

AN OVERVIEW OF NANOPARTICLE PROPERTIES AND MICROBIOLOGICAL USES IN RELATION TO THEIR BIOACTIVITY

ABSTRACT

The term “nanoparticles” being expressed in microbiology is coined from the Greek word “nano” meaning “dwarf”. Nanoparticles range in size from 1-100nm. Nanoparticles vary in size, shape, and other properties and can exist with capping agents present after structure-controlled synthesis with starting materials like metals with or without organic agents. This systematic literature review article discusses current opinions on the properties of nanoparticles including the size and shape, surface area and surface charge, surface chemistry and reactivity and their magnetic properties. We also discuss the mechanisms of bioactivity of nanoparticles in reference to their interactions with microorganisms, penetration into microorganisms, disruption of cellular processes and their effects on microbial growth. We also discuss specifically, their antibacterial, antifungal and antiviral properties. This is followed by a review of their diagnostic and therapeutic applications, the factors affecting nanoparticle bioactivity (exposure time and other intrinsic physicochemical properties) and how the intrinsic properties of microorganisms such as strain selection and growth conditions are affected by the activity of nanoparticles. In this review, we also compare nanoparticle research in the new world with activities in third world countries. We conclude by discussing the toxicity and safety concerns in the use of nanoparticles including the environmental impact and regulatory guidelines in the use of nanoparticles followed by a recommendation on future guidelines for research.

Keywords: Nanoparticles, Bioactive, Antimicrobial, Properties, Bacteria, Antibacterial

INTRODUCTION

The term “nanoparticles” being expressed in microbiology is coined from the Greek word “nano” meaning “dwarf” (Panja *et al.*, 2022). With size of one-billionth of a meter in diameter, nanoparticles commonly are viewed using electron microscopy (Akbarizadeh *et al.*, 2022; Mikhutkin *et al.*, 2022). They range in size from 1-100nm. Nanoparticles vary in size, shape, and other properties and can exist with capping agents present after structure-controlled synthesis with starting materials like metals with or without organic agents (Parkash, 2023).

The size of a nanoparticle contributes to its versatility and enables it to be taken up more easily taken up by cells and other materials. This versatility aids in in-vitro research studies and in industry (Nejabat *et al.*, 2023; Ravishankar *et al.*, 2023). Fields that employ the use of nanoparticles ranging from chemistry to physics to microbiology and to biomedicine and this attribute commonly leads to interdisciplinary studies (Al-Byati *et al.*, 2023; Sanchis-Gual *et al.*, 2023; Sayes *et al.*, 2023).

Nanoparticles can be incorporated into antimicrobials to speed up reaction time and to increase efficacy of the resulting polymer molecule. This is however a task that will benefit from innovations in antimicrobial research showing the broad use and potential (Ramin *et al.*, 2023).

In antimicrobial research, the size of the nanoparticle also affects its ability to enter cells and its ability to be used as a carrier molecule in drug delivery and vaccine production (Yin *et al.*, 2023). This attribute of NPs with a range of uses have enabled them stand out and remain relevant in the future of Multi-Drug Resistance solution research (Ifijen *et al.*, 2023; Ye and Chen 2023).

This article provides insight into the versatility, attributes and multidimensional applicability of nanoparticles as it relates to microbiology.

What they can be synthesized from

The top-down method of nanoparticle synthesis involves deconstruction of larger metals and molecules into smaller bits till the size becomes a nanoparticle (Cui *et al.*, 2023). The bottom-up approach involves the fusion of colloids till the nanoparticles are built up. The bottom-up approach reduces the loss of size and concentration of the final product (Scarabelli *et al.*, 2023; Wojtaszek *et al.*, 2023). This approach offers a more cost effective method of nanoparticle synthesis than other approaches to nanoparticle synthesis. Green synthesis of nanoparticles is the use of natural substances such as plants, plant extract or cellulose as the substrate from which nanoparticles are made (Ahmad *et al.*, 2023). The involvement of microorganisms for nanoparticle creation is a phenomenon whereby the metabolic products and activities of microorganisms are harnessed in the creation of nanoparticles (Nouri *et al.*, 2023).

Types of nanoparticles include carbon-based nanoparticles, lipid-based nanoparticles, ceramic nanoparticles, metal nanoparticles, semiconductor nanoparticles and polymeric nanoparticles. As will be discussed, nanoparticles synthesised from gold are believed to have broad range of positive and negative effects on life forms (Kuppusamy *et al.*, 2023; Zhu *et al.*, 2023). Small concentrations of nanoparticles synthesized from silver are highly useful in orthodontics (Afkhani *et al.*, 2023). They exhibit effects on the occurrence and prevalence of the microorganisms that form the biofilm matrix of the oral setting targeting microorganisms like *Lactobacillus* and *Streptococcus* (Mallineni *et al.*, 2023). Copper-chitosan nanoparticle complexes have proven to be effective in the prevention and control of biofilm forming cariogenic species of *Candida* and *Streptococcus* as demonstrated by Raile *et al.*, 2023.

Nanoparticles, as stated by Zhang *et al.*, (2023) and Kushawa *et al.*, (2023) can be found naturally as part of food (cheese, milk, whey proteins and butter) and agricultural products since the development of modern agriculture (Li *et al.*, 2023). Such nanoparticles include gold, silver, calcium carbonate, selenium and titanium oxide (Tran *et al.*, 2023; Baldassarre *et al.*, 2023; Haris *et al.*, 2023; Lazcano-Ramírez *et al.*, 2023) .

Fields Nanoparticles Can be Harnessed in

Despite the rapid evolution of the field of microbiology and the drift toward more standardised methods and tools in study of microbiological phenomena (McNeilly *et al.*, 2023), articles originating from 3rd world countries on antimicrobial nanoparticles research still receive less citations from research carried out in 1st world countries as seen when searching scholarly databases with the keywords “Antimicrobial” “Nanoparticle” “Ibadan” (Thomas *et al.*, 2023; Maloma *et al.*, 2023). However, education in less developed countries still employ the tools of crude, antimicrobial research tools such as the Kirby-Bauer method along with Minimum Inhibition Control (MIC) in microbiological research purposes in 3rd world countries as seen in a study by Mustafa *et al.*, 2023. The transfer of tools and technology is hence recommended for nanoparticle research in these countries (Chen *et al.*, 2023).

Novel drug candidates also employ the use of nanoparticles in drug design (Kong *et al.*, 2023). In addition to that, the discovery of the capability of nanoparticles to permeate the brain-blood barrier took place in the late 20th century. This period ushered in more research on the creation of related drugs. It is hence recommended that malaria and syphilis’ drugs research apply NPs in the mitigation of the brain forms of these infectious diseases, including viral disease (e.g H1N1). Literature reviews show that the field of vaccine production, Cancer treatment (Kou *et al.*, 2023; Kasparis *et al.*, 2023), gene delivery (Foster *et al.*, 2023), and disease diagnostics (Koyappayil *et al.*, 2023) all in one way or another employ the use of

nanoparticles with the need to undertake more studies. Nanoparticles have hence contributed hugely in experimental research and health informatics.

The invention of biodegradable, sterile products that range in applications from the food and agriculture industry, dye production to environmental sustainability have also harnessed the potentials of nanoparticles in order to preserve the natural ecosystem (Liang *et al.*, 2023). This justifies the need to provide less toxic food packaging materials with biodegradation potentials. Human existence has hence benefited from nanoparticles.

In medical sciences, medical devices are coated with nanoparticles to enhance antibacterial and therapeutic properties that are beneficial to convalescent individuals (Song *et al.*, 2023).

Promising Use in Microbiology Research

The need to use nanoparticles with immunocompatibility and soluble and metabolic-possibility qualities cannot be over emphasized (Fang *et al.*, 2023; Fang *et al.*, 2023). In the creation of antimicrobial agents, bioactive molecules are often shape-modified by nanoparticles. The shape of the resulting nanoparticle will determine its ability to penetrate the bacterial cell wall. The presence of surface coating on nanoparticles can enhance the efficiency of nanoparticles as antibacterial and antifungals. This is the basis of nanoparticle interaction with microorganisms (Maliki *et al.*, 2023; Kanakari and Dendrinou-Samara, 2023; More *et al.*, 2023).

Antimicrobial chemotherapy using nanoparticles involves the inoculation microorganisms with of petridishes containing nanoparticles or the use of bespoke systems which mimic the environment of the condition being studied (Korte *et al.*, 2023). This benefits studies involving pathogenic microorganisms like *Streptococcus* to detect the antimicrobial activity of the nanoparticle or the synergistic potential with the microorganism of interest (Mohammed *et al.*, 2023). The above represents the method applied in this therapy which is used in addition to recent methods including magnetic and photo/sonodynamic guided therapy in biological investigations (Bag *et al.*, 2023). Incubation in laboratory settings is hence being replaced with repeatable, optimized, biosensor-guided and photosensor-assisted antimicrobial nanoparticle research. Thanks to nanoparticle research, pathogenic bacterial effects which often required elaborate and time-consuming methods are now rapidly being isolated by guided nanoparticle therapies involving the infusion of isolation systems with specific nanoparticles that support the selection and inspection of the exact microorganism being investigated (Limantoro *et al.*, 2023). This shows the promise of the use of nanoparticles in antimicrobial research with high numbers of cited scholarly articles related to bioactive nanoparticle research (Yu *et al.*, 2023; Hamzah *et al.*, 2023; Joseph *et al.*, 2023).

PROPERTIES OF NANOPARTICLES

Classification of Nanoparticles

Nanoparticles can be broadly grouped based on their shape, surface area, surface charge, and surface chemistry. The size and shape of nanoparticles can affect their physicochemical properties and bioactivity. Nanoparticles can be synthesized to pass through cellular membranes, leading to a broad range of activities in the cell. One of such activities of note in microbiology is oxidative stress, disrupting cellular membranes and activities and eventual lysis and destruction of such cells. Microbial cells and other biological cells can be impacted by the activities of nanoparticles. In the study of nanoparticles, it is expected to find variations in its properties in varying degrees, uniquely destroying potentially toxic microorganisms while also being solubilized by microbial metabolites (Sahoo *et al.*, 2023; Carrapiço *et al.*, 2023; Niu and Zhang, 2023).

Size and Shape of Nanoparticles

Whether they be synthesized in a laboratory or gotten from organic sources, nanoparticles vary in size and shape. These attributes contribute individually or together, in association with other properties discussed in this review to their consistency, stability and their ability to

be mixed with other molecules. Most nanoparticles are observed to occur in spherical shapes are typically more stable than those with other shapes (Abdussalam-Mohammed *et al.*, 2023). The size of nanoparticles can also affect their toxicity and cellular uptake. The aspect ratio of nanoparticles can affect their toxicity and cellular uptake as well (Kang *et al.*, 2023). The size and shape of nanoparticles can also influence their interactions with microbial cells. The size of the nanoparticle also affects its ability to enter cells and its ability to be used as a carrier molecule in drug delivery (Zhang *et al.*, 2023). The shape and elasticity of a nanoparticle influences its ability to be taken up by cells (Zou *et al.*, 2023).

Previously reported works on nanoparticle synthesis relied on the analysis of the characteristics of the formed nanoparticle. This was prior to the developments of in-vitro shape control strategies of nanoparticles. This development help in the synthesis of nanoparticles with unique and versatile characteristics, with scientists being able to make several fold increases in the beneficial characteristics (Kagdada *et al.*, 2023). Literature also shows characteristics-wide comparisons between nanoparticles synthesized and the ones synthesized recently, showing reliance on the morphology of the formed nanoparticle, designing experiments using the nanoparticles towards the already formed nanoparticle (de Souza Cabral *et al.*, 2023). There was also no knowledge on the ability of the morphology of the nanoparticle to be known or controlled prior to or during synthesis but current tools like artificial intelligence are helping in this predictive research (Golinejad *et al.*, 2023; Banerjee *et al.*, 2023). Recent works have also shown the synthesis of nanoparticles with various shapes such as cubes, rods, disks and flowers. There are also reports on variations of a known nanoparticle to exhibit toxicological effects at a time, yet having the potential to be a novel drug candidate at other times. Recent works however do outline the methods of control of the type and characteristics of the nanoparticle prior to or during synthesis (Tohgha *et al.*, 2023).

Surface Area and Charge

Nanoparticles exhibit a high surface area-to-volume ratio while in solution, which can increase their distribution and aggregation, showing greater reactions with biological systems than larger molecules (Ayodhya *et al.*, 2023). The surface charge of encapsulated and unencapsulated nanoparticles determine affinity to biological systems and molecules, influencing its overall bioactivity (Koo *et al.*, 2023; Shiromani *et al.*, 2023). The surface charge of a nanoparticle, being positive or negative, influences its affinity and attraction to other ions, and consequently on cells, and this property is closely related to the pH of the environment. Higher pH values are related to negative surface charges (Javadi *et al.*, 2023; Wu *et al.*, 2023). This is especially useful in the selection of nanoparticles for pharmaceutical applications. The surface charge of nanoparticles can also influence its antibacterial activity, stability and toxicity as positively charged nanoparticles are more easily internalized by cells than negative and nanoparticles (Chen *et al.*, 2023). They are however more potentially toxic than negative nanoparticles as cells tend to be negatively charged (Jadhav *et al.*, 2023).

Surface Chemistry and Reactivity

The surface chemistry of a nanoparticle can affect its dispersion and interaction with the ions and molecules in biological systems (Sancak *et al.*, 2023), influencing its total biochemical profile and bioactivity. The permeability of a nanoparticle through biological membranes can be enhanced by the modification of the surface chemistry of the nanoparticle. Such modification of its chemistry hence functionalization influences its attachment to membranes and its chemical reactivity by incorporation of stabilizing agents (Sayes *et al.*, 2023). This phenomenon also improves their end-targeting and biocompatibility (Raikwar *et al.*, 2023). The reactivity of nanoparticles can be increased or decreased due to modifications or the state of the reactive surface area of the nanoparticle which also impacts the electro-mechanical profile of the environment (Xavier, 2023). This is also a basis in the classification of nanoparticles. Surface modification of nanoparticles can also affect their toxicity and safety.

This chemical property is an important factor which can be systematically altered when designing particles for specific applications in microbiology (Mohammad *et al.*, 2023).

Optical and Magnetic Properties

Nanoparticles vary in their properties and can exhibit unique optical and magnetic properties due to their small size. The shape of a nanoparticle can be observed during evaluations (Celin and Ajitha, 2023). Metal nanoparticles like gold, silver, titanium and iron can be studied this way. Generally, the more photosensitive a metal nanoparticle is, the better its antimicrobial and bacterial detection capability (Singh *et al.*, 2023). Silver nanoparticles have been shown to exhibit unique optical response and absorbance during colloidal observations (Plé *et al.*, 2023). The Magnetic property of a nanoparticle can influence its absorption and dispersal and its use and application (Tsogoo *et al.*, 2023 and Ahghary *et al.*, 2023). The dispersion of nanoparticles in surrounding medium and living tissues sets it apart as an important molecule in drug delivery and in cancer research and other aspects of medicine (Min *et al.*, 2023; Kareem *et al.*, 2023; Mosleh-Shirazi *et al.*, 2023). The optical and magnetic properties of nanoparticles can be ultrasonically modified by controlling their size and shape, making them useful for a wide range of applications in microbiology. Incubation in laboratory settings is now being replaced with repeatable, optimized, biosensor-guided antimicrobial nanoparticles (Krishnamoorthy *et al.*, 2023; Toyos-Rodríguez *et al.*, 2023).

The field of spectroscopy uses the idea of visualising nanoparticles in a laboratory using advanced, sophisticated tools and equipment paints a picture of what is worked on but may not do complete justice to the job of studying the antimicrobial attributes of nanoparticles (Kumar *et al.*, 2023). Synthesis affects the exhibited properties and metallic nanoparticles may exert more heat in biological systems although this is a system that needs more research (Pawwar and Takke, 2023) The green synthesis of nanoparticles presents a less toxic and cost-effective mode of synthesis, making them safer alternatives (Das and Biswas, 2023) but desirable properties may not be as potent as chemically synthesized nanoparticles or varying in other properties (Yang *et al.*, 2023). Deleterious effects observed in-vitro in the use of biosynthesized nanoparticles are mainly due to problems in study of nanoparticles properties and this is a drawback in the use of biosynthesized nanoparticles although this phenomenon presents an advantage in the harnessing of such nanoparticles in bacterial cell destruction (Sahoo *et al.*, 2023).

MECHANISMS OF BIOACTIVITY

Interaction with Microorganisms

The bioactive interactions of nanoparticles could be genotypic and phenotypic. This is due to the unique genomic make-up of microorganisms. Bacteria, specifically, are known to undergo mutations which are passed down across generations. These mutations also, lead to observable effects as they are studied in the laboratory. One of such effects is antimicrobial resistance which is a serious global health problem (Lach *et al.*, 2023; Ascensao *et al.*, 2023; Cohen *et al.*, 2023). Cellular processes impacted by the nanoparticle include gene expression and membrane permeability (Rashki *et al.*, 2023). Activity occurs on microorganisms across several states of matter. There are physical and chemical interactions at the cellular level that guide such effects. As observed in studies, nanoparticles exert their effects on microorganisms either in non-complexed forms or in colloids. When the nanoparticle is docked, the new, altered quality will determine the effect of the microbiological activity expressed (Ikram *et al.*, 2023; Qu *et al.*, 2023; Liu *et al.*, 2023; Pathania *et al.*, 2023).

An antimicrobial agent is any substance that can prevent or hinder the growth of microorganisms. In the use of antimicrobial nanoparticles synthesized using green synthesis, the antagonistic or synergistic ability of microorganisms could influence the degree to which the nanoparticle works in such systems. As antimicrobial agents, nanoparticles could be

antimicrobial, antifungal and render antiviral immunity (Roy *et al.*, 2023). Such nanoparticles include gold, biometabolites, chitosan-based nanoparticles and silver among others. Nanoparticles have proven to be bactericidal against even biofilm forms of the named pathogen, effective in anaerobic conditions and in micro aerated environments (Fritz *et al.*, 2023). As antimicrobial agents, nanoparticles have been incorporated into matter to create environmentally friendly, sterile, packaging products (Manzoor *et al.*, 2023). The global burden of antimicrobial resistance can hence be lightened by the use of nanoparticles (Huang *et al.*, 2023).

APPLICATIONS OF NANOPARTICLES IN MICROBIOLOGY

Advances in the particle formation procedures of nanoparticles have led to varieties in the resulting nanoparticle, such that antimicrobial applications can be better applied and optimized (Dappula *et al.*, 2023). Synthesised gold nanoparticles have a range of applications in Microbiology. They act as antimicrobials (Ge *et al.*, 2023), as carrier molecules (Seku *et al.*, 2023) and as biosensors in infection detection (Singh *et al.*, 2023). A common synthesis for the creation of gold nanoparticles is peptoid engineering. This method helps the structural control of the microbiological and bioactive properties of the gold nanoparticles (Ji *et al.*, 2023). In antimicrobial studies, nanoparticles shew great promise in the race to find novel antimicrobials in bioactive nanoparticle research (Ozidal and Gurkok, 2022). There also abounds a high number of scholarly research articles on the antimicrobial effects of nanoparticles in the search of novel antimicrobials to combat the global burden of the multi-drug resistant infectious pathogens. Moreso, biochemical parameters of nanoparticles abound in experimental research. In Japan, there exists several research showing the potential of nanoparticles as feed additives. Some experiments show the hypothetical postulations that nanoparticles may interfere with nutrient assimilation in living systems (Franco-Lagos *et al.*, 2023). Hence, there is a duality of effects in nanoparticles bioactivity: antagonism (Malik *et al.*, 2023) and enhancement.

In a search on Google Scholar, the interdisciplinary field of antimicrobial nanoparticle research has showed altogether more than 1000 citations in peer reviewed journals. This has created the collaboration of the microbiologist and the chemist in novel drug synthesis. It has however introduced the need for referencing of adequate journals in the field of nanoparticle research prior to the in-vitro creation of antimicrobial nanoparticles. Researchers also, give repeated reviews of nanoparticles that have proceeded in the highly scrutinized drug discovery pipelines, especially as molecules that have proceeded for clinical trials.

Antibiotics were discovered in a time when there was serious need to battle infections. The golden age of antibiotics was from 1950 to 1960. In this time, more than half of the drugs in use today were discovered. However, there is a pressing need for novel antibiotics to combat Multi-Drug Resistant (MDR) pathogens (Wasan *et al.*, 2023). The study of nanoparticles requires resources that may not be available in every antimicrobial research laboratory (Brezgin *et al.*, 2023).

It is recommended that the presence and concentration of nanoparticles in products for use in antimicrobial research should be stated clearly. This will aid in further studies on the use of nanoparticles in microbiology research as presence of nanoparticles, which can permeate most biological membranes known, can have an impact on the integrity of such experiments (Singh *et al.*, 2023; Perçin *et al.*, 2023).

Antibacterial Properties of Nanoparticles

Human existence is threatened due to MDR strains of pathogens. The blocking of common antimicrobials as the solution to this problem can hence be removed by the adoption and inclusion of antimicrobial nanoparticles in the environments of these pathogens (Saleem *et*

al., 2023). MDR pathogens include *Escherichia coli*, *Streptococcus*, *Staphylococcus* and *Mycobacterium tuberculosis*.

Lactobacilli are microorganisms that make up the normal flora of the female vagina. They also are found in dairy food items like milk and yoghurt. They have antimicrobial potentials but can be pathogenic in the immunocompromised (Kullar *et al.*, 2023). They also form biofilms in the mouth and are implicated in the formation of dental caries. They also exhibit antagonism against some other bacterial strains (Ribeiro and Paster, 2023; Gu *et al.*, 2023; Amirkhanova *et al.*, 2023). There are studies that suggest that nanoparticle conjugates of *Lactobacillus* and silver and iron are used in the production of antimicrobials against pathogens (Siddiqui *et al.*, 2023; Yang *et al.*, 2023). Nanoparticles also have been noted to have the capability of acting against cariogenic forms of *Lactobacillus* e.g the Zinc Oxide (ZnO) nanoparticle (Shirazi *et al.*, 2023). Biofilms are poly-microbial aggregates that grow and attach on a variety of surfaces including living tissues, indwelling medical devices and other man-made objects in and on water and on any natural surface in the environment (Khalid *et al.*, 2023; Nesse *et al.*, 2023). Due to their polymer-induced aggregation, biofilms pose a public health threat by evading treatment with disinfectants and antibiotics. Biofilm-associated infections and diseases can occur in the blood, mouth, tissues and implants in the human body (Algammal *et al.*, 2023).

Streptococcus is a bacterium with multi drug resistant (MDR) strains. It is implicated in mouth and throat infections including caries and periodontal disease. Periodontal disease is an oral condition that leads to destruction of tooth-supporting tissues and leads to complications in children as well as in adults. This disease is induced by the dental biofilm leading to gingival inflammation (de Miguel *et al.*, 2023; Kuspradini *et al.*, 2023). If left untreated, this condition can spread to the supporting bone tissues. All periodontal diseases are caused by periodontopathogenic biofilms in addition to the hosts' immune responses, behavioural, environmental and genetic susceptibility factors. Periodontal disease is hence, a notorious oral condition of concern (Uzochukwu *et al.*, 2023; Ferrillo *et al.*, 2023; Kulkarni *et al.*, 2023). Studies have shown the use of nanoparticles in the production of antimicrobials against *Streptococcus* and its associated biofilms (Valian *et al.*, 2023; Karnjana *et al.*, 2023; Tabassum *et al.*, 2023). Mechanisms include disruption of cell walls, efflux pumps and oxidative destruction of microbial cells (Ranjary *et al.*, 2023; Mokhtari *et al.*, 2023; Alavi and Hamblin, 2023).

Antifungal Properties

Fungi are microorganisms that thrive in moist environments. Fungi include yeast and moulds. Along with spore production for reproduction and survival, they secrete primary and secondary metabolites as they grow and mature (Xue *et al.*, 2023). These compounds can be toxic to human cells in the case of *Aspergillus fumigatus* and are also capable of being toxic to microbial cells (Xiong *et al.*, 2023). However, these metabolites are also harnessed in the production of antimicrobial drugs (Rousta *et al.*, 2023). As a result of this, they can be tapped in the green synthesis of nanoparticles to produce bespoke antimicrobial nanoparticles and also be used as capping agents to synthesize nanoparticles docked with fungi to enhance certain beneficial features (Nanda, 2023; Ameen *et al.*, 2023). Silver nanoparticles have antifungal effects against *Candida albicans* and *Aspergillus* (Golli *et al.*, 2023 and Naqvi *et al.*, 2023). Other kinds of antifungal nanoparticles include zinc oxide and titanium (Ouzakar *et al.*, 2023; Xing *et al.*, 2023).

Antiviral Properties

Viruses have been responsible for a lot of ailments and pandemics for centuries. The inability for viruses to replicate without a host cell proposes alternate systems for antiviral research (Cruz-Pulido and Mounce, 2023). This has made them difficult to be studied without

the use of sophisticated equipment requiring specialized manpower. Many harmful viruses require biosafety cabinets from BSL 2 to BSL 4 (Mukherjee *et al.*, 2023). However, viruses can be inactivated and used as conjugants in the production of vaccines. These conjugants can be combined with nanoparticles in the production of vaccines (Srividya *et al.*, 2023).

Reports on vaccine production have shed light on the promise of antiviral nanoparticles (Shabatina *et al.*, 2023; Yin *et al.*, 2023). Nanoparticles also play a role in the diagnostics of certain infections and diseases caused by viruses. In this case, they are used as biomarkers due to their optical and magnetic properties (Choi and Yoon, 2023; Hou *et al.*, 2023).

Antiviral nanoparticles inhibit viral attachment and entry into host cells. They also prevent replication of viral cells (as seen in the case of Sars-CoV-2). Antiviral nanoparticles include gold nanoparticles and carbon-based nanoparticles (Heida *et al.*, 2023; Ghosal *et al.*, 2023; Ali *et al.*, 2023; Solanki *et al.*, 2023).

Diagnostic and Therapeutic Applications

There is a wide range of potential applications of nanoparticles in diagnostics and therapeutics with need to study the propensity for in-vitro and industrial reproducibility of already tested nanoparticles (Wu *et al.*, 2023; Gulati *et al.*, 2023; Thirugnanasambandan and Gopinath, 2023). Amenability of dispersal and transportativity to standardisation gradient among others, depending on what product is being envisioned to be made (Arranz *et al.*, 2023; Feng *et al.*, 2023). The type of product will determine the method employed and the attribute to accentuate. For instance, in the production of oral sanitary products, there is need to accentuate features of nanoparticles beneficial in prophylaxis and to reduce biotoxic features (Ahmed *et al.*, 2023; El Shahawi, 2023). In the formulation of stomach sickness medicines, it is required that the compound does not negatively affect to the acidic environment, but rather should provide remedy (Sahu *et al.*, 2023).

FACTORS AFFECTING NANOPARTICLE BIOACTIVITY

For a nanoparticle to be bioactive, there are a number of qualities to be considered. These qualities serve as criteria for nanoparticles to be used for scientific and economic purposes. The bioactivity of nanoparticles has hence drawn attention to the application of nanoparticles in order to exploit their bioactive potentials (Kerry *et al.*, 2023; Cassani *et al.*, 2023). Qualities that drive nanoparticles and nanoparticle-containing final product to the market include reliable elicitation of bioactivity, versatility of abrasive/cojoining index and the ability of the nanoparticle to ameliorate toxicity (Afkhami *et al.*, 2023; Chang *et al.*, 2023). The properties are discussed below.

Nanoparticle Concentration

The bioactivity of a nanoparticle depends on a number of factors which would be discussed shortly. One of such factors is the nanoparticle concentration. Inadequate nanoparticle concentration in a bioassay may lead to low bioactivity although low concentrations of nanoparticles have shown to lead to less biotoxicity (Nguyen *et al.*, 2023). antimicrobial activity is present both in low concentrations and in high concentrations (Yefimova *et al.*, 2023; Abdelghany *et al.*, 2023). This may be because the bioactivity of nanoparticles can be enhanced by combination with other molecules (Rebeiro *et al.*, 2023). High nanoparticle concentration could lead to cytotoxicity. Because of these, there is the need to adjust concentrations of nanoparticles to suit the bioassay under consideration. However, elimination of size-associated diffusion constraints leads to optimal harnessing of the concentration of the nanoparticle (Ibrahim *et al.*, 2023). This means that nanoparticles can be depleted in a bioassay without experiencing the full potentials of the nanoparticles. Nanoparticles can also be engineered to be continually released in living cells. Working in association with the cells uptake ability, being constantly released after each uptake. This keeps the concentration constant in the cellular environment and beneficial features for which

it was engineered stay present in the cell (Băcăiță *et al.*, 2023). Bioassays, especially antibacterial investigations, can also benefit from continuous systems in long term exposure of such systems to bioactive nanoparticles in synthesis and application (Mendoza Villicana *et al.*, 2023; Segura *et al.*, 2023). The nanoparticle concentration also affects its thermal conductivity in bioassays and in its use as a drug in treatment of certain conditions. This directly or indirectly affects its efficacy as a drug in this instance (Ali *et al.*, 2023).

The mass of a nanoparticle precursor is a quantitative parameter that can be modified in the synthesis of a bioactive nanoparticle. The mass concentration of a nanoparticle is a feature that is directly related to its solubility and toxicity (He *et al.*, 2023).

Exposure Time

In this article, the exposure of a bioactive nanoparticle encompasses its bioavailability, biodistribution and its half-life in living systems. The exposure time of a bioactive nanoparticle is also related to its concentration and uptake by cells in a living system. Nanoparticles can be engineered to improve bioactivity by protecting encapsulated bioactive compounds from degradation (Tahir *et al.*, 2023). When nanoparticles are used as carrier bioactive molecules, the rate of metabolism in the cell can be enhanced or reduced, making such reaction times longer (Yin *et al.*, 2023). Delayed-release bioactive nanoparticles can optimize the antibacterial or antiviral ability of the nanoparticle. The half-life of bioactive nanoparticle affects its bioactivity (Elmowafy *et al.*, 2023). In human systems, nanoparticles vary in days required to be completely metabolized and eliminated from the human excretory system. The metabolism of the nanoparticle depends on such primary characteristics of the nanoparticle like size, shape surface characteristics and presence of other combining molecules in its synthesis (Liu *et al.*, 2023; Pershina *et al.*, 2023).

Organic nanoparticles are said to be more easily changed and metabolized by cells while the metallic ones have longer half-life and are said to be more toxic. The duration of exposure of metallic nanoparticles should hence be altered by concentration and surface area reducing strategies in order to be more easily eliminated from living tissues (Yuan *et al.*, 2023; Suthar *et al.*, 2023).

Physicochemical Properties

From the information above, it can be said that the size, shape, and surface chemistry of nanoparticles influence their bioactivity. These parameters keep changing and can be altered to produce desirable bioactive effects. The physical properties are those parameters that can be measured physically and they exist as a result of the origin of the nanoparticle (Khalifa *et al.*, 2023). Chemical properties occur as a result of its intrinsic and extrinsic molecular definition. The chemical properties of a nanoparticle and its physical properties related to form and morphology are sometimes collectively studied. The physicochemical properties of nanoparticles are unique to each nanoparticle and govern their bioactivity and govern their use in living systems (Wang *et al.*, 2023).

The physical and chemical properties of nanoparticles, including the shape, size, roughness, zeta potential, doping modification, environmental conditions are often studied together. These factors influence the bioactivity of the nanoparticles. The properties of the nanoparticles influence the functionality as antimicrobial agents. The shape of the nanoparticles will determine its ability to penetrate the bacterial cell wall. The presence of surface coating (leading to roughness) can influence the efficiency of nanoparticles as antibacterial and antifungals. The zeta potential affects the ability of the NP to oxidatively stress a microorganism, leading to cell damage (Wouters *et al.*, 2023; Kerry *et al.*, 2023).

Due to these factors, along with their versatility, nanoparticles make for ideal candidates in cellular and biologic in-vitro studies in antimicrobial research, a quality that set them apart from conventional antibiotics (Alavi and Hamblin, 2023; Alavi and Ashengroph, 2023). nanoparticles can hence be incorporated into antimicrobials to speed up reaction time and

increase efficacy of the resulting polymer molecule, as demonstrated in a study involving the combination of silver nanoparticles with wound dressings, improving efficacy (Rybka *et al.*, 2023). This is an area that will benefit from innovations in antimicrobial and nanoparticle research as it shows the broader use and potential of nanoparticles.

Microbial Strain Growth Conditions

This is a property of microorganisms that affects its attraction to nanoparticles and consequently their effect on the microorganism in addition to the selection of the microorganism as a substrate in the production of nanoparticles (Ahmed *et al.*, 2023; Rahman *et al.*, 2023). Microorganisms exhibit a wide variety of phenotypic properties which in some cases, change rapidly. The phenotypic properties are related, majorly to the genes present in the microorganism's genome. Bacteria are a group of microorganisms that grow under various conditions. The presence of nutrients, adequate pH, and temperature are features that bacteria need for their growth and survival (Dias *et al.*, 2023). The ability of nanoparticles to affect these characteristics make them molecules of choice to influence the growth of microorganisms in-vitro and in living systems. Some strains of bacteria are susceptible to the effects of nanoparticles while others are resistant to the action of bioactive nanoparticles (Shehabeldine *et al.*, 2023).

The activity of bioactive nanoparticles can also have an impact on the genetic composition of microorganisms, in cases where there are mutations to the cells. The mutations are also targeted for expression in studies of the impacts on nanoparticles on certain gene expression pathways. These mutations can then be passed down to future generations of the bacterium. These factors are also heavily influenced by the environment in which the microorganisms grow (Quadir *et al.*, 2023).

There are reports on the synthesis of nanoparticles that encountered a problem, not in the experimental design of nanoparticle synthesis but in the structure of final product from the synthesis and shed light on industrial production of nanoparticles and their multipurpose attributes and versatility (Zhang *et al.*, 2023; Tu *et al.*, 2023).

Nanoparticle selection error, insufficient product, change in layers of concentration gradient (Panda, 2023) and, more recently, biogenic delivery methodology inefficacy or uncertainty (Bidian *et al.*, 2023) are parameters that matter as methods and calibrations are switched in the study of nanoparticles. However, problems encountered in nanoparticle research may not reflect the fault being that of the scientist but as a result of the use of ineffective or unstandardized methods in the synthesis of nanoparticles (Ara *et al.*, 2023).

The doping modification ability of NPs is the process by which an NP is mixed with another particle to create a colloid with pre-determined properties to improve its efficacy as an antimicrobial agent. The surface coating of an NP can hence be changed after addition or removal of metal ions on the surface of the NP or its colloid to increase its bioactive potential (Anukool *et al.*, 2023; Ray *et al.*, 2023). The environmental conditions presents an extrinsic factor that may confer on the NP to render it active or inactive as an antimicrobial. The environmental condition is a feature that affects all the other factors discussed above. These properties can be manipulated in the synthesis procedures to create custom made molecules to suit the proposed purpose (Makofane *et al.*, 2023; Liu *et al.*, 2023).

Studies show the importance of the synthesis of nanoparticles particularly against microorganisms in creation of preservatives, packaging and other consumable food product from nanoparticles. The importance of the absence of other external mixture changing the product homogeneity in the production of such materials with nanoparticle in order to reduce toxicity and improve food safety. (Popescu *et al.*, 2023; Jadhav *et al.*, 2023; Ntunya *et al.*, 2023).

TOXICITY AND SAFETY PROFILE

Nanoparticle toxicity occurs in both prokaryotes and eukaryotes. Investigations on the cytotoxicity profile of antimicrobial nanoparticles need to be standardised to lower reaction time in the drug design pipeline (Arranz *et al.*, 2023). In the age of advancement in science and research, procurement of nanoparticles for antimicrobial studies to yield potential new drugs will require proper identification of the exact and pure NP to be used for study and standardisation of methodology involving obtaining precursors of NPs for study (Younas *et al.*, 2023; Sun *et al.*, 2023; Aksoy *et al.*, 2023). This will assist in the attainment of global repeatability in experimental design and microbiological assays.

Internal use of nanoparticles (e.g in food) happens deliberately or without prior knowledge however its use as an antimicrobial, encourages its use and incorporation to more products. Hence, toxicology assays using mice, shrimps, or drosophila should be performed to determine its harmfulness in related environments (Shakil *et al.*, 2023; Tamboli *et al.*, 2023; Kaur *et al.*, 2023; Zhang *et al.*, 2023; Wang *et al.*, 2023).

Gold nanoparticles are shown to have antibacterial qualities against *Streptococcus* and other bacteria. However, they have the health drawback of being nephrotoxic. Silver nanoparticles also have antibacterial properties however, they may be cytotoxic to other cells (Amini *et al.*, 2023; Alshammari *et al.*, 2023; Tabassum *et al.*, 2023; Chauhan *et al.*, 2023). Copper NPs, which also have antimicrobial properties, have been shown to be toxic to the aquatic environment, in addition to carrying other harmful toxic and carcinogenic molecules that disrupt the natural ecosystem (Kalińska *et al.*, 2023; Rodríguez *et al.*, 2023). The presence of antimicrobials in the natural environment can contribute to the antimicrobial resistance of deadly pathogens, contributing to the global burden of antimicrobial resistance. The toxicity of Zinc oxide nanoparticles to human lungs has been suspected and studied (Abbasi *et al.*, 2023; Zhao *et al.*, 2023), despite its use as an antiviral in H1N1 prophylaxis (Yavuz *et al.*, 2023). Cobalt nanoparticles have demonstrated the ability to prevent the growth of gram-negative enteric pathogens (Rajeswari *et al.*, 2023) however, cobalt nanoparticles have shown negative effects in the reproductive system of mice, altering the organ and reducing testicular volume (Klein *et al.*, 2023).

There are also reports on the propensity of the method and other extrinsic factors to affect the pharmacomicrobial profile assembly of bioactive nanoparticles. With removal of errors, there may be tiny changes and repetition of true negatives in results obtained from research involving the use of nanoparticles (Hadidi *et al.*, 2023). Reasons being the possibility, that the final equipment used being progressively newer respectively affected the levels of synthesis products, leading to small changes (Tam *et al.*, 2023).

Showing the importance of accuracy and precision in nanoparticle synthesis and research, Hosseinzadeh *et al.*, (2023) reported the importance of calibrative manipulation in the synthesis of bioactive and potential drug complexes from nanoparticles.

Just as the beneficial properties of nanoparticles can be enhanced for better bioactivity, unfavourable properties including toxicity can be introduced in nanoparticle synthesis (Namiot *et al.*, 2023; Gao *et al.*, 2023). Therefore the prevention of unfavourable physicochemical properties and also prophylaxis of negative health effects of nanoparticles should be taken into consideration. Activities like the toxicological screening of nanoparticles either in-vitro, in living systems like mice and rats and using artificial intelligence can help in the study of the potential harmfulness of nanoparticles (Kour *et al.*, 2023; Karnwal *et al.*, 2023).

Environmental Impact

The environmental impact of nanoparticles have been extensively studied in the United States of America and the world alike. This is in part due to the presence of nanoparticles in waste products which end up in ground water, the environment and in water bodies. This could lead to the transfer of these nanoparticles up the food chain (Pandey and Saha, 2023; Maamoun *et*

al., 2023; Roychoudhury *et al.*, 2023). Nanoparticles in the environment can be reduced by the synthesis of nanoparticles with biodegradable properties for example in the production of plastics and other disposable products. Also, the disposal of toxicological nanoparticle samples should be directed to environments with containment strategies (Adeyeye *et al.*, 2023; Molahalli *et al.*, 2023; Mathew *et al.*, 2023). Regulatory guidelines should also stipulate how nanoparticle wastes should be properly disposed. These guidelines should be prepared, taking into consideration the origin of the nanoparticles and also by experts in the handling of these nanoparticles. Regulatory guidelines are also prepared based on the potential toxicity of the nanoparticles and the effects of its impact when it is exposed to the environment. Products containing nanoparticles should also be labelled appropriately, especially in products containing potentially toxic chemicals. These risk assessments are often periodically carried out in developed countries and differ in each region (Summer *et al.*, 2023; Ameer *et al.*, 2023; Xu *et al.*, 2023; Chang *et al.*, 2023).

Tools used in the Study of Nanoparticles

It has become necessary to employ the term “nanoscience” and the tools used in its study as it will be employed in microbiology in order to prevent the growth and spread of pathogenic microorganisms or support the growth of certain ones (Alduraimhem *et al.*, 2023; Tejaswini *et al.*, 2023). The problem in nanoparticle research was further promoted as Marica *et al.*, (2023) mentioned a problem in the acceptance of the recognition of the efforts and methodology stating that non uniformity in synthesis yields could lead to this problem, and some papers not being fully cited nor accepted for publication may be due to archaic methods, despite being hailed in industry and in the news for an innovative useful method to synthesize nanoparticles which became adopted in industry and in coastal research. Methods on the synthesis of nanoparticles, for the purpose of research are reported by (Udom *et al.*, 2023; Gambhir *et al.*, 2023; Mbatha *et al.*, 2023) more organic methods are reported by Dabhane *et al.*, (2023) and Alizadeh *et al.*, (2023).

Challenges in the study of antimicrobial nanoparticles include the cumbersome investigation into the abundant data on the advantages and toxicity of popular nanoparticles. However there is the need to conduct thorough investigations on the nephrotoxicity and cytotoxicity of newly synthesized nanoparticles to guide in further laboratory investigations on the promising nanoparticles. Another challenge lies in the study of the standardisation of antimicrobial nanoparticle research and nanoparticle-colloids utilisation including dose determination and calibration of doses in drug creation. The need to evaluate the interaction of nanoparticles with cells cannot be overemphasized. Challenges also include the investigation of the effects of nanoparticles on the normal flora of the host. Nanoparticles have often disrupted the microbiome in their utility as antimicrobial agents (Zhang *et al.*, 2023). This will prevent solving a problem and creating another one simultaneously. Another challenge lies in the sorting out of the methods used in nanoparticle creation as there are various independent researches in nanoparticle research, with various experts presenting their own ideas in nanoparticle reports. Reports on duality need to be classified appropriately in order to distinguish the two-pronged attributes of nanoparticles that have both positive and negative properties within the same frame.

Summary of Key Points

Nanoparticles are particles with sizes ranging from 1 to 100 nanometers and possess unique properties such as high surface area, reactivity, and optical and magnetic properties. Nanoparticles have shown potential in various applications in microbiology, including antimicrobial activity, drug delivery, and diagnostic imaging. The mechanisms of bioactivity of nanoparticles involve interaction with microorganisms, penetration into microorganisms, disruption of cellular processes, and effects on microbial growth. Factors affecting

nanoparticle bioactivity include nanoparticle concentration, exposure time, physicochemical properties, and microbial strain and growth conditions.

Recent works on antimicrobial nanoparticle research have focused on the antimicrobial and diagnostic capabilities of Nanoparticles along with investigations on the effectiveness of nanoparticles. Future work will show the interdisciplinary research of nanoparticle engineering and reengineering, organic combination with nanoparticles and reimaging AMR drug design.

Future Directions for Research

Further research is needed to fully understand the potential applications and mechanisms of action of nanoparticles in microbiology. Future studies should aim to optimize nanoparticle design for specific applications, investigate the potential for nanoparticle-based combination therapies, and assess the safety and environmental impact of nanoparticle use. Additionally, the development of standardized protocols and guidelines for nanoparticle characterization and testing is necessary for accurate and reproducible research.

Future prospects will include more studies on nanoparticles and their toxicity before human use and the inclusion of data of safe, standardised nanoparticle drug-complexes into health informatics databases. Prospects also include more funding in the field of harnessing nanoparticles in diagnosis and treatment of diseases like cancer, diabetes, autoimmune diseases and antimicrobial resistant infections as more experiments are required. Finally, the spelling out of the safety guidelines in the use of nanoparticles for experimental research, including a thorough investigation of the toxicity and effects of bioactive nanoparticles on the host will help in nanoparticle research. Including this information in informatics databases will further embellish the field of antimicrobial nanoparticle research.

Implications for Microbiological Applications

The unique properties and mechanisms of bioactivity of nanoparticles have the potential to revolutionize the field of microbiology. The use of nanoparticles in antimicrobial applications could provide alternative treatments for antibiotic-resistant infections, and nanoparticle-based diagnostic and therapeutic methods could improve the accuracy and effectiveness of microbial detection and treatment. However, the safety and environmental impact of nanoparticle use must be carefully considered and monitored to prevent adverse effects on human health and the environment.

REFERENCES

- Abbasi, R., Shineh, G., Mobaraki, M., Doughty, S., & Tayebi, L. (2023). Structural parameters of nanoparticles affecting their toxicity for biomedical applications: a review. *Journal of Nanoparticle Research*, 25(3), 43.
- Abdelghany, T. M., Al-Rajhi, A. M., Yahya, R., Bakri, M. M., Al Abboud, M. A., Yahya, R., ... & Salem, S. S. (2023). Phytofabrication of zinc oxide nanoparticles with advanced characterization and its antioxidant, anticancer, and antimicrobial activity against pathogenic microorganisms. *Biomass Conversion and Biorefinery*, 13(1), 417-430.
- Abdussalam-Mohammed, W., Mohamed, L., Abraheem, M. S., Mansour, M. M., & Sherif, A. M. (2023). Biofabrication of Silver Nanoparticles Using Teucrium Apollinis Extract: Characterization, Stability, and Their Antibacterial Activities. *Chemistry*, 5(1), 54-64.
- Adeyeye, S. A. O., Babu, A. S., Guruprasath, N., & Ganesh, P. S. (2023). Starch Nanocrystal and its Food Packaging Applications. *Current Research in Nutrition and Food Science Journal*, 11(1).
- Afkhami, F., Forghan, P., Gutmann, J. L., & Kishen, A. (2023). Silver Nanoparticles and Their Therapeutic Applications in Endodontics: A Narrative Review. *Pharmaceutics*, 15(3), 715.

- Ahghari, M. R., Amiri-Khamakani, Z., & Maleki, A. (2023). Synthesis and characterization of Se doped Fe₃O₄ nanoparticles for catalytic and biological properties. *Scientific Reports*, 13(1), 1007.
- Ahmad, A., Javed, M. S., Khan, S., Almutairi, T. M., Mohammed, A. A., & Luque, R. (2023). Green synthesized Ag decorated CeO₂ nanoparticles: Efficient photocatalysts and potential antibacterial agents. *Chemosphere*, 310, 136841.
- Ahmed, A., Usman, M., Ji, Z., Rafiq, M., Yu, B., Shen, Y., & Cong, H. (2023). Nature-inspired biogenic synthesis of silver nanoparticles for antibacterial applications. *Materials Today Chemistry*, 27, 101339.
- Ahmed, O. A. K., Sibuyi, N. R. S., Fadaka, A. O., Maboza, E., Olivier, A., Madiehe, A. M., ... & Geerts, G. (2023). Prospects of Using Gum Arabic Silver Nanoparticles in Toothpaste to Prevent Dental Caries. *Pharmaceutics*, 15(3), 871.
- Akbarizadeh, M. R., Sarani, M., & Darijani, S. (2022). Study of antibacterial performance of biosynthesized pure and Ag-doped ZnO nanoparticles. *Rendiconti Lincei. Scienze Fisiche e Naturali*, 33(3), 613-621.
- Aksoy, A., Alazragi, R., Alabdali, A. Y., Aljazzar, R., El Sadi, S., Alostaz, M., & El Hindi, M. (2023). Antibacterial activity of metallic-core gold and silver nanoparticles against some animal pathogens. *Annals of Animal Science*.
- Alavi, M., & Ashengroph, M. (2023). Mycosynthesis of AgNPs: mechanisms of nanoparticle formation and antimicrobial activities. *Expert Review of Anti-infective Therapy*, 21(4), 355-363.
- Alavi, M., & Hamblin, M. R. (2023). Antibacterial silver nanoparticles: effects on bacterial nucleic acids. *Cellular, Molecular and Biomedical Reports*, 3(1), 35-40.
- Al-Byati, M. K. A. A., & Al-Duhaidahawi, A. M. J. (2023). Synthesis of Aluminum Oxide Nanoparticles and Their Applications in Dye-Sensitized Solar Cells as a Clean Energy. *Biomedicine and Chemical Sciences*, 2(1), 48-52.
- Alduraihem, N. S., Bhat, R. S., Al-Zahrani, S. A., Elnagar, D. M., Alobaid, H. M., & Daghestani, M. H. (2023). Anticancer and antimicrobial activity of silver nanoparticles synthesized from pods of *Acacia nilotica*. *Processes*, 11(2), 301.
- Algammal, A., Hetta, H. F., Mabrok, M., & Behzadi, P. (2023). Emerging multidrug-resistant bacterial pathogens "superbugs": A rising public health threat. *Frontiers in Microbiology*, 14.
- Ali, L., Ali, B., & Iqbal, T. (2023). Finite element analysis of the impact of particles aggregation on the thermal conductivity of nanofluid under chemical reaction. *Waves in Random and Complex Media*, 1-21.
- Ali, M. F., Saraya, R. E., El Deeb, S., Ibrahim, A. E., & Salman, B. I. (2023). An Innovative Polymer-Based Electrochemical Sensor Encrusted with Tb Nanoparticles for the Detection of Favipiravir: A Potential Antiviral Drug for the Treatment of COVID-19. *Biosensors*, 13(2), 243.
- Alizadeh, S. R., Biparva, P., Goli, H. R., Khan, B. A., & Ebrahimzadeh, M. A. (2023). Green Synthesis of AuNPs by *Crocus caspius*—Investigation of Catalytic Degradation of Organic Pollutants, Their Cytotoxicity, and Antimicrobial Activity. *Catalysts*, 13(1), 63.
- Alshammari, G. M., Al-Ayed, M. S., Abdelhalim, M. A., Al-Harbi, L. N., & Yahya, M. A. (2023). Effects of antioxidant combinations on the renal toxicity induced rats by gold nanoparticles. *Molecules*, 28(4), 1879.
- Ameen, F., Al-Homaidan, A. A., Al-Sabri, A., Almansob, A., & AlNadhari, S. (2023). Anti-oxidant, anti-fungal and cytotoxic effects of silver nanoparticles synthesized using marine fungus *Cladosporium halotolerans*. *Applied Nanoscience*, 13(1), 623-631.
- Ameer, K., Jiang, G., Zhao, C. C., Nadeem, M., Murtaza, M. A., Mueen-ud-Din, G., & Mahmood, S. (2023). Silver Nanoparticles as Food Packaging Additives for Shelf-Life Extension. In *Nanotechnology Interventions in Food Packaging and Shelf Life* (pp. 203-216). CRC Press.

- Amini, S. M., Hadighi, R., Najm, M., Alipour, M., Hasanpour, H., Vosoogh, M., ... & Badirzadeh, A. (2023). The Therapeutic Effects of Curcumin-coated Gold Nanoparticle Against Leishmania Major Causative Agent of Zoonotic Cutaneous Leishmaniasis (ZCL): An In Vitro and In Vivo Study. *Current Microbiology*, 80(4), 104.
- Amirkhanova, Z., Akhmetova, S., Kozhakhmetov, S., Kushugulova, A., Bodeeva, R., Ahvlediani, L., & Turmukhambetova, A. (2023). The ability of *Lactobacillus helveticus*-13 (Lh-13) Isolate Isolated from Lactic Acid Products to form A biofilm by Applying Modern Microscopy Methods. *Biological*, 16(1), 163.
- Anukool, W., El-Nabulsi, R. A., & Dabagh, S. (2023). Effect of Al³⁺ doping on dielectric properties of cobalt ferrite nanoparticle for using in high frequency applications. *Journal of Sol-Gel Science and Technology*, 1-11.
- Ara, L., Shah, L. A., Ye, D., & Khattak, N. S. (2023). Silver nanoparticles doped polymethylmethacrylate [Ag/PMMA] nanocomposite as smart material for non-enzymatic glucose sensor. *Journal of Dispersion Science and Technology*, 1-9.
- Arranz, D., Weigand, R., & de la Presa, P. (2023). Towards the standardization of photothermal measurements of iron oxide nanoparticles in two biological windows. *Nanomaterials*, 13(3), 450.
- Ascensao, J. A., Wetmore, K. M., Good, B. H., Arkin, A. P., & Hallatschek, O. (2023). Quantifying the local adaptive landscape of a nascent bacterial community. *Nature Communications*, 14(1), 248.
- Ayodhya, D., Sumalatha, V., Gurrapu, R., & Babu, M. S. (2023). Catalytic degradation of HIV drugs in water and antimicrobial activity of Chrysin-conjugated Ag-Au, Ag-Cu, and Au-Cu bimetallic nanoparticles. *Results in Chemistry*, 100792.
- Băcăiță, E. S., Rață, D. M., Cadinoiu, A. N., Ghizdovăț, V., Agop, M., & Luca, A. C. (2023). Drug release from nanoparticles (polymeric nanocapsules and liposomes) mimed through a multifractal tunnelling-type effect. *Polymers*, 15(4), 1018.
- Bag, N., Bardhan, S., Roy, S., Roy, J., Mondal, D., Guo, B., & Das, S. (2023). Nanoparticle-mediated stimulus-responsive antibacterial therapy. *Biomaterials Science*, 11(6), 1994-2019.
- Baldassarre, F., Schiavi, D., Ciarroni, S., Tagliavento, V., De Stradis, A., Vergaro, V., ... & Ciccarella, G. (2023). Thymol-Nanoparticles as Effective Biocides against the Quarantine Pathogen *Xylella fastidiosa*. *Nanomaterials*, 13(7), 1285.
- Banerjee, A., Kar, S., Pore, S., & Roy, K. (2023). Efficient predictions of cytotoxicity of TiO₂-based multi-component nanoparticles using a machine learning-based q-RASAR approach. *Nanotoxicology*, 1-16.
- Ben Khalifa, S., Chebaane, S., & Beji, L. (2023). Optical and photoluminescence studies of CoFe₂O₄ nanoparticles deposited on different substrates. *Optical and Quantum Electronics*, 55(5), 435.
- Bidian, C., Filip, G. A., David, L., Moldovan, B., Olteanu, D., Clichici, S., ... & Baldea, I. (2023). Green Synthesized Gold and Silver Nanoparticles Increased Oxidative Stress and Induced Cell Death in Colorectal Adenocarcinoma Cells. *Nanomaterials*, 13(7), 1251.
- Brezgin, S., Parodi, A., Kostyusheva, A., Ponomareva, N., Lukashev, A., Sokolova, D., ... & Kostyushev, D. (2023). Technological aspects of manufacturing and analytical control of biological nanoparticles. *Biotechnology Advances*, 108122.
- Carrapiço, A., Martins, M. R., Caldeira, A. T., Mirão, J., & Dias, L. (2023). Biosynthesis of Metal and Metal Oxide Nanoparticles Using Microbial Cultures: Mechanisms, Antimicrobial Activity and Applications to Cultural Heritage. *Microorganisms*, 11(2), 378.
- Cassani, L., Marcovich, N. E., & Gomez-Zavaglia, A. (2023). Seaweed bioactive compounds: Promising and safe inputs for the green synthesis of metal nanoparticles in the food industry. *Critical Reviews in Food Science and Nutrition*, 63(11), 1527-1550.

- Celin, S. R., & Ajitha, R. (2023). Synthesis and characterization of biocompatible silver nanoparticles with increased anti-Diabetic and anti-Microbial effectiveness via the mediation of aquatic plant *Hygrophila corymbosa*. *Materials Today: Proceedings*.
- Chang, C. H., Tsai, L. H., Lee, Y. C., Yao, W. C., & Lin, J. J. (2023). Synergistic Effects of Silicate-Platelet Supporting Ag and ZnO, Offering High Antibacterial Activity and Low Cytotoxicity. *International Journal of Molecular Sciences*, 24(8), 7024.
- Chang, T., Khort, A., Saeed, A., Blomberg, E., Nielsen, M. B., Hansen, S. F., & Odnevall, I. (2023). Effects of interactions between natural organic matter and aquatic organism degradation products on the transformation and dissolution of cobalt and nickel-based nanoparticles in synthetic freshwater. *Journal of Hazardous Materials*, 445, 130586.
- Chauhan, V., Dhiman, V. K., Mahajan, G., Pandey, A., & Kanwar, S. S. (2023). Synthesis and characterization of silver nanoparticles developed using a novel lipopeptide (s) biosurfactant and evaluating its antimicrobial and cytotoxic efficacy. *Process Biochemistry*, 124, 51-62.
- Chen, J., Zhang, Y., Kuzyakov, Y., Wang, D., & Olesen, J. E. (2023). Challenges in upscaling laboratory studies to ecosystems in soil microbiology research. *Global Change Biology*.
- Chen, W., Li, X., Cheng, H., Zhan, X., & Xia, W. (2023). Synthesis, characterization, and anticancer activity of protamine sulfate stabilized selenium nanoparticles. *Food Research International*, 164, 112435.
- Choi, H. K., & Yoon, J. (2023). Nanotechnology-Assisted Biosensors for the Detection of Viral Nucleic Acids: An Overview. *Biosensors*, 13(2), 208.
- Cohen, Y., Rozen, G. A., Pennings, P., Katz, S., & Hershberg, R. (2023). Compensatory adaptation does not fully alleviate the costs associated with rifampicin resistance and occurs predominantly through off-target mutations. *bioRxiv*, 2023-01.
- Cruz-Pulido, Y. E., & Mounce, B. C. (2023, January). Good cop, bad cop: Polyamines play both sides in host immunity and viral replication. In *Seminars in Cell & Developmental Biology*. Academic Press.
- Cui, Z., Liu, Q., Zhu, J., Wang, H., Gao, M., Wang, W., ... & Zou, R. (2023). Pseudopyrolysis of Metal–Organic Frameworks: A Synchronous Nucleation Mechanism to Synthesize Ultrafine Metal Compound Nanoparticles. *Nano Letters*.
- Dabhane, H., Ghotekar, S., Zate, M., Lin, K. Y. A., Rahdar, A., Ravindran, B., ... & Medhane, V. (2023). A novel approach toward the bio-inspired synthesis of CuO nanoparticles for phenol degradation and antimicrobial applications. *Biomass Conversion and Biorefinery*, 1-16.
- Dappula, S. S., Kandrakonda, Y. R., Shaik, J. B., Mothukuru, S. L., Lebaka, V. R., Mannarapu, M., & Amooru, G. D. (2023). Biosynthesis of zinc oxide nanoparticles using aqueous extract of *Andrographis alata*: Characterization, optimization and assessment of their antibacterial, antioxidant, antidiabetic and anti-Alzheimer's properties. *Journal of Molecular Structure*, 1273, 134264.
- Das, U., & Biswas, R. (2023). Unravelling optical properties and morphology of plasmonic gold nanoparticles synthesized via a novel green route. *Chemical Papers*, 1-9.
- de Miguel, S., Pérez-Abeledo, M., Ramos, B., García, L., Arce, A., Martínez-Arce, R., ... & Sanz, J. C. (2023). Distribution of Multidrug-Resistant Invasive Serotypes of *Streptococcus pneumoniae* during the Period 2007–2021 in Madrid, Spain. *Antibiotics*, 12(2), 342.
- de Souza Cabral, A., Verdan, M., Presciliano, R., Silveira, F., Correa, T., & Abreu, F. (2023). Large-Scale Cultivation of Magnetotactic Bacteria and the Optimism for Sustainable and Cheap Approaches in Nanotechnology. *Marine Drugs*, 21(2), 60.
- Dias, C., Santos, J. A., Reis, A., & Lopes da Silva, T. (2023). The Use of Oleaginous Yeasts and Microalgae Grown in Brewery Wastewater for Lipid Production and Nutrient Removal: A Review. *Waste and Biomass Valorization*, 1-24.
- El Shahawi, A. M. (2023). Incorporation of zinc oxide nanoparticles and its antibacterial effect on toothpaste. *Bulletin of the National Research Centre*, 47(1), 1-5.

- Elmowafy, M., Shalaby, K., Elkomy, M. H., Alsaidan, O. A., Gomaa, H. A., Abdelgawad, M. A., & Mostafa, E. M. (2023). Polymeric Nanoparticles for Delivery of Natural Bioactive Agents: Recent Advances and Challenges. *Polymers*, 15(5), 1123.
- Fang, M., Zhang, H., Wang, Y., Zhang, H., Zhang, D., & Xu, P. (2023). Biomimetic selenium nanosystems for infectious wound healing. *Engineered Regeneration*, 4(2), 152-160.
- Fang, R. H., Gao, W., & Zhang, L. (2023). Targeting drugs to tumours using cell membrane-coated nanoparticles. *Nature Reviews Clinical Oncology*, 20(1), 33-48.
- Feng, J., Xiu, Q., Huang, Y., Troyer, Z., Li, B., & Zheng, L. (2023). Plant Derived Vesicle- Like Nanoparticles as Promising Biotherapeutic Tools: Present and Future. *Advanced Materials*, 2207826.
- Ferrillo, M., Giudice, A., Migliario, M., Renó, F., Lippi, L., Calafiore, D., ... & de Sire, A. (2023). Oral–Gut Microbiota, Periodontal Diseases, and Arthritis: Literature Overview on the Role of Probiotics. *International Journal of Molecular Sciences*, 24(5), 4626.
- Foster, T., Lewkowicz, M., Quintas, C., Ionescu, C. M., Jones, M., Wagle, S. R., ... & Al- Salami, H. (2023). Novel Nanoencapsulation Technology and its Potential Role in Bile Acid- Based Targeted Gene Delivery to the Inner Ear. *Small*, 19(8), 2204986.
- FRANCO-LAGOS, C. L., SÁNCHEZ, E., PALACIO-MÁRQUEZ, A., PÉREZ-ÁLVAREZ, S., TERRAZAS-GÓMEZ, M., VILLALOBOS-CANO, O., & RAMÍREZ-ESTRADA, C. A. (2023). Efficacy of the application of boron nanofertilizer on biomass, yield, nitrogen assimilation and photosynthetic activity in green beans. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca*, 51(1), 12795-12795.
- Fritz, S. R., Armijo, L. M., Simpson, K., Lopez, K., Osinski, M., Bandara, N., ... & Xu, W. (2023, March). Superparamagnetic nanoparticles for the treatment of periodontal disease. In *Colloidal Nanoparticles for Biomedical Applications XVIII* (Vol. 12395, pp. 50-59). SPIE.
- Gambhir, R. P., Vibhute, A. A., Patil, T. P., & Tiwari, A. P. (2023). Surface-Functionalized Iron Oxide (Fe₃O₄) Nanoparticles for Biomedical Applications. In *Chemically Deposited Metal Chalcogenide-based Carbon Composites for Versatile Applications* (pp. 411-432). Cham: Springer International Publishing.
- Gao, J., Karp, J. M., Langer, R., & Joshi, N. (2023). The future of drug delivery. *Chemistry of Materials*, 35(2), 359-363.
- Ge, P., Zhang, J., Ding, T., & Xianyu, Y. (2023). Surface Chemistry of Gold Nanoparticles for Bacterial Detection and Antimicrobial Applications. *ACS Materials Letters*, 5(3), 638-655.
- Ghosal, K. (2023). Tackling COVID- 19 Using Antiviral Nanocoating's—Recent Progress and Future Challenges. *Particle & Particle Systems Characterization*, 40(1), 2200154.
- Golinejad, S., Mirjalili, M. H., Rezadoost, H., & Ghorbanpour, M. (2023). Molecular, biochemical, and metabolic changes induced by gold nanoparticles in *Taxus baccata* L. cell culture. *Industrial Crops and Products*, 192, 115988.
- Golli, R., Thummaneni, C., Pabbathi, D. D., Srungarapu, T., Jayasri, G., & Vangalapati, M. (2023). Silver nanoparticles synthesized by *Brassica oleracea* (Broccoli) acting as antifungal agent against *Candida albicans*. *Materials Today: Proceedings*.
- Gu, M., Cho, J. H., Suh, J. W., & Cheng, J. (2023). Potential oral probiotic *Lactobacillus pentosus* MJM60383 inhibits *Streptococcus mutans* biofilm formation by inhibiting sucrose decomposition. *Journal of Oral Microbiology*, 15(1), 2161179.
- Gulati, N., Dua, K., & Dureja, H. (2023). Enhancing the Therapeutic Potential of Nanomedicines by Modifying Surface Characteristics. *Current Drug Delivery*.
- Hadidi, M., Tan, C., Assadpour, E., Kharazmi, M. S., & Jafari, S. M. (2023). Emerging plant proteins as nanocarriers of bioactive compounds. *Journal of Controlled Release*, 355, 327-342.
- Hamzah, W. M., Reyes, I. G. C., & Mendoza Pérez, J. A. (2023). Nanotechnology for Pest and Microbiological Control. In *Agricultural and Environmental Nanotechnology: Novel*

- Technologies and their Ecological Impact (pp. 393-409). Singapore: Springer Nature Singapore.
- Haris, M., Hussain, T., Mohamed, H. I., Khan, A., Ansari, M. S., Tauseef, A., ... & Akhtar, N. (2023). Nanotechnology—A new frontier of nano-farming in agricultural and food production and its development. *Science of The Total Environment*, 857, 159639.
- He, J., Xie, Y., Zhong, J., Chen, W., Fang, S., Chen, X., ... & Liu, C. (2023). Improving shikonin solubility and stability by encapsulation in natural surfactant-coated shikonin nanoparticles. *Journal of Food Science*.
- Heida, R., Akkerman, R., Silva, P. H. J., Lakerveld, A. J., Ortiz, D., Bigogno, C., ... & Hinrichs, W. L. (2023). Development of an inhalable antiviral powder formulation against respiratory syncytial virus. *Journal of Controlled Release*, 357, 264-273.
- Hosseinzadeh, E., Foroumadi, A., & Firoozpour, L. (2023). What is the role of phytochemical compounds as capping agents for the inhibition of aggregation in the green synthesis of metal oxide nanoparticles? A DFT molecular level response. *Inorganic Chemistry Communications*, 147, 110243.
- Hou, F., Sun, S., Abdullaha, S. W., Tang, Y., Li, X., & Guo, H. (2023). The application of nanoparticles in point-of-care testing (POCT) immunoassays. *Analytical Methods*.
- Huang, T., Li, X., Maier, M., O'Brien-Simpson, N. M., Heath, D. E., & O'Connor, A. J. (2023). Using inorganic nanoparticles to fight fungal infections in the antimicrobial resistant era. *Acta Biomaterialia*.
- Ibrahim, B., Akere, T. H., Chakraborty, S., Valsami-Jones, E., & Ali-Boucetta, H. (2023). Gold Nanoparticles Induced Size Dependent Cytotoxicity on Human Alveolar Adenocarcinoma Cells by Inhibiting the Ubiquitin Proteasome System. *Pharmaceutics*, 15(2), 432.
- Ifijen, I. H., Maliki, M., Udokpoh, N. U., Odiachi, I. J., & Atoe, B. (2023, February). A concise review of the antibacterial action of gold nanoparticles against various bacteria. In *TMS 2023 152nd Annual Meeting & Exhibition Supplemental Proceedings* (pp. 655-664). Cham: Springer Nature Switzerland.
- Ikram, M., Haider, A., Imran, M., Haider, J., Naz, S., Ul-Hamid, A., ... & Ali, S. (2023). Assessment of catalytic, antimicrobial and molecular docking analysis of starch-grafted polyacrylic acid doped BaO nanoparticles. *International Journal of Biological Macromolecules*, 123190.
- Jadhav, R., Pawar, P., Choudhari, V., Topare, N., Raut-Jadhav, S., Bokil, S., & Khan, A. (2023). An overview of antimicrobial nanoparticles for food preservation. *Materials Today: Proceedings*, 72, 204-216.
- Javadi, A., Nourizade, M., Rahmani, M., & Eckert, K. (2023). Interaction of Catalyst Nanoparticles and Pollutant Molecules in Photocatalytic Wastewater Treatment: Novel Characterization via Dynamic Surface Properties. *Chemical Engineering Science*, 118459.
- Ji, X., Li, Q., Su, R., Wang, Y., & Qi, W. (2023). Peroxidase-Mimicking Hierarchically Organized Gold Particles for Glucose Detection. *Langmuir*, 39(9), 3216-3224.
- Joseph, T. M., Kar Mahapatra, D., Esmaili, A., Piszczyk, Ł., Hasanin, M. S., Kattali, M., ... & Thomas, S. (2023). Nanoparticles: Taking a unique position in medicine. *Nanomaterials*, 13(3), 574.
- Kagdada, H. L., Bhojani, A. K., & Singh, D. K. (2023). An Overview of Nanomaterials: History, Fundamentals, and Applications. *Nanomaterials*, 1-26.
- Kalińska, A., Jaworski, S., Wierzbicki, M., Kot, M., Radzikowski, D., Smulski, S., & Gołębiewski, M. (2023). Silver and Copper Nanoparticles as the New Biocidal Agents Used in Pre-and Post-Milking Disinfectants with the Addition of Cosmetic Substrates in Dairy Cows. *International Journal of Molecular Sciences*, 24(2), 1658.
- Kanakari, E., & Dendrinou-Samara, C. (2023). Fighting Phytopathogens with Engineered Inorganic-Based Nanoparticles. *Materials*, 16(6), 2388.

- Kang, M. S., Lee, G. H., Kwon, I. H., Yang, M. J., Heo, M. B., Choi, J. W., ... & Park, E. J. (2023). Uptake and toxicity of cerium dioxide nanoparticles with different aspect ratio. *Toxicology Letters*, 373, 196-209.
- Kareem, M. M., Babu, M. H., & Lakshmi, G. V. (2023). Anticancer, antibacterial, antioxidant, and photo-catalytic activities of eco-friendly synthesized Ni nanoparticles. *Inorganic Chemistry Communications*, 148, 110274.
- Karnjana, K., Jewboonchu, J., Niyomtham, N., Tangngamsakul, P., Bunluepuech, K., Goodla, L., & Mordmuang, A. (2023). The potency of herbal extracts and its green synthesized nanoparticle formulation as antibacterial agents against *Streptococcus mutans* associated biofilms. *Biotechnology Reports*, 37, e00777.
- Karnwal, A., Kumar, G., Pant, G., Hossain, K., Ahmad, A., & Alshammari, M. B. (2023). Perspectives on Usage of Functional Nanomaterials in Antimicrobial Therapy for Antibiotic-Resistant Bacterial Infections. *ACS Omega*.
- Kasparis, G., Sangnier, A. P., Wang, L., Efstathiou, C., LaGrow, A. P., Sergides, A., ... & Thanh, N. T. K. (2023). Zn doped iron oxide nanoparticles with high magnetization and photothermal efficiency for cancer treatment. *Journal of Materials Chemistry B*.
- Kaur, H., Rauwel, P., & Rauwel, E. (2023). Antimicrobial nanoparticles: synthesis, mechanism of actions. In *Antimicrobial activity of nanoparticles* (pp. 155-202). Elsevier.
- Kerry, R. G., Singh, K. R., Mahari, S., Jena, A. B., Panigrahi, B., Pradhan, K. C., ... & Majhi, S. (2023). Bioactive potential of morin loaded mesoporous silica nanoparticles: A noble and efficient antioxidant, antidiabetic and biocompatible abilities in in-silico, in-vitro, and in-vivo models. *OpenNano*, 10, 100126.
- Khalid, A., Cookson, A. R., Whitworth, D. E., Beeton, M. L., Robins, L. I., & Maddocks, S. E. (2023). A Synthetic Polymicrobial Community Biofilm Model Demonstrates Spatial Partitioning, Tolerance to Antimicrobial Treatment, Reduced Metabolism, and Small Colony Variants Typical of Chronic Wound Biofilms. *Pathogens*, 12(1), 118.
- Klein, J. P., Mery, L., Boudard, D., Ravel, C., Cottier, M., & Bitounis, D. (2023). Impact of Nanoparticles on Male Fertility: What Do We Really Know? A Systematic Review. *International Journal of Molecular Sciences*, 24(1), 576.
- Kong, X., Qi, Y., Wang, X., Jiang, R., Wang, J., Fang, Y., ... & Hwang, K. C. (2023). Nanoparticle Drug Delivery Systems and Their Applications as Targeted Therapies for Triple Negative Breast Cancer. *Progress in Materials Science*, 101070.
- Koo, S. Y., Hwang, K. T., Hwang, S., Choi, K. Y., Park, Y. J., Choi, J. H., ... & Kim, S. M. (2023). Nanoencapsulation enhances the bioavailability of fucoxanthin in microalga *Phaeodactylum tricorutum* extract. *Food Chemistry*, 403, 134348.
- Korte, I., Petry, M., & Kreyenschmidt, J. (2023). Antimicrobial activity of different coatings for packaging materials containing functional extenders against selected microorganisms typical for food. *Food Control*, 148, 109669.
- Kou, S., Chen, W., Sun, C., & Sun, F. (2023). SpyStapler-mediated assembly of nanoparticle vaccines. *Nano Research*, 16(2), 2821-2828.
- Kour, S., Biswas, I., Sheoran, S., Arora, S., Sheela, P., Duppala, M. S. K., ... & Kumar, R. (2023). Artificial intelligence and nanotechnology for cervical cancer treatment: Current status and future perspectives. *Journal of Drug Delivery Science and Technology*, 104392.
- Koyappayil, A., Yagati, A. K., & Lee, M. H. (2023). Recent Trends in Metal Nanoparticles Decorated 2D Materials for Electrochemical Biomarker Detection. *Biosensors*, 13(1), 91.
- Krishnamoorthy, S., Zait, N. N., Nasir, A. M., Ishar, S. M., Hamzah, N. H., Din, R. D. R., & Osman, K. (2023). Towards development of green nanoparticles in applied health application: A mini review. *Materials Today: Proceedings*.
- Kulkarni, V. K., Dixit, M., Balasubramanian, S., & Jetpurwala, A. (2023). Gingival and Periodontal Diseases in Children. *Illustrated Pediatric Dentistry-Part 2*, 264.

- Kullar, R., Goldstein, E. J., Johnson, S., & McFarland, L. V. (2023). Lactobacillus Bacteremia and Probiotics: A Review. *Microorganisms*, 11(4), 896.
- Kumar, V., Singh, E., Singh, S., Pandey, A., & Bhargava, P. C. (2023). Micro-and nano-plastics (MNPs) as emerging pollutant in ground water: Environmental impact, potential risks, limitations and way forward towards sustainable management. *Chemical Engineering Journal*, 459, 141568.
- Kuppusamy, P., Kim, S., Kim, S. J., Park, M., & Song, K. D. (2023). Sederia pink ruby Extract-Mediated Synthesis of Gold and Silver Nanoparticles and Their Bioactivity against Livestock Pathogens and in Different Cell Lines. *Antibiotics*, 12(3), 507.
- KUSHWAHA, A., SINGH, G., & SHARMA, M. (2023). STABILITY AND FATE OF NANOPARTICLES IN FOODS. *NANOTECHNOLOGY HORIZONS IN FOOD PROCESS ENGINEERING*, 1.
- Kuspradini, H., Kusuma, I. W., Batubara, I., Yamauchi, K., & Mitsunaga, T. (2023). Garcidepsidon B from *Garcinia parvifolia*: Antimicrobial Activities of The Medicinal Plants from North Kalimantan against Dental Caries and Periodontal Disease Pathogen.
- Lach, S. R., Kumar, S., Kim, S., Im, W., & Konovalova, A. (2023). Conformational rearrangements in the sensory RcsF/OMP complex mediate signal transduction across the bacterial cell envelope. *PLoS Genetics*, 19(1), e1010601.
- Lazcano-Ramírez, H. G., Garza-García, J. J., Hernández-Díaz, J. A., León-Morales, J. M., Macías-Sandoval, A. S., & García-Morales, S. (2023). Antifungal Activity of Selenium Nanoparticles Obtained by Plant-Mediated Synthesis. *Antibiotics*, 12(1), 115.
- Li, Y., Zhang, P., Li, M., Shakoor, N., Adeel, M., Zhou, P., ... & Rui, Y. (2023). Application and mechanisms of metal-based nanoparticles in the control of bacterial and fungal crop diseases. *Pest Management Science*, 79(1), 21-36.
- Liang, Y., Zhao, Y., Sun, H., Dan, J., Kang, Y., Zhang, Q., ... & Zhang, W. (2023). Natural melanin nanoparticle-based photothermal film for edible antibacterial food packaging. *Food Chemistry*, 401, 134117.
- Limantoro, C., Das, T., He, M., Dirin, D., Manos, J., Kovalenko, M. V., & Chrzanowski, W. (2023). Synthesis of Antimicrobial Gallium Nanoparticles Using the Hot Injection Method. *ACS Materials Au*.
- Liu, J., Zhang, K., Shang, R., Zhang, H., Shen, J., Liu, H., ... & Chen, S. (2023). Theory-guided doping of LaCoO₃ nanoparticles for enhanced antimicrobial performance. *Chemical Engineering Journal*, 464, 142710.
- Liu, M., Lai, W., Chen, M., Wang, P., Liu, J., Fang, X., ... & Wang, C. (2023). Prominent Enhancement of Peptide-mediated Targeting Efficiency for Human Hepatocellular Carcinomas With Composition-engineered Protein Corona on Gold Nanoparticles. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, 131016.
- Liu, Z., Liu, H., Vowden, R., Hughes, L., Qi, D., Francis, W., ... & Xia, Z. (2023). Combination of cobalt, chromium and titanium nanoparticles increases cytotoxicity in vitro and pro-inflammatory cytokines in vivo. *Journal of Orthopaedic Translation*, 38, 203-212.
- Maamoun, I., Falyouna, O., Eljamal, R., Idham, M. F., Tanaka, K., & Eljamal, O. (2023). Bench-scale injection of magnesium hydroxide encapsulated iron nanoparticles (nFeO@ Mg (OH) 2) into porous media for Cr (VI) removal from groundwater. *Chemical Engineering Journal*, 451, 138718.
- Makofane, A., Motaung, D. E., & Hintsho- Mbita, N. C. (2023). Green Synthesis of Metal Ferrite Nanoparticles for the Photocatalytic Degradation of Dyes in Wastewater. *Photoreactors in Advanced Oxidation Processes: The Future of Wastewater Treatment*, 109-150.
- Malik, S., Kishore, S., & Dutta, A. K. (2023). Antagonistic activity of endophytic nanoparticles against plant and human pathogens. In *Endophytic Association: What, Why and How* (pp. 333-352). Academic Press.

- Maliki, M., Omorogbe, S. O., Ifijen, I. H., Aghedo, O. N., & Ighodaro, A. (2023, February). Incisive review on magnetic iron oxide nanoparticles and their use in the treatment of bacterial infections. In TMS 2023 152nd Annual Meeting & Exhibition Supplemental Proceedings (pp. 487-498). Cham: Springer Nature Switzerland.
- Mallineni, S. K., Sakhamuri, S., Kotha, S. L., AlAsmari, A. R. G. M., AlJefri, G. H., Almotawah, F. N., ... & Sajja, R. (2023). Silver Nanoparticles in Dental Applications: A Descriptive Review. *Bioengineering*, 10(3), 327.
- Maloma, M. R., Adebayo-Tayo, B. C., Alli, Y. A., & Oladoye, P. O. (2023). Synthesis and Characterization of T. polyzona and Laccase-Mediated Silver Nanoparticles: Antimicrobial and Printing Press Wastewater Treatment Efficiency. *Chemistry Africa*, 1-13.
- Manzoor, A., Khan, S., Dar, A. H., Pandey, V. K., Shams, R., Ahmad, S., ... & Pandiselvam, R. (2023). Recent insights into green antimicrobial packaging towards food safety reinforcement: A review. *Journal of Food Safety*, e13046.
- Marica, I., Stefan, M., Boca, S., Falamaş, A., & Farcău, C. (2023). A simple approach for coffee-ring suppression yielding homogeneous drying patterns of ZnO and TiO₂ nanoparticles. *Journal of Colloid and Interface Science*, 635, 117-127.
- Mathew, J. T., Adetunji, C. O., Inobeme, A., Monday, M., Azeh, Y., Otori, A. A., ... & Ezekiel, T. (2023). Removal of Heavy Metals Using Bio-remedial Techniques. In *Modern Approaches in Waste Bioremediation: Environmental Microbiology* (pp. 117-130). Cham: Springer International Publishing.
- Mbatha, L. S., Akinyelu, J., Chukwuma, C. I., Mokoena, M. P., & Kudanga, T. (2023). Current Trends and Prospects for Application of Green Synthesized Metal Nanoparticles in Cancer and COVID-19 Therapies. *Viruses*, 15(3), 741.
- McNeilly, O., Mann, R., Cummins, M. L., Djordjevic, S. P., Hamidian, M., & Gunawan, C. (2023). Development of Nanoparticle Adaptation Phenomena in *Acinetobacter baumannii*: Physiological Change and Defense Response. *Microbiology Spectrum*, e02857-22.
- Mendoza Villicana, A., Gochi Ponce, Y., Grande, D., José Manuel, C. B., Zizumbo López, A., González Joaquín, M. C., ... & Villarreal-Gómez, L. J. (2023). Evaluation of strategies to incorporate silver nanoparticles into electrospun microfibers for the preparation of wound dressings and their antimicrobial activity. *Polymer-Plastics Technology and Materials*, 62(8), 1029-1056.
- Mikhutkin, A. A., Kamyshinsky, R. A., Kuznetsov, N. M., Lebedev-Stepanov, P. V., Stepko, A. S., & Vasiliev, A. L. (2022). Study of the 3D Structure of a Hydrogel with Gold Nanoparticles by Cryogenic Electron Microscopy. *Nanobiotechnology Reports*, 17(3), 396-401.
- Min, K. H., Shin, J. W., Ki, M. R., & Pack, S. P. (2023). Green synthesis of silver nanoparticles on biosilica diatomite: Well-dispersed particle formation and reusability. *Process Biochemistry*, 125, 232-238.
- Mohammad, F., Bwatanglang, I. B., Al-Lohedan, H. A., Shaik, J. P., Al-Tilasi, H. H., & Soleiman, A. A. (2023). Influence of Surface Coating towards the Controlled Toxicity of ZnO Nanoparticles In Vitro. *Coatings*, 13(1), 172.
- Mohammed, A. A., Hegazy, A. E., & Salah, A. (2023). Novelty of synergistic and cytotoxicity activities of silver nanoparticles produced by *Lactobacillus acidophilus*. *Applied Nanoscience*, 13(1), 633-640.
- Mokhtari, H., Shafiqhi, S. T., Salehzadeh, A., & Ataei Jaliseh, S. (2023). Investigating the Effect of Thymol Active Ingredient and ZnO Nanoparticle Conjugated by Thiosemicarbazone on the Expression of Efflux Pump and Biofilm Genes in *Pseudomonas aeruginosa*. *Journal of Genetic Resources*, 9(1), 75-82.
- Molahalli, V., Shetty, A., Sharma, A., Bijapur, K., Soman, G., & Hegde, G. (2023). Risks and ethics of nanotechnology: an overview. *Nanoparticles and Plant-Microbe Interactions*, 35-68.

- More, P. R., Pandit, S., Filippis, A. D., Franci, G., Mijakovic, I., & Galdiero, M. (2023). Silver Nanoparticles: Bactericidal and Mechanistic Approach against Drug Resistant Pathogens. *Microorganisms*, 11(2), 369.
- Mosleh-Shirazi, S., Kasaei, S. R., Dehghani, F., Kamyab, H., Kirpichnikova, I., Chelliapan, S., ... & Amani, A. M. (2023). Investigation through the anticancer properties of green synthesized spinel ferrite nanoparticles in present and absent of laser photothermal effect. *Ceramics International*, 49(7), 11293-11301.
- Mukherjee, S., Malik, P., & Mukherjee, T. K. (2023). Establishment of a Cell Culture Laboratory. In *Practical Approach to Mammalian Cell and Organ Culture* (pp. 1-40). Singapore: Springer Nature Singapore.
- Mustafa, H. N., & Al-Ogaidi, I. (2023). EFFICACY OF ZINC SULFIDE-CHITOSAN NANOPARTICLES AGAINST BACTERIAL DIABETIC WOUND INFECTION. *Iraqi Journal of Agricultural Sciences*, 54(1), 1-17.
- Namiot, E. D., Sokolov, A. V., Chubarev, V. N., Tarasov, V. V., & Schiöth, H. B. (2023). Nanoparticles in Clinical Trials: Analysis of Clinical Trials, FDA Approvals and Use for COVID-19 Vaccines. *International Journal of Molecular Sciences*, 24(1), 787.
- Nanda, N. (2023). Comparative Study of Effects of Endophytic Fungal Silver Nanoparticles and Nanoemulsion on *Escherichia coli*. *Applied Biochemistry and Biotechnology*, 1-14.
- Naqvi, S. I. Z., Kausar, H., Afzal, A., Hashim, M., Mujahid, H., Javed, M., ... & Anjum, S. (2023). Antifungal Activity of Juglans-regia-Mediated Silver Nanoparticles (AgNPs) against *Aspergillus-ochraceus*-Induced Toxicity in In Vitro and In Vivo Settings. *Journal of Functional Biomaterials*, 14(4), 221.
- Nejabat, M., Samie, A., Ramezani, M., Alibolandi, M., Abnous, K., & Taghdisi, S. M. (2023). An Overview on Gold Nanorods as Versatile Nanoparticles in Cancer Therapy. *Journal of Controlled Release*, 354, 221-242.
- Nesse, L. L., Osland, A. M., & Vestby, L. K. (2023). The Role of Biofilms in the Pathogenesis of Animal Bacterial Infections. *Microorganisms*, 11(3), 608.
- Nguyen, T. T. T., Tran, N. T. K., Le, T. Q., Nguyen, T. T. A., Nguyen, L. T. M., & Van Tran, T. (2023). Passion fruit peel pectin/chitosan based antibacterial films incorporated with biosynthesized silver nanoparticles for wound healing application. *Alexandria Engineering Journal*, 69, 419-430.
- Niu, B., & Zhang, G. (2023). Effects of Different Nanoparticles on Microbes. *Microorganisms*, 11(3), 542.
- Nouri, S., Yousef-Saber, F., Emtiazi, G., & Habibi, N. (2023). Microbial synthesis of nano-selenium and nano-titanium dioxide: mechanisms of selenite respiration. *Bioinspired, Biomimetic and Nanobiomaterials*, 1-12.
- Nthunya, L. N., Mbakop, S., Makgabutlane, B., Matlou, G., Mhlanga, S., & Richards, H. (2023). Fungal synthesis of copper nanoparticles and their applications in agri-food, environmental, and biomedical sectors. In *Fungal Cell Factories for Sustainable Nanomaterials Productions and Agricultural Applications* (pp. 91-114). Elsevier.
- Ouzakar, S., Senhaji, N. S., Saidi, M. Z., El Hadri, M., El Baaboua, A., El Harsal, A., & Abrini, J. (2023). Antibacterial and antifungal activity of zinc oxide nanoparticles produced by *Phaeodactylum tricornutum* culture supernatants and their potential application to extend the shelf life of sweet cherry (*Prunus avium* L.). *Biocatalysis and Agricultural Biotechnology*, 49, 102666.
- Ozdam M, Gurkok S. Recent advances in nanoparticles as antibacterial agent. *ADMET DMPK*. 2022 Feb 2;10(2):115-129. doi: 10.5599/admet.1172. PMID: 35350114; PMCID: PMC8957245.
- Panda, B. (2023). Use of Gold Nanoparticles in the Synthesis of Heterocyclic Compounds. *Letters in Organic Chemistry*, 20(1), 18-27.

- Pandey, K., & Saha, S. (2023). Encapsulation of zero valent iron nanoparticles in biodegradable amphiphilic janus particles for groundwater remediation. *Journal of Hazardous Materials*, 445, 130501.
- Panja, A., Mishra, A. K., Dash, M., Pandey, N. K., Singh, S. K., & Kumar, B. (2022). Solid Lipid Nanoparticles: A Promising Novel Carrier. *Research Journal of Pharmacy and Technology*, 15(12), 5879-5885.
- Parkash, A. (2023). Effects of Capping Agents on Shape, Stability, and Oxygen Evolution Reaction Activity of Copper Nanoparticles. *ECS Advances*.
- Pathania, K., Sah, S. P., Salunke, D. B., Jain, M., Yadav, A. K., Yadav, V. G., & Pawar, S. V. (2023). Green synthesis of lignin-based nanoparticles as a bio-carrier for targeted delivery in cancer therapy. *International Journal of Biological Macromolecules*, 229, 684-695.
- Pawar, S., & Takke, A. (2023). Regulatory Aspects, Types, and Bioapplications of Metallic Nanoparticles: A Review. *Current Drug Delivery*.
- Perçin, I., Bayrak, G., Keleş, A. F., & Denizli, A. (2023). Antimicrobial Cryogels for Biomedical Use. In *Antimicrobials in Pharmaceutical and Medicinal Research* (pp. 1-18). CRC Press.
- Pershina, A. G., Demin, A. M., Perekucha, N. A., Brikunova, O. Y., Efimova, L. V., Nevskaya, K. V., ... & Ogorodova, L. M. (2023). Peptide ligands on the PEGylated nanoparticle surface and human serum composition are key factors for the interaction between immune cells and nanoparticles. *Colloids and Surfaces B: Biointerfaces*, 221, 112981.
- Plé, J., Dabert, M., Lecoq, H., Hellé, S., Ploux, L., & Balan, L. (2023). Antimicrobial and mechanical properties of functionalized textile by nanoarchitected photoinduced Ag@ polymer coating. *Beilstein Journal of Nanotechnology*, 14(1), 95-109.
- Popescu, V., Prodan, D., Cuc, S., Saroşi, C., Furtos, G., Moldovan, A., ... & Bomboş, D. (2023). Antimicrobial Poly (Lactic Acid)/Copper Nanocomposites for Food Packaging Materials. *Materials*, 16(4), 1415.
- Qu, L. Y., Liu, J. L., Liu, Y. Y., Zhang, G. Q., Xu, Y. J., Zhu, P., & Wang, Y. Z. (2023). Anchoring silver nanoparticles using catechol-derived resins: An efficient and versatile approach for producing durable antimicrobial fabrics. *Progress in Organic Coatings*, 176, 107397.
- Quadir, S., Khan, N., Singh, D., Faraz, A., Jhingan, G., & Joshi, M. (2023). Exposure to high dosage of gold nanoparticles accelerates growth rate in bacteria and yeast by modulating ribosomal protein expression.
- Rahman, H., Rauf, A., Khan, S. A., Ahmad, Z., Alshammari, A., Alharbi, M., ... & Suleria, H. A. R. (2023). Green Synthesis of Silver Nanoparticles Using *Rhazya stricta* Decne Extracts and Their Anti-Microbial and Anti-Oxidant Activities. *Crystals*, 13(3), 398.
- Raikwar, S., Bidla, P. D., Jain, A., & Jain, S. K. (2023). Plant polysaccharides-based nanoparticles for drug delivery. In *Plant Polysaccharides as Pharmaceutical Excipients* (pp. 195-214). Elsevier.
- Raile, P. N., Oliveira, V. D. C., Macedo, A. P., Curylofo, P. A., Marcato, P. D., Watanabe, E., ... & Pagnano, V. O. (2023). Action of chitosan- based solutions against a model four- species biofilm formed on cobalt- chromium and acrylic resin surfaces. *Gerodontology*.
- Rajeswari, V. D., Khalifa, A. S., Elfakhany, A., Badruddin, I. A., Kamangar, S., & Brindhadevi, K. (2023). Green and ecofriendly synthesis of cobalt oxide nanoparticles using *Phoenix dactylifera* L: Antimicrobial and photocatalytic activity. *Applied Nanoscience*, 13(2), 1367-1375.
- Ramin, N. A., Ramachandran, M. R., Saleh, N. M., Mat Ali, Z. M., & Asman, S. (2023). Magnetic Nanoparticles Molecularly Imprinted Polymers: A Review. *Current Nanoscience*, 19(3), 372-400.
- Ranjbar, A. G., Saleh, G. K., Azimi, M., Karimian, F., Mehrzad, J., & Zohdi, J. (2023). Superparamagnetic Iron Oxide Nanoparticles Induce Apoptosis in HT-29 Cells by

- Stimulating Oxidative Stress and Damaging DNA. *Biological Trace Element Research*, 201(3), 1163-1173.
- Rashki, S., Ghanbari, M., Khudhair, Z. H., Marzhoseyni, Z., Bameri, Z., Afsharikhah, S., ... & Salavati-Niasari, M. (2023). Evaluate the effect of graphitic carbon nitride nanosheets decorated with copper nanoparticles on biofilm and *icaA* gene expression in *Staphylococcus aureus* isolated from clinical samples. *Arabian Journal of Chemistry*, 104882.
- Ravishankar, S., Nedumaran, A. M., Gautam, A., Ng, K. W., Czarny, B., & Lim, S. (2023). Protein nanoparticle cellular fate and responses in murine macrophages. *NPG Asia Materials*, 15(1), 1-16.
- Ray, S., Yadav, J., Mishra, A., & Dasgupta, S. (2023). In-vitro antimicrobial & biocompatibility study of Spherical 52S4. 6 Submicron-Bioactive glass synthesized by Stöber Method: Effect of Ag Doping. *Journal of Sol-Gel Science and Technology*, 1-18.
- Ribeiro, A. A., & Paster, B. J. (2023). Dental caries and their microbiomes in children: what do we do now?. *Journal of Oral Microbiology*, 15(1), 2198433.
- Ribeiro, A. I., Vieira, B., Dantas, D., Silva, B., Pinto, E., Cerqueira, F., ... & Zille, A. (2023). Synergistic Antimicrobial Activity of Silver Nanoparticles with an Emergent Class of Azoimidazoles. *Pharmaceutics*, 15(3), 926.
- Rodríguez, C. H., Bueno, J. D. J. P., Pérez, A. X. M., Flores, M. R., & Oza, G. (2023). Photoelectrocatalytic activity of silicon nanowires decorated with electroless copper nanoparticles and graphene oxide using a plasma jet for removal of methyl orange under visible light. *RSC advances*, 13(16), 10621-10635.
- Rousta, N., Aslan, M., Yesilcimen Akbas, M., Ozcan, F., Sar, T., & Taherzadeh, M. J. (2023). Effects of fungal based bioactive compounds on human health. *Critical reviews in food science and nutrition*, 1-24.
- Roy, S., Hasan, I., & Guo, B. (2023). Recent advances in nanoparticle-mediated antibacterial applications. *Coordination Chemistry Reviews*, 482, 215075.
- Roychoudhury, A., & Bhowmik, R. (2023). Nanoremediation of Heavy Metals in Agricultural Soil. In *Agricultural and Environmental Nanotechnology: Novel Technologies and their Ecological Impact* (pp. 433-450). Singapore: Springer Nature Singapore.
- Rybka, M., Mazurek, Ł., & Konop, M. (2023). Beneficial Effect of Wound Dressings Containing Silver and Silver Nanoparticles in Wound Healing—From Experimental Studies to Clinical Practice. *Life*, 13(1), 69.
- Sahoo, B., Panigrahi, L. L., Jena, S., Jha, S., & Arakha, M. (2023). Oxidative stress generated due to photocatalytic activity of biosynthesized selenium nanoparticles triggers cytoplasmic leakage leading to bacterial cell death. *RSC Advances*, 13(17), 11406-11414.
- Sahu, B. K., Sharma, S., Kaur, K., Chandel, M., Sood, P., Singh, M., & Shanmugham, V. (2023). Farm waste-eggshell nanoparticles constitute gel for safe navigation of probiotic across the stomach. *Materials Today Communications*, 34, 104876.
- Saleem, F., Safdar, N., Fatima, I., Yasmin, A., & Hussain, W. (2023). Functionalization of ampicillin and gentamicin with biogenic copper nanoparticles (CuNPs) remodel antimicrobial and cytotoxic outcome against MDR clinical isolates. *Archives of Microbiology*, 205(3), 88.
- Sancak, S., Yazgan, İ., Bayarslan, A. U., Ayna, A., Evecen, S., Taşdelen, Z., ... & Çeter, T. (2023). Surface chemistry dependent toxicity of inorganic nanostructure glycoconjugates on bacterial cells and cancer cell lines. *Journal of Drug Delivery Science and Technology*, 79, 104054.
- Sanchis-Gual, R., Coronado-Puchau, M., Mallah, T., & Coronado, E. (2023). Hybrid nanostructures based on gold nanoparticles and functional coordination polymers: Chemistry, physics and applications in biomedicine, catalysis and magnetism. *Coordination Chemistry Reviews*, 480, 215025.
- Sayes, C. M., Ameh, T., Zarzosa, K., Dickinson, J., & Evan Braswell, E. W. (2023). Nanoparticle surface stabilizing agents influence antibacterial action. *Frontiers in Microbiology*, 14, 286.

- Scarabelli, L., Sun, M., Zhuo, X., Yoo, S., Millstone, J. E., Jones, M. R., & Liz-Marzán, L. M. (2023). Plate-Like Colloidal Metal Nanoparticles. *Chemical reviews*.
- Segura, A., Rodriguez, A., Hernández, P., Pesenti, H., Hernández-Montelongo, J., Arranz, A., ... & Recio-Sánchez, G. (2023). Sulfidogenic Bioreactor-Mediated Formation of ZnS Nanoparticles with Antimicrobial and Photocatalytic Activity. *Nanomaterials*, 13(5), 935.
- Seku, K., Hussaini, S. S., Reddy, M. R., Reddy, G. B., & Kumar, K. K. (2023). Fungal-mediated synthesis of gold nanoparticles and their biological applications. In *Fungal Cell Factories for Sustainable Nanomaterials Productions and Agricultural Applications* (pp. 23-58). Elsevier.
- Shabatina, T. I., Vernaya, O. I., Shimanovskiy, N. L., & Melnikov, M. Y. (2023). Metal and Metal Oxides Nanoparticles and Nanosystems in Anticancer and Antiviral Theragnostic Agents. *Pharmaceutics*, 15(4), 1181.
- Shakil, M. S., Bhuiya, M. S., Morshed, M. R., Babu, G., Niloy, M. S., Hossen, M. S., & Islam, M. A. (2023). Cobalt Ferrite Nanoparticle's Safety in Biomedical and Agricultural Applications: A Review of Recent Progress. *Current medicinal chemistry*.
- Shehabeldine, A. M., Amin, B. H., Hagrass, F. A., Ramadan, A. A., Kamel, M. R., Ahmed, M. A., ... & Salem, S. S. (2023). Potential antimicrobial and antibiofilm properties of copper oxide nanoparticles: time-kill kinetic essay and ultrastructure of pathogenic bacterial cells. *Applied Biochemistry and Biotechnology*, 195(1), 467-485.
- Shirazi, M., Qazvini, F. F., & Mohamadrezaie, S. (2023). Antimicrobial properties of glass-ionomer cement incorporated with zinc oxide nanoparticles against mutans streptococci and lactobacilli under orthodontic bands: An in vivo split-mouth study. *Dental Research Journal*, 20(1), 45.
- Shiromani, S., Patil, M. M., Nallamuthu, I., Rajamanickam, R., Singsit, D., & Anand, T. (2023). Shellac/caseinate as a composite nanocarrier for improved bioavailability of quercetin. *Food Hydrocolloids for Health*, 3, 100113.
- Siddiqui, A. J., Patel, M., Adnan, M., Jahan, S., Saxena, J., Alshahrani, M. M., ... & Ouhtit, A. (2023). Bacteriocin-Nanoconjugates (Bac10307-AgNPs) Biosynthesized from *Lactobacillus acidophilus*-Derived Bacteriocins Exhibit Enhanced and Promising Biological Activities. *Pharmaceutics*, 15(2), 403.
- Singh, N., Dkhar, D. S., Chandra, P., & Azad, U. P. (2023). Nanobiosensors Design Using 2D Materials: Implementation in Infectious and Fatal Disease Diagnosis. *Biosensors*, 13(2), 166.
- Singh, P., Ali, S. W., & Kale, R. D. (2023). Antimicrobial Nanomaterials as Advanced Coatings for Self-Sanitizing of Textile Clothing and Personal Protective Equipment. *ACS omega*, 8(9), 8159-8171.
- Singh, S. K., Mazumder, S., Vincy, A., Hiremath, N., Kumar, R., Banerjee, I., & Vankayala, R. (2023). Review of Photoresponsive Plasmonic Nanoparticles That Produce Reactive Chemical Species for Photodynamic Therapy of Cancer and Bacterial Infections. *ACS Applied Nano Materials*, 6(3), 1508-1521.
- Solanki, R., Shankar, A., Modi, U., & Patel, S. (2023). New insights from nanotechnology in SARS-CoV-2 detection, treatment strategy and prevention. *Materials Today Chemistry*, 101478.
- Song, Y., Zheng, X., Hu, J., Ma, S., Li, K., Chen, J., ... & Wang, X. (2023). Recent advances of cell membrane-coated nanoparticles for therapy of bacterial infection. *Frontiers in Microbiology*, 14, 416.
- Srividya, D., Seema, J. P., & Navya, H. M. (2023). Microbial metallonanoparticles—an alternative to traditional nanoparticle synthesis. *Environmental Applications of Microbial Nanotechnology*, 149-166.
- Summer, M., Tahir, H. M., Ali, S., Abaidullah, R., Mumtaz, S., & Nawaz, S. (2023). Bactericidal potential of different size sericin- capped silver nanoparticles synthesized by heat, light, and sonication. *Journal of Basic Microbiology*.

- Sun, L., Chen, X., Chen, R., Ji, Z., Mu, H., Liu, C., ... & Xia, L. (2023). Balancing the antibacterial and osteogenic effects of double-layer TiO₂ nanotubes loaded with silver nanoparticles for the osseointegration of implants. *Nanoscale*, 15(6), 2911-2923.
- Suthar, J. K., Vaidya, A., & Ravindran, S. (2023). Toxic implications of silver nanoparticles on the central nervous system: A systematic literature review. *Journal of Applied Toxicology*, 43(1), 4-21.
- Tabassum, N., Khan, F., Kang, M. G., Jo, D. M., Cho, K. J., & Kim, Y. M. (2023). Inhibition of Polymicrobial Biofilms of *Candida albicans*–*Staphylococcus aureus*/*Streptococcus mutans* by Fucoïdan–Gold Nanoparticles. *Marine Drugs*, 21(2), 123.
- Tahir, M. Y., Sillanpaa, M., Almutairi, T. M., Mohammed, A. A., & Ali, S. (2023). Excellent photocatalytic and antibacterial activities of bio-activated carbon decorated magnesium oxide nanoparticles. *Chemosphere*, 312, 137327.
- Tam, K. T., Thuy, N. T., Ngan, N. T. K., Khai, N. M., & Van Thanh, D. (2023). Green synthesis of Piper chaudiocanum stem extract mediated silver nanoparticles for colorimetric detection of Hg²⁺ ions and antibacterial activity. *Royal Society Open Science*, 10(2), 220819.
- Tamboli, Q. Y., Patange, S. M., Mohanta, Y. K., Sharma, R., & Zakde, K. R. (2023). Green Synthesis of Cobalt Ferrite Nanoparticles: An Emerging Material for Environmental and Biomedical Applications. *Journal of Nanomaterials*, 2023.
- Tejaswini, G., Beebi, S., Baba, G. M., Sanyasinaidu, G., & Lakshmi, K. B. (2023). *E laeocarpus Sylvestris* mediated green approach for fabrication of magnetite nanoparticles: Antimicrobial and antioxidant potentialities. *Applied Nanoscience*, 1-14.
- Thirugnanasambandan, T., & Gopinath, S. C. (2023). Laboratory to industrial scale synthesis of chitosan-based nanomaterials: A review. *Process Biochemistry*.
- THOMAS, O. E., ALABI, O. S., & OSHARODE, P. E. Characterization, antimicrobial and catalytic activities of silver nanoparticles biosynthesized using aqueous extract of *Euphorbia graminea*. *ACTA Pharmaceutica Scientia*, 61(2).
- Tohgha, U. N., Crenshaw, E. P., McConney, M. E., Lee, K. M., & Godman, N. P. (2023). Tuning of optical properties and phase behavior of Nanomaterial-stabilized blue phase liquid crystals. *Journal of Colloid and Interface Science*, 639, 401-407.
- Toyos-Rodríguez, C., Valero-Calvo, D., & de la Escosura-Muñiz, A. (2023). Advances in the screening of antimicrobial compounds using electrochemical biosensors: is there room for nanomaterials?. *Analytical and Bioanalytical Chemistry*, 415(6), 1107-1121.
- Tran, N. B., Nguyen, Q. K., Vu, T. V., Hoang, A. Q., Pham, T. D., Pham, D. T., ... & Pham, T. N. M. (2023). Polycation-stabilized PDADMAC-gold nanoparticles as a highly sensitive colorimetric sensor for the detection of the chlorpyrifos pesticide. *Colloid and Polymer Science*, 1-12.
- Tsogoo, A., Tsedev, N., Gibaud, A., Daniel, P., Kassiba, A., Fukuda, M., ... & Ganbold, E. O. (2023). Experimental and ab initio studies on the structural, magnetic, photocatalytic, and antibacterial properties of Cu-doped ZnO nanoparticles. *RSC Advances*, 13(2), 1256-1266.
- Tu, J., Hu, L., Mohammed, K. J., Le, B. N., Chen, P., Ali, E., ... & Sun, L. (2023). Application of logistic regression, support vector machine and random forest on the effects of titanium dioxide nanoparticles using macroalgae in treatment of certain risk factors associated with kidney injuries. *Environmental Research*, 220, 115167.
- Udom, G. J., Frazzoli, C., Ekhatör, O. C., Onyena, A. P., Bocca, B., & Orisakwe, O. E. (2023). Pervasiveness, bioaccumulation and subduing environmental health challenges posed by polycyclic aromatic hydrocarbons (PAHs): A systematic review to settle a one health strategy in Niger Delta, Nigeria. *Environmental Research*, 115620.
- Uzochukwu, I., Moyes, D., Proctor, G., & Ide, M. (2023). The key players of dysbiosis in Noma disease; A systematic review of etiological studies. *Frontiers in Oral Health*, 4, 10.

- Valian, A., Goudarzi, H., Nasiri, M. J., Roshanaei, A., & Sadeghi Mahounak, F. (2023). Antibacterial and Anti-biofilm Effects of Chitosan Nanoparticles on Streptococcus Mutans Isolates. *Journal of Iranian Medical Council*, 6(2), 292-298.
- Wang, T., Fleming, E., & Luo, Y. (2023). An overview of the biochemistry, synthesis, modification, and evaluation of mucoadhesive polymeric nanoparticles for oral delivery of bioactive compounds. *Advanced Composites and Hybrid Materials*, 6(1), 6.
- Wang, Z., Zhang, L., & Wang, X. (2023). Molecular toxicity and defense mechanisms induced by silver nanoparticles in *Drosophila melanogaster*. *Journal of Environmental Sciences*, 125, 616-629.
- Wasan, H., Singh, D., Reeta, K. H., & Gupta, Y. K. (2023). Landscape of Push Funding in Antibiotic Research: Current Status and Way Forward. *Biology*, 12(1), 101.
- Wojtaszek, K., Cebula, F., Rutkowski, B., Wytrwal, M., Csapó, E., & Wojnicki, M. (2023). Synthesis and Catalytic Study of NiAg Bimetallic Core-Shell Nanoparticles. *Materials*, 16(2), 659.
- Wouters, R. D., Muraro, P. C. L., Druzian, D. M., Viana, A. R., de Oliveira Pinto, E., da Silva, J. K. L., ... & da Silva, W. L. (2023). Zinc oxide nanoparticles: Biosynthesis, characterization, biological activity and photocatalytic degradation for tartrazine yellow dye. *Journal of Molecular Liquids*, 371, 121090.
- Wu, Y., Zhang, N., Yuen, G., & de Lannoy, C. F. (2023). Cross-linked iron nanoparticle-doped reduced graphene oxide membranes for micropollutant removal from water. *Chemical Engineering Journal*, 455, 140624.
- Wu, Z., Li, W., Cheng, S., Liu, J., & Wang, S. (2023). Novel fabrication of bioengineered injectable chitosan hydrogel loaded with conductive nanoparticles to improve therapeutic potential of mesenchymal stem cells in functional recovery after ischemic myocardial infarction. *Nanomedicine: Nanotechnology, Biology and Medicine*, 47, 102616.
- Xavier, J. R. (2023). Influence of surface modified mixed metal oxide nanoparticles on the electrochemical and mechanical properties of polyurethane matrix. *Frontiers of Chemical Science and Engineering*, 17(1), 1-14.
- Xing, Y., Fan, X., Li, X., Xu, Q., Tang, J., Wu, L., ... & Liu, X. (2023). Green synthesized TiO₂ nanoparticles: Structural characterization and photoinduced antifungal activity against *P. steckii*. *Journal of Food Science*, 88(1), 328-340.
- Xiong, Z., Zhang, N., Xu, L., Deng, Z., Limwachiranon, J., Guo, Y., ... & Scharf, D. H. (2023). Urease of *Aspergillus fumigatus* Is Required for Survival in Macrophages and Virulence. *Microbiology Spectrum*, 11(2), e03508-22.
- Xu, Y., Du, H., Wang, C., Yue, L., Chen, F., & Wang, Z. (2023). CeO₂ Nanoparticles-Regulated Plasmid Uptake and Bioavailability for Reducing Transformation of Extracellular Antibiotic Resistance Genes. *Nanomaterials*, 13(6), 969.
- Xue, M., Hou, X., Fu, J., Zhang, J., Wang, J., Zhao, Z., ... & Zhou, L. (2023). Recent advances in search of bioactive secondary metabolites from fungi triggered by chemical epigenetic modifiers. *Journal of Fungi*, 9(2), 172.
- Yang, J., Ju, P., Dong, X., Duan, J., Xiao, H., Tang, X., ... & Hou, B. (2023). Green synthesis of functional metallic nanoparticles by dissimilatory metal-reducing bacteria "Shewanella": A comprehensive review. *Journal of Materials Science & Technology*.
- Yang, Y., Hu, T., Bian, Y., Meng, F., Yu, S., Li, H., ... & Liang, R. (2023). Coupling probiotics with 2D CoCuMo- LDH nanosheets as tumor microenvironment- responsive platform for precise NIR- II photodynamic therapy. *Advanced Materials*, 2211205.
- Yavuz, E., Dursun, S., Kara, M., & Dinc, S. (2023). Role of metal nanoparticles for treatment of and prevention of viral infections. In *Smart Nanomaterials to Combat the Spread of Viral Infections* (pp. 97-123). Academic Press.
- Ye, J., & Chen, X. (2023). Current Promising Strategies against Antibiotic-Resistant Bacterial Infections. *Antibiotics*, 12(1), 67.

- Yefimova, S., Klochkov, V., Kavok, N., Tkachenko, A., Onishchenko, A., Chumachenko, T., ... & Ocakoglu, K. (2023). Antimicrobial activity and cytotoxicity study of cerium oxide nanoparticles with two different sizes. *Journal of Biomedical Materials Research Part B: Applied Biomaterials*, 111(4), 872-880.
- Yin, A. Y., Xu, J., Yang, C. S., & Hsu, S. H. (2023). Antiviral and Antibacterial Sulfated Polysaccharide–Chitosan Nanocomposite Particles as a Drug Carrier. *Molecules*, 28(5), 2105.
- Younas, M., Rasool, M. H., Khurshid, M., Khan, A., Nawaz, M. Z., Ahmad, I., & Lakhan, M. N. (2023). Moringa oleifera leaf extract mediated green synthesis of silver nanoparticles and their antibacterial effect against selected gram-negative strains. *Biochemical Systematics and Ecology*, 107, 104605.
- Yu, Y. B., Liu, Y., Liang, H., Dong, X., Yang, X. Y., Li, S., & Guo, Z. (2023). A Nanoparticle-Based Anticaries Vaccine Enhances the Persistent Immune Response To Inhibit Streptococcus mutans and Prevent Caries. *Microbiology Spectrum*, e04328-22.
- Yuan, L., Chen, Q., Riviere, J. E., & Lin, Z. (2023). Pharmacokinetics and tumor delivery of nanoparticles. *Journal of Drug Delivery Science and Technology*, 104404.
- Zhang, H., Shi, K., Liu, J., & Xie, G. (2023). One-step preparation of titanium sharkskin bionic antibacterial surface. *Ceramics International*, 49(8), 11950-11959.
- Zhang, J., Sun, B., Zhang, M., Su, Y., Xu, W., Sun, Y., ... & Wu, F. (2023). Modulating the local coordination environment of cobalt single-atomic nanozymes for enhanced catalytic therapy against bacteria. *Acta Biomaterialia*.
- Zhang, L., Zhang, Y., Jiang, X., Mao, L., Xia, Y., Fan, Y., ... & Chen, C. (2023). Disruption of the lung-gut-brain axis is responsible for cortex damage induced by pulmonary exposure to zinc oxide nanoparticles. *Toxicology*, 485, 153390.
- Zhang, T., Li, L., Chunta, S., Wu, W., Chen, Z., & Lu, Y. (2023). Enhanced oral bioavailability from food protein nanoparticles: A mini review. *Journal of Controlled Release*, 354, 146-154.
- Zhang, W., Taheri-Ledari, R., Ganjali, F., Mirmohammadi, S. S., Qazi, F. S., Saeidirad, M., ... & Maleki, A. (2023). Effects of morphology and size of nanoscale drug carriers on cellular uptake and internalization process: a review. *RSC advances*, 13(1), 80-114.
- Zhao, L., Wang, S., Ilves, M., Lehtonen, S., Saikko, L., El-Nezami, H., ... & Karisola, P. (2023). Transcriptomic Profiling the Effects of Airway Exposure of Zinc Oxide and Silver Nanoparticles in Mouse Lungs. *International Journal of Molecular Sciences*, 24(6), 5183.
- Zhu, G., Li, Z., Zhang, Y., Meng, X., Guan, M., Hu, Z., ... & Sun, T. (2023). Biosafety risk assessment of gold and aluminum nanoparticles in tumor-bearing mice. *APL bioengineering*, 7(1), 016116.
- Zou, D., Wu, Z., Yi, X., Hui, Y., Yang, G., Liu, Y., ... & Zhao, C. X. (2023). Nanoparticle elasticity regulates the formation of cell membrane-coated nanoparticles and their nano-bio interactions. *Proceedings of the National Academy of Sciences*, 120(1), e2214757120.