Chapter

# Antibacterial, Antifungal and Antiviral Nanocomposites: Recent Advances and Mechanisms of Action

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## Abstract

Over the past ten years, there has been a significant increase in research into the study of nanocomposites. Nanocomposites vary in their physical and chemical properties. In today's era, eco-friendly, nontoxic, biocompatible, biobased fillers and composites should be synthesized to increase their societal value in various aspects. These materials have seen extensive use across several industries, from biosensors to biomedicine. Great strides have been made in the field of Microbiology, particularly as Antibacterial agents, among these applications. The objective of this review is to present a thorough analysis of several Nanocomposites that reveal promising antibacterial activity. Such Nanocomposites are reviewed in detail, as well as their antibacterial efficacy is discussed.

**Keywords:** antibacterial activities, antifungal activities, antiviral activities, nanocomposites

## 1. Introduction

A composite material is referred to as a nanocomposites when it contains a phase with nanoscale morphology, such as nanoparticles, nanotubes, or lamellar nanostructure. As a result of their numerous phases, they qualify as multiphase materials, and at least one of those phases must have a diameter between 10 and 100 nm. In order to get beyond the limits of present engineering materials, nanocomposites have developed as suitable substitutes. Nanocomposites may be categorized based on their dispersed matrix and dispersed phase materials [1]. Thanks to this rapidly emerging field, it is now possible to generate a wide range of exciting new materials with distinctive properties.

The interfacial and morphological features of the originals, together with their own characteristics, had a significant impact on the so-called found's characteristics. It is evident that, parent component parts are unaware of the newly created feature in the composite material and this intricate structure enhances its applicability [2, 3]. In order to create new materials with amazing flexibility and an increase in their physical properties, nanocomposites are based on the idea of employing building pieces that have dimensions in the nano scale range. Nanocomposites are made up of a bulk matrix and one or more nano dimensional phase(s) that differ from one another in terms of their chemical and structural makeup and properties. Inorganic nanoclusters, fullerenes, clays, and biological molecules can be mixed with a range of organic polymers, organic and organometallic chemicals, biological molecules, enzymes, and sol-gel produced polymers. Inorganic nanoclusters, fullerenes, clays, metals, oxides, or semiconductors can be mixed with a range of organic polymers, organic and organometallic chemicals, biological molecules, enzymes, and sol-gel produced polymers to produce nanocomposites.

## 2. Nanocomposites that reveal promising antibacterial activity

Antimicrobially active products are a recent development in nanoparticle-based materials that have gained significant attention. It has been documented that nanoscaled materials, such as fabrics, plastics, and metals coated with nano-silver, as well as nanocomponents based on titanium dioxide, magnesium oxide, copper, copper oxide, zinc oxide, cadmium selenide/telluride, chitosan, and carbon nanotubes, possess biocidal or bacteriostatic properties [4]. Both gram-positive and gram-negative bacteria, including *Escherichia coli* and *Pseudomonas aeruginosa*, have demonstrated the antibacterial activity of nanosized metal compounds. These bacteria include *Staphylococcus aureus* and *Bacillus subtilis*. The most frequently used antibacterial agents are nanomaterials with a silver base [5]. The antibacterial properties of metallic, ionic, and nanoscale silver compounds added to alumina nanopowder were described. However, gram-positive and gram-negative bacteria differ in their sensitivity to silver-doped nanocrystalline material [6].

Antimicrobially effective nanomaterials exist in the form of salts, oxides, complexes, and elemental nanoparticles. Because of their small size, chemical toxicity, and distinctive shape, they are effective at damaging cell membranes. Cell membrane surface loading and permeability may be disturbed as a result of nanoparticles' detrimental effects. Probably the most frequent method by which nanoparticles affect bacteria is through the production of reactive oxygen species (ROS) [7]. On "model" bacterial strains like *E. coli*, newly developed or modified nanoparticles' antimicrobial properties are typically tested. An assay for turbidity, a microdilution method, and the disc diffusion method are the main procedures. The antimicrobial activity of some industrial products was tested using a number of ISO regulations, such as ISO 20743 for textile products and ISO 22196 for plastics and other non-porous materials [8].

In tests with *E. coli*, *P. aeruginosa*, S. aureus, and *B. subtilis*, a potential wound healing nano-based material composed of genipin-crosslinked chitosan, poly (ethylene glycol), zinc oxide, and silver produced significant antibacterial activity [9]. With the addition of silver nanoparticles to hydrogels, researchers successfully achieved a significant antimicrobial impact for chitosan films, making them potentially useful in wound dressings as well [10]. The antimicrobial effect of the combination of silver nitrate and titanium dioxide nanoparticles applied to facemasks was described [11]. After 48 hours of testing, they noticed a 100% decrease in viable *E. coli* cells. The magnetic nanocomposite film created after dispersing magnetic nano—$Fe_2O_3$ in a chitosan matrix has potential uses in biosensors and tissue [12].

The use of highly toxic chemical reagents in the production of nanoparticles for medical applications should be avoided, especially when using materials containing silver (Ag). As a result, a "green synthesis approach" is taken into account. For instance, aqueous solutions of $AgNO_3$, glucose, and starch can be used to produce starch-protected Ag nanoparticles. Using these solutions, the reduction of Ag $(NH_3)^{2+}$ by carbohydrates results in the production of nano-Ag films (50–200 nm), Ag hydrosols (20–50 nm), and Ag colloids. Can also be used to reduce Ag $(NH_3)^{2+}$. In tests with *E. coli*, *P. aeruginosa, S. aureus*, and *B. subtilis*, a nano-based substance with the potential to treat wounds and containing genipin-crosslinked chitosan, poly (ethylene glycol), zinc oxide, and silver, demonstrated antibacterial activity [13].

Since chitosan nanoproducts have been shown to have potential antimicrobial properties, many medical applications of nanoproducts (chitosan-carbon dots, chitosan-i-cysteine quantum dots, chitosan-based biosensors and biomarkers) [14] are based on these materials. Chitosan-poly(N-vinylpyrrolidone)-$TiO_2$ Nanocomposite was proposed as a wound dressing material due to its significant antibacterial impact against *P. aeruginosa*, *E. coli*, S. aureus, and *B. subtilis*. In this study, the titanium dioxide nanocomponent was suggested to be responsible for the adsorption of bacteria and their inactivation [15].

By combining chitosan and 4-(ethoxycarbonyl) phenyl-1-amino-oxobutanoic acid with nano-Ag, Srivastava et al., 2011. created a nanocomposite. The effect of the obtained nano-film on bacteria like *S. aureus*, *E. coli*, and *P. aeruginosa* led to its proposal as a material for use in medicine [16]. Numerous medical applications benefit from the antibacterial properties of nanoparticle-based materials, including implants, wound and burn dressings, medical devices, filters, and dental plaque reduction materials. One of the most crucial justifications for the application of novel nanocomposites for clinical use is their potential impact on antibiotic-resistant bacteria, which pose a serious problem in current medical settings. In textile modification and impregnation, as well as "construction" elements for implants, cements, and resins, in the antibacterial coatings of external ventricular drains and venous catheters that lessen the risk of potential infections, nanocomposites can be used [4].

The most promising areas of nanotechnology applications are in the development of new antibacterial agents. Nanocluster engineering can broaden the application of Ag- and Au-based antimicrobial preparations. The commercial application of nanoproducts should also be carefully monitored because of their potential negative environmental effects. The use of Au, Ag, and Cu-based nanoclusters in medicine and biosensing is widespread. According to Zheng et al., 2016 the generation of ROS is the mechanism that most likely causes pathogenic bacteria to be destroyed in the presence of Ag-nanoclusters, whereas the core surface speciation of the nanoclusters may be related to their cellular toxicity. Due to the significantly higher surface-to-volume ratio they can achieve due to their ultra small size and interaction with intracellular components, they have a stronger antibacterial effect. It's possible that adding Ag nanoclusters to medications will enhance their therapeutic effects. In the presence of combined daptomycin-Ag nanoclusters, damage to microbial DNA was noted [17]. The nucleation and growth mechanism of Thiolate-protected Au nanoclusters with different topologies within the inner core of various clusters were described [18].

The development of polypyrrole-based nanocomposites as alternative antibacterial agents also represents a promising strategy to be applied against the prevailing multi-resistant bacteria. The composites are made up of different fillers (metal nanoparticles, carbon nanotubes, and polysaccharides) and strategies to improve their action (such as light and electrical stimulation) [19]. Graphene oxide–silver (Ag–GO) nanocomposite has emerged as a vital antibacterial agent very recently. It was successfully applied to *E. coli* to investigate antibacterial activity by varying its dose concentration. The functional groups of GO facilitated the binding of Ag nanoparticles to silver nanoparticles. The antibacterial properties of GO-Ag nanocomposite were studied using gram-negative *E. coli* ATCC 25922 and gram-positive *S. aureus* ATCC 6538 and showed excellent antibacterial activity. In this study, results demonstrated that GO-Ag nanocomposite, as a kind of antibacterial material, had great promise for application in a wide range of biomedical applications [20].

The $Cu_2O$-GO nanocomposites have rarely been studied before. The $Cu_2O$-GO nanocomposites show potent antibacterial activities against both *E. coli* and *S. aureus*. Bactericidal activity was also observed for the Cu based bionanocomposite samples against both gram-positive (*S. aureus*) and gram-negative (*Klebsiella pneumoniae*) bacteria. Enhancement of antibacterial activity was observed with increasing copper content in nanocomposites. Results confirm the potential of bionanocomposites containing copper nanostructures as new antimicrobial materials [21].

Cellulose/Ag nanocomposites were prepared using two distinct methodologies and two different cellulose substrates: vegetable and bacterial cellulose. Detailed studies on their antibacterial activity were conducted on *B. subtilis*, *S. aureus*, and *K. pneumoniae*. Silver nanoparticles present in these cellulosic fibers in concentrations as low as 5.0 wt% make them effective antibacterial materials [22].

The antibacterial activity of AuNPs-COOH/$AgNO_3$, $MnFe_2O_4$@$SiO_2$@Au and $Bi_2S_3$ nanocomposites against a wide range of gram-negative bacteria has been demonstrated. Green synthesis methods were applied and showed good activity against some gram-negative bacterial strains. A photocatalytic system comprising TNTs/Au/CDs was developed for a bactericidal approach. An Ag–Au/$CeO_2$ nanostructure was produced with a maximum zone of inhibition against *S. aureus* and *E. coli* strains. The produced nanohybrid showed acceptable antibacterial activity and was applicable for marine antifouling paint and sewage treatment. Au@$TiO_2$-NT was light-independent and applicable to the dark environment inside tissues, such as for orthopedic devices and implants [23, 24].

Nanocomposites and a composite based on poly (butylene adipate-co-terephthalate) were synthesized using commercial copper nanoparticles. The materials showed good inhibitory responses against the nonresistant strains *Enterococcus faecalis*, *Streptococcus mutans*, and *S. aureus*. They had the highest biocidal effect, even against resistant bacteria like *Acinetobacter baumannii* [25].

Magnetic cores loaded with metallic nanoparticles can be promising nano-carriers for successful drug delivery at infectious sites. The cobalt acetate was synthesized, and the decoration of AgNPs was carried out with silver acetate. The antibacterial performance of nanocomposites against *E. coli* and *B. subtilis* was found to be density-dependent. Silver nanocomposites exhibiting antiviral, antifungal, antibacterial, antiangiogenic, and antiinflammatory activities are discussed as potential candidates for several biomedical applications due to their ability to bind with the biomolecules of microbial cells [26].

In brief, the antibacterial GN/Ni $(OH)_2$ composite has been prepared using a facile method, providing powerful antibacterial capacity, good biocompatibility, and long-term effectiveness. The antibacterial activity of GN/Ni $(OH)_2$ was dose dependent and obviously exceeded that of rGO and GO. The GN/$Ni(OH)_2$ could efficiently kill gram-negative or positive bacteria with a low dose and exert low toxicity toward normal cells, motivating their potential safe applications. The results revealed that the improved 3D contact between GN/$Ni(OH)_2$ and bacteria enhanced the physical punctures on cells, causing severe leakage of intracellular components and leading to cell apoptosis. The GN/$Ni(OH)_2$ could not induce a remarkable increase in ROS

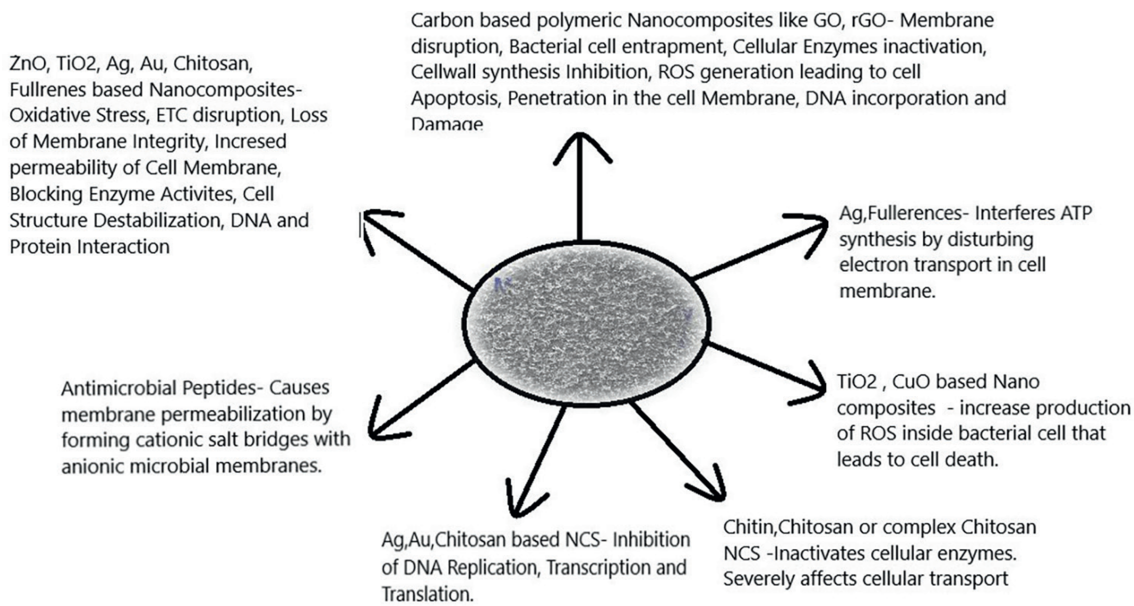


**Figure 1.**
*Various modes of antibacterial and antifungal activities of different nanocomposites.*

production, indicating that the ROS-dependent oxidative stress induced by GN/ $Ni(OH)_2$ will not affect antibacterial efficiency [27]. Nanocomposites that reveal various modes of antimicrobial Activities were enlisted in **Figure 1**.

## 3. Nanocomposites that reveal promising antifungal activity

Growing worldwide populations as a result of medical developments make more patients vulnerable to superficial and serious fungal infections. Dermatophytes like *Microsporum*, *Epidermophtyon*, and *Trichophyton*, as well as species from the genera *Candida*, *Aspergillosis*, and *Cryptococcus*, are among the fungi that are frequently linked to these disorders. Additionally, as the world's population rises, so do agricultural needs. Therefore, owing to food insecurity, fungal infections of preharvested crops and stored food by plant diseases such as *Magnaporthe oryzae* and *Fusarium oxysporum* might have negative socioeconomic impacts. The majority of current antifungal treatment plans are based on small molecule antifungal medications. Poor solubility and bioavailability, however, place restrictions on these medications. Additionally, there is an increase in antifungal resistance to these medications. A significant worldwide healthcare concern is the effect of fungal illnesses and the development of antimicrobial drugs against pathogenic fungus. Silver-loaded hydroxyapatite (Ag/HAP) nanocomposites (NCs) with varying Ag contents were tested against susceptible and resistant *Candida species* for their antifungal efficacy. *Candida krusei* had the inhibitory impact, followed by *Candida parapsilosis sensu stricto* and *Candida tropicalis* [28].

Antimicrobial polymers thus provide a different approach to combat fungi. The cationic regions of antifungal polymers have been reported to react with microbial phospholipids and membranes, and the hydrophobic areas are known to repel water. Such synthetic or natural polymers exhibit various antifungal activities, like fungal cell membrane permeabilization or fungal cell membrane depolarization. It might be challenging to determine their relative importance as Antifungal candidates. Due to these polymers' chemical structure, they can be coupled to provide synergistic effects with other antimicrobial substances such as metal ions, charcoal, lipids, and current antifungal medications. In certain instances, antifungal nanocomposites and polymers surpass typical small molecule antifungal drugs in terms of antifungal efficacy or toxicity [29, 30].

Cationic antimicrobial polymers and nanocomposites with antifungal activity as well as the state of knowledge on the antifungal mode of action were studied. The innate immune response includes antimicrobial peptides (AMPs), sometimes referred to as host defense peptides. The host is shielded against encroaching diseases by these substances, which are generated by plants, animals, and microbes. These peptides have short, amphiphilic sequences with an average length of 100 amino acids. The majority of AMPs are cationic, but those with high levels of histidine have powerful antifungal properties. Cathelicidins are an illustration of this. The primary storage location for this class of antifungal AMPs in macrophages is the lysosome, which is a component of the human innate immune system. However, certain AMPs with anionic charges need metal ions to be activated biologically. For membrane permeabilization, anionic AMPs bind metal ions to create cationic salt bridges with anionic microbial membranes. Even though certain anionic AMPs are credited with this mechanism, less is known about their antibacterial action than with cationic AMPs [31, 32].

In order to study the antifungal efficacy of these peptides against *Candida albicans*, Ramamourthy et al. (2020) synthesized peptides with various numbers of lysine and tryptophan repetitions (KWn-$NH_2$). The antifungal and biofilm-eradication abilities of these peptides increase with peptide length, with the longest peptide, KW5, exhibiting toxicity in a human keratinocyte cell line, while the smallest peptide, KW2, showed no antifungal activity by Ramamourthy et al., 2020. The membranes of fungus cells were not damaged by the KW4 peptide. However, KW4 was shown to be linked to fungal RNA in the cytoplasm of *C. albicans*, as revealed by laser-scanning Confocal Microscopy. This indicates that not all of these peptides antifungal mechanisms include membrane permeabilization. Instead, these synthetic AMPs localize within the cell where they disrupt cellular activities by attaching to specific receptors after entering fungal cells [33].

Despite synthetic AMPs showing broad-spectrum antifungal activity and low toxicity, research into antimicrobial polymers is often focused on synthetic polymers as they are considerably cheaper to produce in comparison and share functional cationic similarities with AMPs. Polyhexamethylene biguanide (PHMB) is a synthetic quarternary ammonium polymer which has been established to be an effective antimicrobial agent with the added advantages of low toxicity. It exhibits a high therapeutic index and broad-spectrum antifungal activity due to its biguanide groups and is commonly used as a preservative in cosmetics, water purification systems, and contact lens cleaning solutions. It is also used clinically for wound cleaning, where it shows excellent biocompatibility. Although PHMB shows membrane disruption abilities due to its phospholipid binding, the exact antifungal mechanism of action remains unclear. The antifungal mechanism is thought to involve cell wall destabilization and membrane permeabilization. Gene expression studies in *Saccharomyces cerevisiae* indicated an increase in the expression of cell wall integrity genes and protein kinase C, which regulates cell maintenance. This suggests PHMB also damages the β-glucan structure of the *S. cerevisiae* cell wall [34].

Polyethylenimines (PEI) are amine-containing polymers with a two-carbon ($CH_2CH_2$) spacer. At room temperature, they can be found in branched and linear polymeric forms in various states. They have been widely used in in vitro transfections and drug delivery. Such study has demonstrated depolarization of *C. albicans* membranes for its inactivation, though the precise antifungal mechanism is unknown [35, 36].

HTCC, a chitosan derivative used as a preservative in the cosmetics industry, is an antimicrobial polymer. In a study by Hoque et al. 2016, HTCC was shown to have strong antifungal activity (MIC = 125,250 g/ml), with killing occurring in just two hours. It targets the fungal cell membrane, increasing membrane permeability, similarly to chitosan, and exhibits extremely low toxicity ($HC_{50}$ = > 100 g/ml) in a mouse model [37, 38].

Polymethacrylates (PMMA) is a polymer made of methacrylic acid esters. It is used as a wrinkle filler in cosmetics and as an intraocular lens in ophthalmology. Because it is used in medical devices, it is susceptible to microbial colonization by pathogens like *C. albicans*. Undecylenic acid (UA), a monounsaturated lipid with established antifungal activity at various UA concentrations (3–12%), changed the surface of PMMA by making it more hydrophilic. At UA concentrations of 6%, *C. albicans* exposed to these PMMA-UA composites exhibited decreased attachment, growth, and increased death of these fungal cells. Despite the fact that UA concentrations of 9% showed a 95% eradication of *C. albicans*, these composites were extremely toxic to human cells, with a 50% reduction in viability [39].

Antimicrobial metal nanoparticles (NPs) are used more frequently than antimicrobial drugs because they reduce the risk of antimicrobial resistance. They do, however, have a toxic reputation. They can be incorporated into biomaterials like proteins, peptides, and sugars to increase biocompatibility. The Ag-Au alloy nanoparticles (Ag-AuNPs) with potential broad-spectrum uses, such as a coating material for medical devices or for drug delivery, were created using a green synthesis approach [7].

The concentration of Ag used in the synthesis of NPs determines its size and shape. Due to the silver ions, these nanocomposites effectively combatted *C. albicans*. The Ag-Au alloy nanoparticles, however, displayed improved performance. Due to its broad-spectrum antibacterial activity and low toxicity toward mammalian cells, cotton is the most commonly used natural fiber for textiles today. Silver nanoparticles have recently been added to it [40].

Likewise functionalized fabric treated with a nanocomposite made of silver nanoparticles and carboxymethyl chitosan had excellent antifungal and antibacterial properties against *C. albicans* and *Aspergillus niger* (AgNPs-CMC). This fabric was functionalized to demonstrate how this fabric could be used to make hospital clothing to lower nosocomial infections. In this research, reported synthesis of silver-incorporated Chitosan nanocomposites (Ag@CS), CS was used as a reducing and stabilizing agent. The fungicide Antracol (An) was then combined with Ag@CS/An to effectively combat *Phytophthora capsici*. Researchers discovered that Ag@CS/An was found to have significantly stronger and synergistic antifungal ability than Ag@CS nanocomposites or Antracol nanocomposites, which had diameters upto 44.6 nm [41]. The $TiO_2$-NPs, in particular, are also effective as antimicrobial agents due to their high aspect ratio, large surface-to-volume ratio, and reactivity [42].

Nanomaterials made upof metals or metal oxides are produced using living things or their components. AgNPs against *Candida glabrata* were made in spherical or rod shapes with crystal structures made of 80% anatase and 20% rutile. Under spherical AgNPs (with a diameter range of 1–24 nm) produced by a filtrated suspension of *Aspergillus sydowii* fungi, *C. glabrata* has demonstrated a minimum inhibitory concentration of 0.125 ppm [43]. Additionally, a hydrothermal technique was used to decorate $TiO_2$@ZnO nanocomposites with AuNPs that shown antifungal activity against *C. albicans* (MTCC 282) and an antiproteinase activity [44].

Hesperidin, a flavanone disaccharide extracted from orange peel, was used to make ZnONPs, which demonstrated notable antiviral activity against the *Hepatitis A* virus and *Respiratory Syndrome CoronaVirus* 2 (SARS-CoV-2). They also displayed activity that was suitable for treating HIV infection (50% inhibition at 100 ppm) [45].

Seven novel silver chromite nanocomposites were synthesized and assayed to evaluate their antimicrobial, antiviral, and cytotoxic activities. Five bacterial species were used in this study: three gram-positive (*B. subtilis*, *Micrococcus luteus*, and *S. aureus*) and two gram-negative (*E. coli*, and *Salmonella enterica*). Three fungal species were also tested: *C. albicans*, *A. niger*, and *Aspergillus flavus*. The MIC of the tested compounds was determined using the bifold serial dilution method. These tested compounds could be attractive and alternative antibacterial compounds that open a new path in chemotherapy [46].

A sustainable and green method was used to prepare silver nanoparticles (Ag-NPs), followed by their incorporation into a tertiary nanocomposite consisting of starch, oxidized cellulose, and ethyl cellulose. Ag-NC significantly suppressed the growth of tested bacterial strains (*E. coli, P. aeruginosa, S. aureus,* and *B. subtilis*) as compared with controls. It has also exhibited antiviral effects against *Herpes Simplex Virus*, *Adenovirus* and *Coxsackie B Virus* in a dose-dependent manner. In conclusion, the prepared tertiary Ag-NCs had promising antibacterial, antifungal, as well as antiviral activities [7, 40].

Binary $TiO_2$/AgBr nanocomposites were synthesized using a facile ultrasonic irradiation route and characterized by various instruments. After adding AgBr nanoparticles, the antifungal activity was markedly enhanced. Silver ions in AgBr have a broad antimicrobial spectrum and can inhibit the growth of fungi. A sample with 20% of silver bromide represented the highest inhibitory concentration for the mycelial growth of *F. graminearum* and *S. sclerotiorum*. The inactivation rate decreased with increasing ultrasound irradiation time [47].

The negative effects of various biotic and/or biotic stresses on plants may be mitigated by silicon and its nanomaterials. For regulating the growth parameters and yield of *faba beans* infected with *Botrytis cinerea*, the antifungal role of silver/silicon dioxide nanocomposite (Ag/$SiO_2$NC) biosynthesized using a free-cell supernatant of *E. coli* was examined. In vitro tests revealed significant in vitro activity with a minimal inhibitory concentration (MIC) of 40 ppm. These are all encouraging findings for the use of the biosynthesized Ag/$SiO_2$NC as a secure and efficient antifungal agent against *B. cinerea* [48].

Nanocomposites that reveal various modes of antimicrobial inhibition enlisted in **Figure 1**.

## 4. Nanocomposites that reveal promising antiviral activity

The most recent research on viruses-designed coating materials as well as potential nanocoatings to stop the spread of the contagious SARS-COV-2 virus in response to the global health outbreak was well explored. Due to viral adhesion/colonization, subsequent proliferation, and biofilm formation, the exposed surfaces are contaminated. Hence, surface contamination possibly removed using the traditional disinfecting cleaning method, but studies shown that disinfecting only offers a momentary relief. The field of antiviral coating has seen some promising work, but more study is undoubtedly needed. In the creation of antiviral coatings, it is thought that nanomaterials like metal oxide nanostructures, Graphene, Carbon Nano Tube, Carbon quantum dots, Titanium dioxide, bio-based nanoparticles like chitosan, capped silver, Graphene, Gold and Silicon nanoparticles could play a key role [49, 50].

A team of researchers has shown that surface-adsorbed viruses can be effectively removed from surfaces using nanoparticles. The antiviral effect, which most likely results from a "contact killing mechanism," is highly dependent on the type of polymer and the affinity of the nanoparticles for the polymer. In this regard surface coatings made of nanocomposite materials with a polymer matrix and Cu/CuO nanoparticles synthesized and shown that surface-adsorbed viruses could be effectively removed [51].

Numerous viruses can survive and maintain their infectiousness on plastics for several days when exposed to ambient conditions. Measuring the persistence of various virus types on frequently used composite materials, like carbon-epoxy and glass-polyester laminates, is necessary. The polymer composites community has received a clear message from the SARS-CoV-2 global pandemic that there are opportunities for next-generation materials with virus-resistant surfaces [52].

Polymer Nano-Composites (PNC), such as polysaccharides nanocomposites, may play a significant role in the development of an antiviral drug for Covid-19. PNC could manage the health system, reduce lockdown times, and reduce social isolation while also saving money and energy [53].

The unique structure of graphene oxide sheets could contribute to the inhibition of infection by feline coronavirus with a lipid envelope. GO sheets with silver particles exhibited antiviral activity against both enveloped viruses and non-enveloped viruses. Negatively charged GO can absorb positively charged lipid membranes and induce rupture of membranes. The interactions between GO and the membrane can attract the absorption of more lipid membranes [54].

This study, proposed a blocking strategy against model respiratory viruses, severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) pseudovirus and porcine reproductive and respiratory syndrome virus (PRRSV) (PRRSV and SARS-CoV-2) infection by heparan sulfate analogue-modified two-dimensional (2D) transition metal carbides (MXenes) nanocomposites. The functional 2D nanocomposites with excellent physicochemical properties and abundant heparin analogue (MPS) demonstrated several unique advantages for antiviral research. Firstly, the $Ti_3C_2$-Au-MPS nanocomposites with a relatively uniform particle size and excellent biocompatibility can be synthesized in a facile method. Secondly, $Ti_3C_2$-Au-MPS nanocomposites can block PRRSV infection by inactivating PRRS virions in vitro and inhibiting its adsorption and invasion in host cells. Thirdly, Ti3C2-Au MPS nanocomposites have a potent inhibitory effect on SARS-CoV-2 infection, suggesting that these materials have broadspectrum antiviral activity against PRRSV and SARS-CoV-2 [55].

According to a study, aqueous medium was used to create Ag NP/Chitosan composites with antiviral activity against the Influenza A virus. Unreacted Ag NPs were not found in the composites, which were obtained as yellow or brown flocs. The experimental results demonstrate that virions and composites interacted. The synthesis methods control the antiviral and cytotoxic properties of the silver nanoparticle or nanocomposite by modifying its size, shape, morphology, and surface charge. As discussed in this work, biological approaches have emerged as a result of the shortcomings of physical and chemical approaches [56].

Antibacterial, antifungal, and antiviral properties of ZnO NPs and Activated Carbon nanoparticles were synthesized. On the human WI38 cell line, their

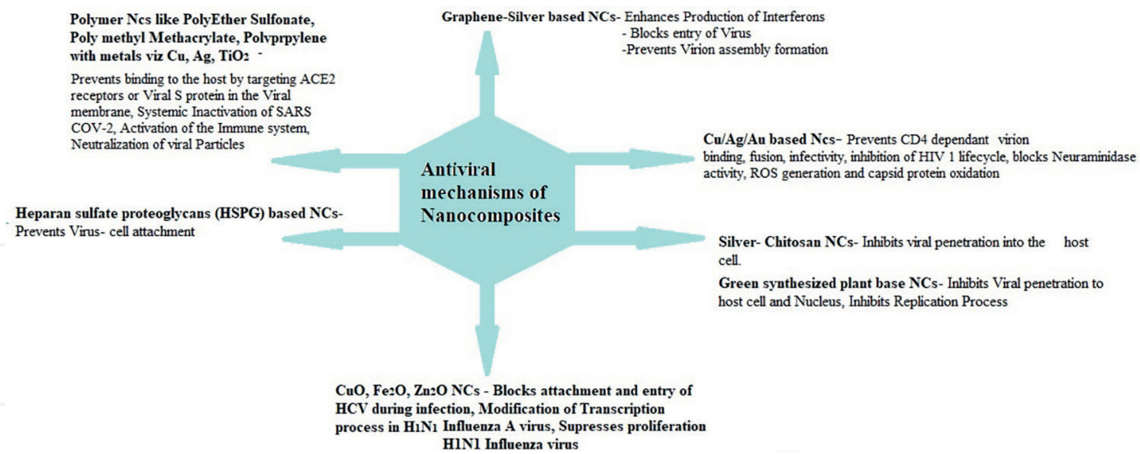


**Figure 2.**
*Various modes of antiviral activities of different nanocomposites.*

cytotoxicity was tested. Such nanocomposites reported as lethal at minimally toxic concentration reduced the Herpes Simplex Virus1 count by about 83%. (MNTC) [57].

The suggested TiO2 PL-DNA nanocomposites can be used to effectively and specifically inhibit different subtypes of influenza A virus. The proposed $TiO_2$ PL-DNA nanocomposites have remarkable antiviral activity, making them excellent platforms for drug development against a wide range of nucleic acid-related diseases, from infectious diseases to hereditary disorders [58]. Various Nanocomposites discussed above have shown antiviral activities against respected viruses. Possible Mechanisms of Antiviral activities were enlisted in **Figure 2**.

## 5. Conclusion

Antibacterial nanocomposites incorporating inorganic nanoparticles present higher antibacterial activity compared with their bulk counterparts due to their higher surface-to-volume ratio, resulting in improved contact with microorganisms. Antibacterial properties have been usually tested on nonpathogenic bacterial strains like *E. coli* and *S. aureus* as model organisms, but research should focus on other bacterial pathogens of different families. This would account for the increasing antibiotic resistance among various bacteria and their association as a severe hazard to worldwide public health. Some Graphene like nanocomposites with small-sized NPs are more effective against Gram-negative bacteria since they have larger surface area in contact with the bacteria. Well-dispersed nanomaterials show stronger antibacterial activity than the aggregated ones. The main challenge is obtaining reliable information on the interaction between bacteria and nano-structures. Another challenge is to analyze the toxicity associated with them. Antifungal polymers can be combined with other anti-microbial compounds to enhance their antibacterial activity. This flexibility provides great promise for applications that range from postharvest food preservation to healthcare, according to the World Health Organization (WHO). The potential of antifungal composites to replace antifungal drugs still remained unexplored. Likewise viral infections are difficult to treat because viruses spread and multiply quickly. Numerous new, deadly viruses, including the *Coronavirus, Ebola virus, Dengue virus, HIV,* and *Influenza virus*, are already causing chaos on people. Moreover Silver and biobased polymers as Nanocomposites which are selective antimicrobial compounds should be explored in future to enhance its applicability. Silver biobased nanocomposites are thought to be a powerful and cutting-edge pharmacological agent with strong antiviral activity against these viruses and microorganisms. This is to be thoroughly studied in all respects.

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## Conflict of interest

The authors declare that there is no conflict of Interest regarding this publication.

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