracteate, zygomorphic unisexual, epigynous flowers. It has biseriate, homochlamydeous, and syntepalous calyx. The inferior ovary is present in all Zingiberales (Takhtadzhian, Takhtajan, & Takhtajan, 1997).

**Phytochemical Analysis of *Zingiber Officinale*:** The principal phytochemical categories found in *Z. officinale* are phenolic compounds, carbohydrates, proteins, saponins, steroids, terpenoids, and essential (Kumar et al., 2011).

*Z. officinale* has a moisture content of 80%, 2% fiber and protein, 1% mineral, 12% carbohydrates, and 0.9% fat (Al-Awwadi, 2017).

Phytochemically in *Z. officinale* steroids, glycosides, phenolic compounds, tannins, amino acids, carbohydrates, proteins, triterpenoids, and saponins are present. (Kemper, 1999)

In *Z.officinale* rhizome manganese (Mn), zinc (Zn), calcium (Ca), copper (Cu), sodium (Na), iron (Fe), potassium (K) and phosphorus (P) are present (Ogbuewu et al., 2014).

Many active compounds are found in *Z.officinale*. paradol, gingerol, zingerone, shogaol, trans-3-hydroxy-1,8-cineole-O- $\beta$ -D-glucopyranoside and trans-1,8-cineole-3,6-dihydroxy-3-O- $\beta$ -D-glucopyranoside are derived from ginger. Shogaol and gingerenone- A are known to enhance antimicrobial activity (Rampogu et al., 2018).

*Z.officinale* covers a range of pungent and bioactive components such as phenolics, flavonoids, gingerol, shogaol, and zingeror. Gingerol is the most plentiful bioactive compound among the recognized components. Gingerols have some nutraceutical advantages, including the prevention of obesity and diabetes. Gingerols successfully cured malignant tumors

in animal models. The toxicological profile of ginger metabolites is favorable (Semwal, Semwal, Combrinck, & Viljoen, 2015).

**Pharmacological Activity:** Zingiberaceae plants have more significance because they generate many compounds which are beneficial in food as herbs and spice also as antimicrobial and reducing agents. These qualities expand their use in the medical and cosmetics industry (Ghasemzadeh, Jaafar, & Rahmat, 2016)

*Zingiber officinale* has been shown to protect the gastric mucosa from ulcerogenic substances such as cholinergic and histaminic receptors. Because of its antioxidant and anti-cholinergic qualities, ginger is quite beneficial in situations of ulcerogenesis (Dugasani et al., 2010). *Z.officinale* regulates genetic pathway by suppressing tumor of genes (Duarte et al., 2016).

Menstrual cramps are relieved by its antiplatelet and cyclooxygenase inhibitory effects, as well as its anti-inflammatory action upon prostaglandin. Antimicrobial capabilities, cholesterol modulation, and hypotensive qualities all help to alleviate pain (Rajagopal, Byran, Jupudi, & Vadivelan, 2020). *Zingiber officinale* has anti-tumor, anti-apoptosis, anti-hyperglycemia, anti-cough, and cold and anti-inflammation properties (Dadfar, Hosseini, & Bahaoddini, 2014).

According to a study published in the British Journal of Clinical Pharmacology and Experimental Medicine, gingerol is the most predominant functional molecule in ginger, with many pharmacological effects (Ghasemzadeh et al., 2016).

The addition of ginger and turmeric powders made a substantial contribution to the anti-oxidant properties of soybean oil by supplying high lipid-soluble bioactive substances such as 6-gingerol and curcumin, respectively. The antioxidant activity of soybean oils added with ginger and turmeric has been found to improve linearly with the increase of phenolic yields (Tinello, Zannoni, & Lante, 2020).

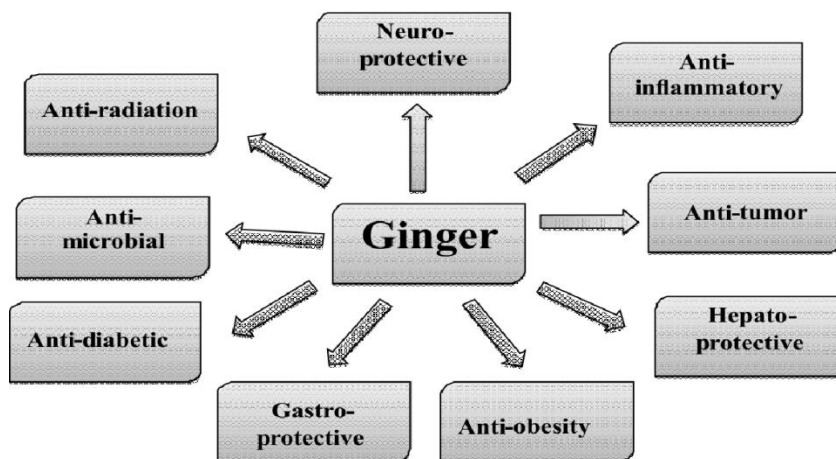


Figure 4. Uses of *Z.officinale* (Ginger)

*Zingiber officinale* anti-inflammatory properties can alleviate muscle pain after severe physical exertion. Similarly, ginger's anticancer potential is well known, and its bioactive components such as gingerols, shogaol, and paradols are vital substances that can block off many cancers, induction and inhibition of apoptosis and stopping of cell cycle. Cardiovascular disease, diabetes mellitus, and gastrointestinal conditions are enhanced by these substances (Mashhadi et al., 2013).

#### Pharmacological Properties of *Zingiber officinale*

**Anti-oxidant effect:** At many concentrations, ginger extract displayed extremely strong antioxidant activity, almost equal to that of synthetic antioxidants (BHA and BHT). Because of its good thermal stability and 85.2% inhibition of peroxidation of linoleic acid peroxidation when heated at 185°C for 120 minutes, ginger extract can be utilized as an anti-oxidant to reduce lipid oxidation (Salariya & Habib, 2003). *Zingiber officinale* extract and its four pure components 6-gingerol, 8-gingerol, 10-gingerol, and 6-shogaol exhibited antioxidant properties that might be attributed to their hydroxyl groups and suitable solubilizing side chains. 6-Shogaol and 10-gingerol exhibited higher activity at 60°C than 6-gingerol and 8-gingerol (Si, Chen, Zhang, Chen, & Chung, 2018). Antioxidant activity of *Zingiber officinale* extract containing polyphenol components is linked to their capacity to be donors of hydrogen atoms or electrons and to capture (Mošovská, Nováková, & Kaliňák, 2015).

In comparison to synthetic antioxidants like vitamin E, ginger's lower concentration ethanolic extract has a strong antioxidant activity. It can be used as an effective natural antioxidant in the food and pharmaceutical sectors for the formulation of functional foods (Mukherjee et al., 2014).

**Anticancer activity:** In numerous tumor cell lines, *Zingiber officinale* extract and its principal pungent components, 6-shogaol and 6-gingerol, have been shown to inhibit tumor cell proliferation. Ginger extract has potential anticancer activity via triggering RS-mediated autosis in pancreatic cancer cells, and it needs further investigation to build an effective candidate treatment (Akimoto, Iizuka, Kanematsu, Yoshida, & Takenaga, 2015). In a variety of prostate cancer cells, ginger extract has strong growth inhibitory and death-inducing actions. GE was shown to disrupt cell-cycle development, decrease reproductive capability, and alter cellular regulatory components, according to studies (Karna et al., 2012). 03157075207

*Z. officinale* has a plentiful flavonoid substance named quercetin. It has an antioxidant activity that plays cytoprotective roles in opposition to oxidative stress. Quercetin secures cells from damaging free radicals by the antioxidant effect. It stops tumourigenesis. However,

by pro-oxidant function, it encourages the death of apoptotic cells (Rahman, Salehin, & Iqbal, 2011).

Cholangiocarcinoma (CCA) is a rare adenocarcinoma that develops from the bile duct's epithelial cells. The crude ethanolic extract of ginger demonstrated potential antitumor efficacy against CCA while exhibiting no major toxicity (Plengsuriyakarn et al., 2012).

**Anti-inflammatory effect:** *Zingiber officinale* anti-oxidant, anti-inflammation, and anti-coagulation properties have been researched, and the plant's efficacy in reducing pain and improving nausea and vomiting has been demonstrated (Arablou & Aryaeian, 2018). *Z. officinale* is highly effective in curing osteoarthritis of the knee. It lessens the symptoms of the disease (Altman & Marcussen, 2001). *Zingiber officinale* is both safe and effective in curing migraine in individuals with aches that manifest themselves after 2 hours (L. Chen & Cai, 2021).

**Antifungal Activity:** The *Z. officinale* in ethanol extract was found to have antifungal activity against two strains of *Candida albicans* (PTCC 5027 and ATCC 10231). The results demonstrated the extract's potent antifungal potency (Kumar et al., 2011).

**Antibacterial Activity:** Flavonoids and crude polysaccharides in aqueous and ethanol extracts of *Z. officinale* were found to have antibacterial activity. Ethanol extracts and crude flavonoids have antibacterial action towards *Staphylococcus aureus*, *Escherichia coli*, *Proteus vulgaris*, *Pseudomonas aeruginosa*, and *Shigella flexneri* but polysaccharides and aqueous extracts do not have such activity (Kumar et al., 2011).

Some volatile oils present in ginger, such as ar-curcumin, trimethyl heptadienol, carbaldehyde, camphene, and nerol, have been shown to stop the development of test bacteria (Suciya & Adnyana, 2017). The synthesized materials nanoparticles from ginger extract have antibacterial activity against Gram negative bacteria *E. coli*, with 22 mm diameters of inhibition zone. Strong antioxidant and antifungal properties are shown in iron oxide nanoparticles (Kirdat et al., 2021).

**Antiviral Activity:** When compared to the presently used medication Hydroxychloroquine (5.47), the chemical components of pepper, such as Piperdardine and Piperanine, and ginger, such as 8-Gingerol and 10-Gingerol, were substantially active against COVID-19 with a considerable Glide score (Rajagopal et al., 2020).

Phytochemical substances found in *C. medica* and *Z. officinale* can reduce viral load and SARS-CoV-2 shedding in the nasal passages (Haridas et al., 2021).

Ginger and lemon are considered the finest of all herbal remedies. They include numerous natural vitamins, minerals (magnesium, potassium, zinc, selenium, iron), and phenolic compounds (quercetin, gingerol, shogaol, paradol, limonene, limonins, and

hesperidin) that are effective antiviral substances. They enter the mucous secretion of the nasal pathway which boosts immunity. These substances also stop the replication of COVID-19 (Omoruyi, 2021).

**Conclusion:** In the present study, it is concluded that *Z. officinale* was used as a reducing agent in the green synthesis of iron oxide nanoparticles. Due to the antioxidant, anti-inflammatory, and anti-tumorigenic properties of *Z. officinale* the iron nanostructures prepared from it also have enhanced pharmacological properties. These nanostructures can be used in biomedical applications due to their low cost, low toxicity, and strong magnetic properties. However, the method of synthesis opted for is also eco-friendly and cost-effective. Resultantly, the synthesis of iron oxide nanostructures by using biological material proves to be beneficial in the manufacturing of nanoparticles.

## REFERENCES

- Aisida, S. O., N. Madubuonu, M. H. Alnasir, I. Ahmad, S. Botha, M. Maaza and F. I. Ezema (2020). Biogenic synthesis of iron oxide nanorods using *Moringa oleifera* leaf extract for antibacterial applications. *Appl. Nanosci.* 10(1): 305-315.
- Abbas, G., S. Jaffrery, A. H. Hashmi, M. Arshad, S. J. Usmani, M. S. Imran, A. J. Tanveer, M. Tariq, M. Saleem, Q. Amin, A. A. Khan, M. A. Alvi, S. B. Shabbir, R. A. M. Qureshi, A. Mustafa, T. A. Iqbal, A. Iqbal, M. Hassan, S. Abbas, W. Abbas, H. Abbas, S. G. Mohyuddin, W. Ismail, D. K. A. AL-Taey, & B. Shaukat. 2022. Current prospects of nanotechnology use in animal production and its future scenario. *Pakistan Journal of Science*, 74 (3), 203–222. <https://doi.org/10.57041/pjs.v74i3.789>.
- Bibi, E., S. M. Hassan, Z. Perveen, B. S. Ali, M. Kanwal and M. A. Ibrahim (2023). An overview of classification, synthesis and characterization of nanomaterials. *Pakistan Journal of Sciences*. 75(4): 781-790.
- Chen, M., S. Yamamuro, D. Farrell and S. A. Majetich (2003). Gold-coated iron nanoparticles for biomedical applications. *J. Appl. phys.* 93(10): 7551-7553.
- De, M., P. S. Ghosh and V. M. Rotello (2008). Applications of nanoparticles in biology. *Adv. Mater.* 20(22): 4225-4241.
- Hussain, I., N. Singh., A. Singh., H. Singh and S. Singh (2016). Green synthesis of nanoparticles and its potential application. *Biotechnol.* 38(4): 545-560.
- Iravani, S (2011). Green synthesis of metal nanoparticles using plants. *Green Chem.* 13(10): 2638-2650.
- Mukherjee, S., N. Mandal, A. Dey and B. Mondal (2014). An approach towards optimization of the extraction of polyphenolic antioxidants from ginger (*Zingiber officinale*). *J. Food Sci. Technol.* 51(11): 3301-3308.
- Nasef, A. N. Z. (2018). Study the effect of chicory (*Cichorium Intybus*) leaves powder on some biochemical and biological parameters of hepatotoxicity induced by Ccl4 in rats. *J. Home Econ.* 28(1):23-29.
- Norhidayah, A., and M. Rusop (2013). The Effect of Drying Methods on Physicochemical Properties of Nanostructured *Zingiber officinale* Rosc.(Ginger) Rhizome. *Adv. Mat. Res.* 9(3): 34-39.
- Nurbas, M., H. Ghorbanpoor and H. Avci (2017). An eco-friendly approach to synthesis and characterization of magnetite (Fe<sub>3</sub>O<sub>4</sub>) nanoparticles using *Platanus orientalis* L. Leaf extract. *Dig. J. Nanomat. Biostruc.* 12(4): 35-41.
- Ogbuewu, I., P. Jiwuba, C. Dig. J. Nanomater, M. Uchegbu, I. Okoli and M. Iloeje (2014). Evaluation of phytochemical and nutritional composition of ginger rhizome powder. *Int. J. Agri. Rur. Develop.* 17(1): 1663-1670.
- Okuyama, K., D. Huang, J. H. Seinfeld, N. Tani and Y. Kousaka (1991). Aerosol formation by rapid nucleation during the preparation of SiO<sub>2</sub> thin films from SiCl<sub>4</sub> and O<sub>2</sub> gases by CVD process. *Chem. Eng. Sci.* 46(7): 1545-1560.
- Okuyama, K. and I. W. Lenggono (2003). Preparation of nanoparticles via spray route. *Chem. Eng. Sci.* 58(3): 537-547.
- Pillai, V., P. Kumar, M. Hou, P. Ayyub and D. Shah (1995). Preparation of nanoparticles of silver halides, superconductors and magnetic materials using water-in-oil microemulsions as nano-reactors. *Adv. Colloid. Interfac.* 55: 241-269.
- Renugadevi, K., N. Kumar and C. V. Nachiyar (2017). Phytosynthesis of Silver Nanoparticle using Ginger extract as a Reducing agent by Microwave Irradiation method and invitro Evaluation of its Antibacterial activity and Cytotoxicity. *Res. J. Pharm. Technol.* 10(12): 4142-4146.
- Salata, O. V. (2004). Applications of nanoparticles in biology and medicine. *J. Nanobiotechnol.* 2(1): 1-6.
- Vasantharaj, S., S. Sathiyavimal, P. Senthilkumar, F. L. Oscar and A. Pugazhendhi (2019). Biosynthesis of iron oxide nanoparticles using leaf extract of *Ruellia tuberosa*: antimicrobial properties and their applications in photocatalytic degradation. *J. Photoch. Photobio. Biol.* 192: 74-82.
- Yan, W., H. L. Lien, B. E. Koel and W. X. Zhang (2013). Iron nanoparticles for environmental clean-up:

- recent developments and future outlook. *Environ. Sci. Pro. Imp.* 15(1): 63-77.
- Yuvakkumar, R. and S. Hong (2014). Green synthesis of spinel magnetite iron oxide nanoparticles. *Adv. Mat. Res.* 12(4): 23-29.
- Abdullah, S., N. Y. Kamaruddin and A. R. Harun (2018). The effect of gamma radiation on plant morphological characteristics of *Zingiber officinale Roscoe*. *Int. J. Adv. Sci. Eng. Infor. Technol.* 8(5): 2085-2091.
- Adebowale, B. O., B. L. Gbenga and F. Yewande (2014). Morphology, functional and pasting properties of ginger starches prepared by four different drying methods. *J. Pharm. Res. Int.* 23: 1439-1450.
- Aisida, S. O., N. Madubuonu, M. H. Alnasir, I. Ahmad, S. Botha, M. Maaza and F. I. Ezema (2020). Biogenic synthesis of iron oxide nanorods using *Moringa oleifera* leaf extract for antibacterial applications. *Appl. Nanosci.* 10(1): 305-315.
- Akimoto, M., M. Iizuka, R. Kanematsu, M. Yoshida and K. Takenaga (2015). Anticancer effect of ginger extract against pancreatic cancer cells mainly through reactive oxygen species-mediated autotic cell death. *PloS one.* 10(5): 26-32.
- Al-Awwadi (2017). Potential health benefits and scientific review of ginger. *J. Pharmacognosy Phytother.* 9(7), 111-116.
- Ali Mansoori, G., T. R. Bastami, A. Ahmadpour and Z. Eshaghi (2008). Environmental application of nanotechnology. *Nano. Res.* 12: 439-493.
- Altman, R. D. and K. Marcussen (2001). Effects of a ginger extract on knee pain in patients with osteoarthritis. *Arthritis and Rheum.* 44(11): 2531-2538.
- Arablou, T. and N. Aryaeian (2018). The effect of ginger (*Zingiber officinale*) as an ancient medicinal plant on improving blood lipids. *J. Herb. Med.* 12: 11-15.
- Backman, U. (2005). Studies on nanoparticle synthesis via gas-to-particle conversion. *Nano Sci.* 12:12-24.
- Bayda, S., M. Adeel, T. Tuccinardi, M. Cordani and F. Rizzolio (2020). The history of nanoscience and nanotechnology: from chemical-physical applications to nanomedicine. *Molecules.* 25(1): 112-119.
- Bi, S., L. Shi and L. I. Zhang (2008). Application of nanoparticles in domestic refrigerators. *Appl. Therm. Eng.* 28(14): 1834-1843.
- Cha, C., S. R. Shin., N. Annabi., M. R. Dokmeci and A. Khademhosseini (2013). Carbon-based nanomaterials: multifunctional materials for biomedical engineering. *ACS nano.* 7(4): 2891-2897.
- Chen, L. and Z. Cai (2021). The efficacy of ginger for the treatment of migraine: A meta-analysis of randomized controlled studies. *J. Exp. Med.* 46: 567-571.
- Chen, M., S. Yamamuro, D. Farrell and S. A. Majetich (2003). Gold-coated iron nanoparticles for biomedical applications. *J. Appl. Phys.* 93(10): 7551-7553.
- Christian, P., F. Von der Kammer, M. Baalousha and T. Hofmann (2008). Nanoparticles: structure, properties, preparation and behaviour in environmental media. *Ecotoxicol.* 17(5): 326-343.
- Costantini, E., S. Lessovaia and Y. Vodyanitskii (2006). Using the analysis of iron and iron oxides in paleosols (TEM, geochemistry and iron forms) for the assessment of present and past pedogenesis. *Quat. Int.* 156: 200-211.
- Dadfar, F., S. E. Hosseini and A. Bahaoddini (2014). A review of phytochemical, pharmacological and physiological properties of ginger (*Zingiber officinale*). *Clin. Excell.* 3(1): 72-86.
- Dai, C., Y. Pan and B. Liu (2020). Conjugated polymer nanomaterials for solar water splitting. *Adv. Ener. Mater.* 10(42): 20-24.
- De, M., P. S. Ghosh and V. M. Rotello (2008). Applications of nanoparticles in biology. *Adv. Mater.* 20(22): 4225-4241.
- Duarte, M. C., G. S. Tavares, D. G. Valadares, D. P. Lage, T. G. Ribeiro, L. M. Lage and E. S. Silva (2016). Antileishmanial activity and mechanism of action from a purified fraction of *Zingiber officinalis Roscoe* against *Leishmania amazonensis*. *Exp. Parasitol.* 166: 21-28.
- Dugasani, S., M. R. Pichika, V. D. Nadarajah, M. K. Balijepalli, S. Tandra and J. N. Korlakunta (2010). Comparative antioxidant and anti-inflammatory effects of [6]-gingerol, [8]-gingerol, [10]-gingerol and [6]-shogaol. *J. Ethnopharmacol.* 127(2): 515-520.
- Emerich, D. F. and C. G. Thanos (2003). Nanotechnology and medicine. *Expert. Opin. Biol. Ther.* 3(4): 655-663.
- Fanfair, D., S. Desai and C. Kerty (2007). The early history of nanotechnology. *Connexions.* 6(1):15-21.
- Fang, J., Z. Zhou., M. Xiao, Z. Lou, Z. Wei and G. Shen (2020). Recent advances in low-dimensional semiconductor nanomaterials and their applications in high-performance photodetectors. *InfoMat.* 2(2): 291-317.
- Garcia-Pinel, B., C. P. Alcala, A. O. Rodriguez, F. Sarabia, J. Prados, C. Melguizo and J. M. L. Romero (2019). Lipid-based nanoparticles: application and recent advances in cancer treatment. *Nanomater.* 9(4): 638-645.

- Ghasemzadeh, A., H. Z. Jaafar and A. Rahmat (2016). Changes in antioxidant and antibacterial activities as well as phytochemical constituents associated with ginger storage and polyphenol oxidase activity. *Bmc. Complem. Altern. M.* 16(1): 1-11.
- Haridas, M., V. Sasidhar, P. Nath, J. Abhithaj, A. Sabu and P. Rammanohar (2021). Compounds of *Citrus medica* and *Zingiber officinale* for COVID-19 inhibition: in silico evidence for cues from Ayurveda. *Future J. Pharm. Sci.* 7(1): 1-9.
- Hassan, S. M., A. A. Malik and H. H. Shehzad (2022). New Perspective of Calcium Oxide Nanoparticles in Forensic Science. *International journal of electronic crime investigation.* 6(2): 33-48.
- Hassan, S. M., A. A. Malik and A. Hussain (2022). Nanotechnology: An applied and extensive approach in solving crimes. *International journal of electronic crime investigation.* 6(2): 49-55.
- Hassan, S. M., A. A. Malik and E. Razia (2022). ZnO Nanoparticles: Synthesis, Characterization and Applications in Forensics. *International journal of electronic crime investigation.* 6(1): 2022.
- Hassan, S. M., A. A. Malik and Z. Khalid (2022). The role and impact of aluminium oxide nanoparticles in crime investigation. *International journal of electronic crime investigation.* 6(1):15-24.
- Herlekar, M., S. Barve and R. Kumar (2014). Plant-mediated green synthesis of iron nanoparticles. *J. nanomater.* 14-19.
- Holister, P., J. W. Weener, C. Roman and T. Harper (2003). Comparative study of nanoparticles. *Nanopart. Technol.* 3: 1-11.
- Hussain, I., N. Singh, H. Singh and S. Singh (2016). Green synthesis of nanoparticles and its potential application. *Biotechnol. Lett.* 38(4): 545-560.
- Huynh, K.H., X. H. Pham, J. Kim, S. H. Lee, H. Chang, W. Y. Rho and B. H. Jun (2020). Synthesis, properties, and biological applications of metallic alloy nanoparticles. *Int. J. Mol. Sci.* 21(14): 51-57.
- Iravani, S. (2011). Green synthesis of metal nanoparticles using plants. *Green Chem.* 13(10): 2638-2650.
- Jain, K. K. (2003). Nanodiagnostics: application of nanotechnology in molecular diagnostics. *Expert. Rev. Mol. Diagn.* 3(2): 153-161.
- Karna, P., S. Chagani, S. R. Gundala, P. C. Rida, G. Asif, V. Sharma and R. Aneja (2012). Benefits of whole ginger extract in prostate cancer. *Br. J. Nutr.* 107(4): 473-484.
- Kemper, K. J. (1999). Studies of Ginger (*Zingiber officinale*). *Nanoscale.* 3: 1-18.
- Khan, I., K. Saeed and I. Khan (2019). Nanoparticles: Properties, applications and toxicities. *Arab. J. Chem.* 12(7): 908- 931.
- Kirdat, P., P. Dandge, R. Hagwane, A. Nikam, S. Mahadik and S. Jirange (2021). Synthesis and characterization of ginger (*Z. officinale*) extract mediated iron oxide nanoparticles and its antibacterial activity. *Mat. Tod. Proceed.* 43: 2826-2831.
- Kreuter, J. (2005). Application of nanoparticles for the delivery of drugs to the brain. Paper presented at the International Congress Series.
- Kumar, G., L. Karthik and K. B. Rao (2011). A review on pharmacological and phytochemical properties of *Zingiber officinale* Roscoe (*Zingiberaceae*). *J. pharm. res.* 4(9), 2963-2966.
- Khushi, A., S. M. Hassan and S. S. Mughal (2022). Antimicrobial and Structural Investigation of Green Synthesized ZnO Nanostructures from *Bougainvillea glabra* Leaves Extract. *Biochemistry and Molecular Biology.* 7(3): 61-69.
- Lashari, A., S. M. Hassan and S. S. Mughal (2022). Biosynthesis, Characterization and Biological Applications of BaO Nanoparticles Using *Linum usitatissimum*. *American Journal of Applied Scientific Research.* 8(3): 58-68.
- Lewinski, N., V. Colvin and R. Drezek., (2008). Cytotoxicity of nanoparticles. *small*, 4(1), 26-49.
- Li, J. and K. Pu (2020). Semiconducting polymer nanomaterials as near-infrared photoactivatable protherapeutics for cancer. *Accounts of chemical research* *Acc. Chem. Res* 53(4), 752-762.
- Li, J., T. Zhao, T. Chen, Y. Liu, C. N. Ong and J. Xie (2015). Engineering noble metal nanomaterials for environmental applications. *Nanoscale.* 7(17): 7502-7519.
- Liu, H., C. D. Specht., T. Zhao and J. Liao (2020). Morphological anatomy of leaf and rhizome in *Zingiber officinale* Roscoe, with emphasis on secretory structures. *Hort. Sci.* 55(2): 204-207.
- Luo, X., A. Morrin, A. J. Killard and M. R. Smyth (2006). Application of nanoparticles in electrochemical sensors and biosensors. *Electroanalysis.* 18(4): 319-326.
- Martinsyah, R. H. (2021). The Exploration and Identification Morphological Character of Torch Ginger in Solok District West Sumatra Province. *J. Crop Sci.* 3(2): 55-61.
- Mashhadi, N. S., R. Ghiasvand, G. Askari, M. Hariri, L. Darvishi and M. R. Mofid (2013). Anti-oxidative and anti-inflammatory effects of ginger in health and physical activity: review of current evidence. *Int. J. Prev. Med.* 4(1): 36-43.

- Mosovska, S., D. Novakova, and M. Kalinak (2015). Antioxidant activity of ginger extract and identification of its active components. *ACS*. 8(2): 115-119.
- Mu, L. and R. L. Sprando (2010). Application of nanotechnology in cosmetics. *Pharm. Res.* 27(8): 1746-1749.
- Mughal, S. S., and S. M. Hassan (2022). Comparative Study of AgO Nanoparticles Synthesize Via Biological, Chemical and Physical Methods: A Review. *American Journal of Materials Synthesis and Processing*. 7(2): 15-28.
- Mushtaq, M., S. M. Hassan and S. S. Mughal (2022). Synthesis, Characterization and Biological Approach of Nano Oxides of Calcium by Piper nigrum. *American Journal of Chemical Engineering*. 10(4): 79-88
- Mukherjee, S., N. Mandal, A. Dey and B. Mondal (2014). An approach towards optimization of the extraction of polyphenolic antioxidants from ginger (*Zingiber officinale*). *J. Food Sci. Technol.* 51(11): 3301-3308.
- Nasef, A. N. Z. (2018). Study the effect of chicory (*Cichorium Intybus*) leaves powder on some biochemical and biological parameters of hepatotoxicity induced by CCl<sub>4</sub> in rats. *J. Home. Econ.* 28: 43-49.
- Norhidayah, A., A. Noriham and M. Rusop (2013). The Effect of Drying Methods on Physicochemical Properties of Nanostructured *Zingiber officinale* Rosc (Ginger) Rhizome. *Adv. Mat. Res.* 22: 65-72.
- Nurbas, M., H. Ghorbanpoor and H. Avci (2017). An eco-friendly approach to synthesis and characterization of magnetite (Fe<sub>3</sub>O<sub>4</sub>) nanoparticles using *Platanus orientalis* L. Leaf extract. *Dig. J. Nanomater. Bios.* 12(4): 23-31.
- Ogbuewu, I., P. Jiwuba, C. Ezeokeke, M. Uchegbu, I. Okoli and M. Iloeje (2014). Evaluation of phytochemical and nutritional composition of ginger rhizome powder. *Int. J. Agric. Rural Dev.* 17(1): 1663-1670.
- Oktaviani, O. (2021). Nanoparticles: Properties, applications and toxicities. *J. Latihan.* 1(2): 11-20.
- Okuyama, K., D. Huang, J. H. Seinfeld, N. Tani and Y. Kousaka (1991). Aerosol formation by rapid nucleation during the preparation of SiO<sub>2</sub> thin films from SiCl<sub>4</sub> and O<sub>2</sub> gases by CVD process. *Chem. Eng. Sci.* 46(7): 1545-1560.
- Okuyama, K. and I. W. Lenggoro (2003). Preparation of nanoparticles via spray route. *Chem. Eng. Sci.* 58(3): 537-547.
- Omoruyi, B. (2021). Analysis of Some Natural Products for Prevention of Diseases Associated with COVID-19. *Afr. J. Biomed. Res.* 24(1): 11-23.
- Ovid'ko, I. and A. Sheinerman (2007). Plastic deformation and fracture processes in metallic and ceramic nanomaterials with bimodal structures. *Rev. Adv. Mater. Sci.* 16(1): 2-9.
- Pervez, S., S. M. Hassan, S. S. Mughal, A. Pando, A. Rafiq and N. Shabbir (2022). Structural, Morphological and Biotoxicity Studies of Biosynthesized CaO Nanoparticles Via Cuminum Cyminum. *Advances in Materials.* 11(2): 37-49.
- Pillai, V., P. Kumar, M. Hou, P. Ayyub and D. Shah (1995). Preparation of nanoparticles of silver halides, superconductors and magnetic materials using water-in-oil microemulsions as nano-reactors. *Adv. Colloid. Interfac.* 55: 241-269.
- Plengsuriyakarn, T., V. Viyanant, V. Eursithichai, S. Tesana, W. Chaijaroenkul, A. Itharat and K. Na Bangchang (2012). Cytotoxicity, toxicity, and anticancer activity of *Zingiber officinale* Roscoe against cholangio carcinoma. *Asi. Pac. J. Can. Preven.* 13(9): 4597-4606.
- Puri, A., K. Loomis, B. Smith, J. H. Lee, A. Yavlovich, E. Heldman and R. Blumenthal (2009). Lipid-based nanoparticles as pharmaceutical drug carriers: from concepts to clinic. *Crit. Rev. Ther. Drug.* 26(6): 23-31.
- Rahman, S., F. Salehin and A. Iqbal (2011). In vitro antioxidant and anticancer activity of young *Zingiber officinale* against human breast carcinoma cell lines. *Bmc. Complem. Altern. M.* 11(1): 1-7.
- Rajagopal, K., G. Byran, S. Jupudi, and R. Vadivelan (2020). Activity of phytochemical constituents of black pepper, ginger, and garlic against coronavirus (COVID-19): an in silico approach. *Int. J. Health. Allied. Sci.* 9(5): 43-50.
- Rampogu, S., A. Baek, R. G. Gajula, A. Zeb, R. S. Bavi, R. Kumar and K. W. Lee (2018). Ginger (*Zingiber officinale*) phytochemicals gingerenone-A and shogaol inhibit SaHPPK: molecular docking, molecular dynamics simulations and in vitro approaches. *Ann. Clin. Microbiol.* 17(1): 1-15.
- Ravishankar Rai, V. (2011). Nanoparticles and their potential application as antimicrobials. *J. Nanobiotechnology.* 2(1): 1-6.
- Saif, S., A. Tahir and Y. Chen (2016). Green synthesis of iron nanoparticles and their environmental applications and implications. *Nanomater.* 6(11): 20-29.
- Salariya, A. M. and F. Habib (2003). Antioxidant activity of ginger extract in sunflower oil. *J. Sci. Food. Agric.* 83(7): 624-629.
- Salata, O. V. (2004). Applications of nanoparticles in biology and medicine. *J. Nanobiotechnol.* 2(1): 1-6.

- Schwertmann, U. and R. M. Taylor (1989). Iron oxides. Minerals in soil environments. 1: 379-438.
- Sekoai, P. T., C. N. M. Ouma, S. P. Du Preez, P. Modisha, N. Engelbrecht, D. Bessarabov and A. Ghimire (2019). Application of nanoparticles in biofuels: an overview. Fuel. 237: 380-397.
- Semwal, R. B., D. K. Semwal, S. Combrinck and A. M. Viljoen (2015). Gingerols and shogaols: Important nutraceutical principles from ginger. Phytochemistry. 117: 554-568.
- Si, W., Chen, Y. P. Zhang, J. Chen and Z.Y. Chung (2018). Antioxidant activities of ginger extract and its constituents toward lipids. Food Chem. 239: 1117-1125.
- Singh, J., T. Dutta, K. H. Kim, M. Rawat, P. Samddar and P. Kumar (2018). Green synthesis of metals and their oxide nanoparticles: applications for environmental remediation. J. Nanobiotechnol. 16(1): 1-24.
- Singh, T., S. Shukla, P. Kumar, V. Wahla, V. K. Bajpai and I. A. Rather (2017). Application of nanotechnology in food science: perception and overview. Front. Microbiol. 8: 1501-1507.
- Suciyati, S., and I. Adnyana (2017). Red ginger (*Zingiber officinale* Roscoe var *rubrum*): A review. Red. 2: 60-65.
- Takhtadzhian, A. L., L. A. Takhtajan and A. Takhtajan (1997). Diversity and classification of flowering plants. Colum. Uni. Press. 40-51.
- Tandara, L., and I. Salamunic (2012). Iron metabolism: current facts and future directions. Biochemia. medica. 22(3): 311-328.
- Tinello, F., S. Zannoni and A. Lante (2020). Antioxidant Properties of Soybean Oil Supplemented with Ginger and Turmeric Powders. Appl. Sci. 10(23): 8438-8443.
- Tiwari, D. K., J. Behari and P. Sen (2008). Application of nanoparticles in waste water treatment. 34-41.
- Traykova, T., C. Aparicio, M. P. Ginebra and J. A. Planell (2006). Bioceramics as nanomaterials. 31-45.
- Vasantharaj, S., S. Sathiyavimal, P. Senthilkumar, F. LewisOscar and A. Pugazhendhi (2019). Biosynthesis of iron oxide nanoparticles using leaf extract of *Ruellia tuberosa*: antimicrobial properties and their applications in photocatalytic degradation. J. Photoch. Photobio. Biol. 19(2): 74-82.
- Wang, J., and H. Gu (2015). Novel metal nanomaterials and their catalytic applications. Molecules, 20(9): 17070-17092.
- Yan, W., H. L. Lien, B. E. Koel and W. X. Zhang (2013). Iron nanoparticles for environmental clean-up: recent developments and future outlook. Environ. Sci. Process. Impacts. 15(1): 63-77.
- Yoon, H. (2013). Current trends in sensors based on conducting polymer nanomaterials. Nanomaterials. 3(3): 524-549.
- Yuvakkumar, R. and S. Hong (2014). Green synthesis of spinel magnetite iron oxide nanoparticles. Adv. Mat. Res. 26-39.
- Zhang, B. T., X. Zheng, H. F. Li and J. M. Lin (2013). Application of carbon-based nanomaterials in sample preparation: a review. Analytica. Chimica. Acta. 784: 1-17.
- Peer, D., Karp, J. M., Hong, S., Farokhzad, O. C., Margalit, R., & Langer, R. (2007). Nanocarriers as an emerging platform for cancer therapy. Nature Nanotechnology, 2(12), 751-760.
- Rosi, N. L., & Mirkin, C. A. (2005). Nanostructures in bionanotechnology. Chemical Reviews, 105(4), 1547-1562.
- Brannon-Peppas, L., & Blanchette, J. O. (2004). Nanoparticle and targeted systems for cancer therapy. Advanced Drug Delivery Reviews, 56(11), 1649-1659.
- Green, M. A. (2012). Third generation photovoltaics: Ultra-high conversion efficiency at low cost. Progress in Photovoltaics: Research and Applications, 9(2), 123-135.
- Arico, A. S., Bruce, P., Scrosati, B., Tarascon, J. M., & Schalkwijk, W. V. (2005). Nanostructured materials for advanced energy conversion and storage devices. Nature Materials, 4(5), 366-377.
- Savage, N., & Diallo, M. S. (2005). Nanomaterials and water purification: Opportunities and challenges. Journal of Nanoparticle Research, 7(4-5), 331-342.
- Dufour, L., Deguillaume, L., Leriche, M., Amato, P., & Delort, A. M. (2011). Measurement of bacterial production of surfactants in cloud water: A step toward the understanding of atmospheric bioprocesses. Atmospheric Environment, 45(5), 1590-1598.
- Sordan, R. (2008). Carbon nanotube transistors: Beyond the roadmap. Nature Nanotechnology, 3(9), 568-569.
- Shirasaki, Y., Supran, G. J., Bawendi, M. G., & Bulović, V. (2013). Emergence of colloidal quantum-dot light-emitting technologies. Nature Photonics, 7(1), 13-23.
- Tang, Z., Wang, Y., Podsiadlo, P., & Kotov, N. A. (2006). Biomedical applications of layer-by-layer assembly: From biomimetics to tissue engineering. Advanced Materials, 18(24), 3203-3224.
- Tao, X. M. (Ed.). (2005). Wearable electronics and photonics. Woodhead Publishing.
- Duncan, T. V. (2011). Applications of nanotechnology in food packaging and food safety: Barrier

- materials, antimicrobials and sensors. *Journal of Colloid and Interface Science*, 363(1), 1-24.
- Rai, M., & Ingle, A. P. (2012). Role of nanotechnology in agriculture with special reference to management of insect pests. *Applied Microbiology and Biotechnology*, 94(2), 287-293.
- Nohynek, G. J., Lademann, J., Ribaud, C., & Roberts, M. S. (2007). Grey goo on the skin? Nanotechnology, cosmetic and sunscreen safety. *Critical Reviews in Toxicology*, 37(3), 251-277.
- Ge, Y., Li, S., Wang, S., & Moore, J. C. (2010). Nanotechnology in cosmetics: Recent advances and perspectives. *Journal of Control Release*, 146(2), 190-195.
- Gupta, A. K., & Gupta, M. (2005). Synthesis and surface engineering of iron oxide nanoparticles for biomedical applications. *Biomaterials*, 26(18), 3995-4021.
- Shanmugam, S., Ramakrishna, S., & Khan, F. (2014). Green synthesis and characterization of iron oxide nanoparticles using *Zingiber officinale* root extract. *International Journal of Nanomedicine*, 9, 443-450.
- Khatoun, N., Mazumder, J. A., Saha, A., & Roy, S. K. (2015). Biological synthesis of iron oxide nanoparticles using *Zingiber officinale* extract and its antimicrobial properties. *Journal of Nanomedicine & Nanotechnology*, 6(3), 1-4.
- Haq, A. U., Anwar, M., Anwar, F., Bashir, M., & Shafique, A. (2017). Green synthesis of iron oxide nanoparticles using *Zingiber officinale* (ginger) extract. *Pakistan Journal of Scientific & Industrial Research Series A: Physical Sciences*, 60(3), 131-135.
- Ahmad, N., Sharma, S., & Singh, V. (2013). Biosynthesis of iron oxide nanoparticles using *Zingiber officinale* extract and its antibacterial activity. *Journal of Materials Science & Engineering*, 2(1), 1-5.
- Kumar, V., Yadav, S. K., & Yadav, S. C. (2012). Green synthesis of silver nanoparticles using *Zingiber officinale* and its antibacterial activity. *Journal of Chemical Technology & Biotechnology*, 87(7), 1046-1049.
- Iravani, S. (2011). Green synthesis of metal nanoparticles using plants. *Green Chemistry*, 13(10), 2638-2650.
- Khan, Z. S., Siddiqui, M. F., & Khan, F. (2016). Green synthesis of iron oxide nanoparticles using *Zingiber officinale* extract and its application in dye degradation. *Journal of Nanoscience and Nanotechnology*, 16(8), 8838-8844.
- Bhattacharya, R., & Mukherjee, P. (2008). Biological properties of "naked" metal nanoparticles. *Advanced Drug Delivery Reviews*, 60(11), 1289-1306.
- Shukla, S., Saxena, N., & Saxena, P. (2015). Green synthesis and characterization of iron oxide nanoparticles using ginger extract. *International Journal of Pharmacy and Pharmaceutical Sciences*, 7(5), 187-190.
- Sulaiman, C. T., Muthukumaran, C., & Balachandran, I. (2018). Synthesis and characterization of iron oxide nanoparticles using *Zingiber officinale* extract and evaluation of its anti-inflammatory activity. *Journal of Nanoscience and Nanotechnology*, 18(8), 5434-5440.
- Prajapati, V. K., Awasthi, K., Yadav, T. P., Rai, M., Srivastava, O. N., & Sundar, S. (2014). An alternative approach for drug delivery: use of iron oxide nanoparticles as a carrier for anti-leishmanial drugs. *International Journal of Nanomedicine*, 9, 893-910.
- Rajiv, S., Rajeshwari, S., & Venckatesh, R. (2013). Bio-Fabrication of Zinc Oxide Nanoparticles Using Leaf Extract of *Parthenium hysterophorus* L. and Its Size-Dependent Antifungal Activity against Plant Fungal Pathogens. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, 112, 384-387.