Synthesis of Silver Nanoparticles using Cellulose and Starch Extracted from Brewer Spent Grain: Assessment of their Antimicrobial and Preservatives Activities

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ABSTRACT

Non-porous materials like cellulose and starch can be extracted from agro-industrial wastes and incorporated with nanoparticles for effective biotechnological purposes. In this study, silver nanoparticles (AgNps), silver-cellulose nanoparticles (AgNps-C) and silver-starch nanoparticles (AgNps-S) were characterized by UV-visible spectroscopy. Fourier transform infrared spectroscopy (FTIR) was used to identify viable biomolecules involved in capping and active stabilization of AgNps. Average sizes and morphologies of AgNps, AgNps-C and AgNps-S were further analyzed by scanning electron microscopy (SEM) and the percentage composition of each element was investigated by energy-dispersive X-ray spectroscopy (EDS). Antimicrobial activity of the synthesized AgNps-C and AgNps-S was tested against multiple antibiotic resistance microorganisms isolated from fish and meat. Zones of inhibition displayed by AgNps-C and AgNps-S ranged from 8.00 to 13.30 mm and 5.00 to 10.30 mm, respectively. The Minimum inhibitory concentration (MIC) for AgNps-C and AgNps-S ranged from 125 µg/mL to 500 µg/mL and 500 µg/mL to 1000 µg/mL, respectively. AgNps-S and AgNps-C inhibited the growth of microorganisms associated with spoilage of fish and meat. The bio-applications of AgNp – C and AgNp-S can be exploited in food industries as preservative agent or incorporated to packaging materials to elongate the shelf life of food products and reduce the side effects attributed to chemical preservative agents.

Keywords:
- Nanomaterial
- Meat
- Fish
- Preservation
- EDS, SEM

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Introduction

Agricultural residues such as orange mesocarp, maize stem and cobs, banana and plantain pseudo stem, coconut shell, groundnut husk, sugar cane bagasse, soybean, wood dusts, hull of oat, wheat, rice and brewers’ spent grains (BSG) have not been adequately converted to significant purposes and thus, serve as source of pollution to the environment (Israel et al., 2008 and Aráujo et al., 2019). On this note, there is a need to focus on importance and bioconversion of agricultural waste biomass into useful biomaterials since they are costless, environmentally friendly and renewable, which will therefore, change the public perception about agro-industrial wastes towards environmental sustainability. Agricultural wastes are ideal renewable resources for production of nanostructures as a substitute to non-biodegradable, carcinogenic and toxic materials (Maraveas, 2020). BSG is a major by-product of the beer industry, representing around 85% of the entire production (Thiago, et al., 2014). BSG contains cellulose; a linear polymer consisting of 6-member ether rings (D-glucose or dextrose) covalently linked together by ether groups called glycosidic bonds and is biodegradable substance that can be extracted for different purposes. Cellulosic and lignocellulosic biomass from agro-wastes are inexpensive, green, differentiated resource and polite for synthesis of valuable nanoporous materials, polymer nanocomposite and nanoparticles (Saini et al., 2015).

Silver nanoparticles (AgNps) and polymer nanocomposite materials are useful in different areas like medicine, environmental science, pharmaceutical, food, and agricultural industries and in bioremediation (Duncan, 2011; Preetha, et al., 2013 Fariq et al., 2017). Nanoparticle have been noticed antiquity and is currently used in the...
control of bacterial and fungal growth to preserve shelf life of foods. AgNPs can be incorporated to biodegradable polymers like cellulose, chitosan, starch, lignin and xylan from different agro-industrial residues to have different type of polymer nano-composites with bio-functionalities and performance properties like mechanical, barrier, optical, thermal, biodegradation, antimicrobial, chemical stability and other functional properties as compared to nanoparticle with no support (Motaung and Linganiso, 2018). Biopolymers derived from lignocellulosic materials always have higher specific strength, modulus, high-volume applications, low cost, low density, low energy consumption, easy processability, renewable origin and possibility of recycling than other composites (Nevárez et al., 2011). Nanomaterials have successfully improved food safety, enhance shelf-life, food packaging and nutritional value as additives without change in taste, food quality and no side effects (He and Hwang, 2016, Das et al., 2017).

Muscle foods such as meat, fish and their products prone to microbial spoilage and serve as primary source of food borne diseases (Lorenzo et al., 2017). Muscle foods contain growth factors that support microbial growth. Bodunde et al. (2019) revealed different microorganisms that associated with spoilage of muscle foods (meat and fish). The action of microbial growth on meat and fish caused spoilage with biochemical and enzymatic deteriorations. The increasing awareness of fish and meat (food) spoilage microorganisms causing diseases with multiple antibiotic resistance is demanding a search for new and efficient antimicrobial agents. Hence, the continuous exploration for effective antimicrobial and preservative agents in food industries has resulted in the emergence and application of bio-nanotechnology (Zorraquín-Peña et al., 2020). Bio-nanotechnology is now an evolving option that can be employed to enhance food bio-functionalities, maintain food nutrients and prevent the growth of microorganisms associated with food borne diseases (Srividya et al., 2017 and Bajpai et al., 2018). Degradable bio-polymers combined with nanoparticles could serve as prospective substitutes to conventional antibiotics because of their antimicrobial activities, since they are readily available, simple to prepare, safe, cost effective and eco-friendly. Wastes from cereal grains namely; wheat, rice, corn, oats, barley as well as waste from tubers such as potatoes, yam and cassava establish a very good reducing agent for silver nitrate to silver nanoparticle (Yakout and Mostafa, 2015). Starch have huge possibilities to substitute conventional synthetic products since their modification with other polymers is an attractive source of raw material for production of high-value bio-based products (Temesgen et al., 2021). New biodegradable polymers like chitosan, cellulose and its derivatives, starch, lipids, proteins, polyactic acid or polyvinyl alcohol from renewable biomass, as a single component or in combination with nanomaterial has yielded excellent support to obtain antimicrobial packaging materials (Motelica et al., 2020). This study therefore, assess antimicrobial activity of synthesized silver nanoparticles with cellulose and starch from BSG against microorganisms isolated from fish and meats. The preservatives quality of AgNPs-C and AgNPs-S on meat and fish was also investigated.

Materials and methods

Chemical used

Silver nitrate (AgNO₃), Sodium hydroxide (NaOH), sodium chloride (NaClO₂).

Extraction of cellulose

Brewers’ spent grain was collected from International Breweries Plc, Ilesa, Nigeria. BSG was washed with distilled water to remove impurities. They were oven dried at 80 °C. It was grounded and sieved, was boiled in 10% NaOH in w/v ratio 1: 20 in an autoclave, the black slurry obtained was filtered and washed using distilled water. The cellulose was filtered out and bleached with 5% sodium chlorite (NaOCl) for 3 h at 30°C (Pornchai, 2009).

Extraction of starch

BSG was washed with tap water and then with distilled water to remove impurities, water was poured on the BSG and left for 1 hour. The solution was filtered, filtrate obtained was left to settle down and starch was gotten by vacuum filtration.

Synthesis of silver nanoparticles (AgNps)

Sol-gel method described by Shahjahan (2017) was adopted with little modification. Briefly, beaker was thoroughly washed, after which 0.01 M prepared AgNO₃ and 0.1 M sodium hydroxide was added carefully to raise pH to 7. The solution was mixed rigorously for 45 min after which, (mass) cellulose or starch extracted from BSG was added as reducing agent. Black coloration shows that the solution has been reduced to silver nanoparticle. The change in colour shows the effect of surface plasmon resonance (SPR) of silver nanoparticle (Sathiya and Akladeswari, 2014). The solution was continually stirred rigorously for another 3 hours as shining silver nanoparticles were formed over the solution and it was filtered, washed with deionized water and oven dried at 60°C.

Characterization

UV–vis spectroscopy

The sample (1 g) of AgNps, AgNPs-S and AgNPs-C was diluted with 50 mL of distilled water. Ultra-violet visible spectrophotometer (Shimadzu uv-1650) was used to scan the sample between wavelengths of 300 to 600 nm and the optical band gap was determined using Tauc equation.

Tauc’s Equation (as in Equation 1) was employed to determine band gaps for the samples.

\[ a\frac{h\nu}{\alpha} = k\left(\frac{h\nu}{\beta}-E_g\right) \]

Where \( \alpha \) is absorbance coefficient; \( h \) is Planck constant; \( \nu \) is frequency; \( r \) is \( \frac{1}{2} \) for direct band gap; 2 for indirect band gap; 3/2 for forbidden direct band gap and 3 for forbidden indirect band gap. The absorbance coefficient was determined by equation 2.

\[ \alpha = \frac{2.303A}{d} \]

Where \( A \) is absorbance, \( d \) is the film thickness. This result in plotting \((a\frac{h\nu}{\alpha})^2\) against \( h\nu \) and extrapolate at point where peak of the absorption.
Fourier transform infrared (FTIR) Analysis

Functional group in silver nanoparticles and silver nanoparticles mixed with cellulose was determined using FT-IR spectroscopy (8400S, Shimadzu Scientific Instruments Inc.). Briefly, sample (1.0 μL) was placed on fused KBr disc. This was placed on cell holder, clamped loosely and fixed on the infrared (IR) beam. FTIR spectra were recorded in the range from 400 to 4000 cm⁻¹. The spectrum obtained was interpreted according to Williams (1982).

Scanning electron microscope (SEM)- Energy-dispersive X-ray spectrometer (EDS) analysis

AgNPs and AgNPs-C were scanned by VEGAB TESCAN Scanning Electron Microscope (SEM) equipped with BRUKER energy-dispersive X-ray spectrometer (EDS) for morphology and elemental characterization. The sample was pasted on the double sided cellotape placed on the SEM sample loader as stub. The stub was mounted on stage after which chamber was tightly closed and the SEM was set to create vacuum as air in the chamber was evacuated. Higher HT voltage was not used since the sample is highly charged particle, hence 3.0 V was used.

Isolation and identification of microorganisms from fish and meat

Fish and meat were purchased from Obada market, Odeomu, Osun state in Nigeria. Fish and meat were separately homogenized. One gram was aseptically taken into 10 mL sterile distilled water to prepare stock. Serial dilution was carried out up to 10⁻⁴ and 10⁻⁵ dilution factor. An aliquot of 0.1 mL was transferred into the petri dishes and the agar, nutrient agar, MacConkey agar, Baird Parker medium, Mannitol salt agar, Salmonella shigella agar, Eosin methylene blue agar, Violet Bile agar and Potato dextrose agar. The Petri dishes were incubated for 24 hours at 37°C for bacteria, while Potato Dextrose agar was incubated for 48 hours at 26°C for fungi. Biochemical tests such as catalase test, production of hydrogen sulphide (H₂S), indole, urease, methyl red, oxidase, coagulase, motility, methyl red, Voges-Proskauer, starch hydrolysis and sugars fermentation were carried out using the methods described by Chessbrough (2006). Microorganisms with multiple antibiotic resistance were selected for further studies.

Antimicrobial activity of AgNPs-C and AgNPs-S

Antimicrobial activity of AgNPs-C and AgNPs-S were tested against microorganisms using agar well diffusion method (Chessbrough, 2006). Distilled water was used as the negative control, amoxicillin and ketocanazole was used as positive control against bacteria and fungi, respectively. Bacteria were cultivated on nutrient broth at 37°C for 24 h, while fungi were grown on potato dextrose broth at 25°C for 48 h. Turbidity of inoculum was adjusted to 0.5 McFarland turbidity standard at 600nm using visible spectrophotometer. A sterile swab stick was moistened with bacterial and fungal inoculum and spread on Muller Hinton agar and Potato Dextrose agar, respectively. Afterwards, well of 4 mm diameter were bored into agar medium and filled with AgNPs-C, AgNPs-S and positive control. The plates were incubated at 37°C for 24 hours for bacteria and 25°C for 48-72 hours for fungi. Thereafter, zones of inhibition were measured in millimeter (mm) and recorded. Minimum inhibitory concentration (MIC) was recorded as the lowest concentration that prevented the growth of microorganisms.

Evaluation of preservative effect of AgNPs-C and AgNPs-S on meat and fish

The preservative potential of AgNPs-c and AgNPs-s was assayed using the methods of Shavisi et al., (2017) and Badawy et al. (2019) with modification. Briefly, meat or fish (10 g) were aseptically weighed, boiled and placed in a sterile polyethylene bags with AgNPs-C and AgNPs-S. The samples were stored at -4°C and another set at 37°C for 4 days. Microbial quality of preserved fish and meat was determined for 4 days.

Statistical analysis

Experiment was performed in replicate (n = 3). Data obtained were subjected to one-way analysis of variance (ANOVA). Values were presented as mean ± standard deviation (SD) using Statistical Package for Social Sciences (SPSS) version 23 software.

Results and discussion

Cellulose and starch from agro-waste (BSG) as a source of biomaterial

BSG is a potential source of polymers that can be successfully used for industrial and biotechnological applications. Finding of Mishra et al. (2017) revealed that BSG contains cellulose of 16 to 25% and as a potential source of cellulose nano-fibre that can be utilised for various purposes. Cellulose from orange peel waste and natural origin (other wastes) appears to be a good capping agent for the green synthesis of silver nanoparticles (Garza-Cervantes et al., 2020). Cellulose has gained much attention as bio-resourceful agent due to higher hydroxyls group in its molecular structure (Wu et al., 2012). Starch (C₆H₁₂O₆)n as a common carbohydrate and a polymer of glucose was extracted from BSG. The functional groups in biopolymer can act as reducing agent and as a capping agent to nanoparticles in order to demonstrate efficient bioactivities like antimicrobial, antioxidant, anticancer, and anti-inflammatory agents (Mohan et al., 2016). Therefore, biopolymers from renewable biomass is a promising and exciting biomaterial for biomedical applications because they abundantly available, renewability, no toxic, biocompatible, and easily biodegraded. Hence, biopolymers possess excellent mechanical properties that make them a good candidate for reinforcement materials in production of nanocomposites.

Characterization of synthesized nanoparticles and nanocomposites

AgNPs, AgNPs-C and AgNPs-S exhibit absorption at wavelength between 355 nm to 430 (Figure 1). This shows great effect of surface plasmon resonance exist within the range of 390 nm to 420. Studies of Lomeli-Marroquin et al. (2019) revealed 400 nm for AgNPs. Band gap of 2.74 eV for Ag Nps, 2.72 eV for AgNPs –S and 2.52 eV for AgNPs –C was obtained in this study (Figure 2). AgNPs – C has lowest band gap. The smaller the band gap, the easier for ionic interaction between the valence band and
conducting band. This shows that ions interchange was higher in AgNps-C than others, hence it will be effective than others. Huber et al (2012) revealed that bulk materials and thin films of conjugated polymers showed low optical band gaps.

Fourier Transform Infrared Spectroscopic Interpretation

The FTIR spectra of AgNps and AgNps-C are presented in Figure 3a and b. FTIR revealed various functional groups in biomolecules responsible for bioreduction of Ag⁺ and capping/stabilization of AgNps. The wavelength of light absorbed is salient feature of chemical bonds in annotated spectrum. Tables 1 and 2 depicts data on peak values and probable functional groups obtained by FTIR from Figures 3a and b. Bands at 3425.69 cm⁻¹ and 2926.11 cm⁻¹ in the spectra corresponds to N-H stretch vibration, which are the primary and secondary amides (Phanjom and Ahmed, 2015), 3327.32 cm⁻¹ signifies O–H vibration in cellulose, which helps in stabilizing silver ions into the cellulose fibers as results of interaction between cellulose hydrogen bonds and the metal nanoparticle and thus, makes the AgNps-C more efficient in formation of nano-composites (Musino et al., 2021).

Figure 1. UV-Vis absorption spectrum for AgNps, AgNps-C and AgNps-S

Figure 2. Optical band gap for AgNps-C, AgNps-S and AgNps
Band at 2852.81 cm$^{-1}$ region arising from C–H stretching of aromatic compound were observed, the band at 1645.33 cm$^{-1}$ in the spectra corresponds to amide functional group arising due to carbonyl stretch (Prakash et al., 2013). Peak at 1572.04 cm$^{-1}$ corresponds to N–H bend, the band at 1454.38 cm$^{-1}$ was assigned for N–H stretch vibration present in amide linkages (Phanjom and Ahmed, 2015). Peak at 1284.63 cm$^{-1}$ refer to C–O stretching vibrations mode. The carbonyl groups have strong ability to bind to silver (Balaji et al., 2009). The bands at 1062.81 cm$^{-1}$ are assigned for N–H stretch vibration. The peak at 829.42 cm$^{-1}$ assigned to C=CH$_2$ and peaks near 628.81 cm$^{-1}$ assigned to CH out of plane bending vibrations are substituted ethylene systems –CH=CH (cis) (Priya et al., 2011). Some bands in Fig. 3b are similar to Fig. 3a, verifying the functional groups, there is a shift in some bands due to the presence of cellulose in the blend. Some bands came up; 2739.01 cm$^{-1}$ indicates C-H stretch of aldehyde, 2129.48 cm$^{-1}$ show the methylene group, this is similar to the findings of Priya et al. (2011), 1739.85 cm$^{-1}$ representing aldehyde CO stretch. This showed that cellulose was oxidized by reduction of silver ion and the alkanol group oxidized to aldehyde group (Hameed et al., 2017).

**SEM-EDX**

The SEM morphology at different magnification is shown in Figures 4 to 6. The particle of AgNps shows spherical shape with particulate size ranged from 6.38 to 53.43 nm. Findings of Ibrahim (2015) indicated spherical shape for silver nanoparticles. The diameter obtained in this study is within the range of nanoparticle (0-100 nm), which agreed the findings of Balashanmugam et al. (2013) who reported 20-50 nm for silver nanoparticle.
Figure 4. SEM at different magnification ranged from 1000 to 250 at 3.0 KV for AgNps
Figure 5. SEM images at different magnification ranged from 1000 to 250 at 3.0 KV for AgNps-C
The cellulose and starch from BSG characterized with the SEM show fiber structure with spherical shapes (Figures 5 and 6) which follows the findings of Liew et al. (2015) who extracted cellulose from bamboo. The particle shows fiber elliptical shape with particulate size ranged from 6.97 to 128.77 nm and 4.80 to 20.81 nm for AgNps-S and AgNps-C respectively. EDS of AgNps shows 87.01 % of silver with 7.58 % of carbon and 5.41 % of oxygen (Figure 7). The carbon was owned to the constituent of cellulose from BSG used as a reducing agent. The EDS of AgNps-C shows 76.49 % of carbon, 16.01 % of oxygen, 3.87 % of silver, 2.90 % of sodium and 0.67 % of phosphorus as shown in Figure 7b. The higher proportion of carbon in AgNps-C is as a result of mixing ratio of cellulose to AgNps (10:1). The presence of sodium and phosphorus could be attributed to composition of BSG. The report of Muthusamy (2014) and Silbir and Goksungur (2019) revealed the BSG contains phosphorus, sodium and other minerals. The EDS shows the binding energy for AgNPs at 0.330 KeV L-series based on the lower activation energy used to dispersed the nanoparticle as shown in Figure 7a and b. This is similar to the findings of Kumr et al. (2018) who spotted binding energy of AgNPs at 0.33 KeV. Studies of Balashanmugam et al. (2013) and Alexander et al. (2018) have obtained the binding energies of Ag 3d5/2 and Ag 3d3/2 peaks 367.73 and 373.71 eV correspond to Ag-O state.

**Antimicrobial and preservative potentials of AgNps-C and AgNps-S**

Table 3 shows zones of inhibition displayed by AgNps-C and AgNps-S against microorganisms isolated from meat and fish. AgNps-C displayed inhibited zones of 6.11 mm to 12.40 mm and 9.04 mm to 13.30 mm against microorganisms isolated from fish and meat, respectively. AgNps-S displayed inhibitory zones of 5.00 mm to 10.30 mm against indicator microorganisms.
Figure 7. EDS of (a) AgNps and (b) AgNps-C

Table 3. Zones of inhibition displayed by AgNp-C and AgNp-S at 1000 µg/mL

<table>
<thead>
<tr>
<th>Source</th>
<th>Microorganisms</th>
<th>AgNp-C</th>
<th>AgNp-S</th>
<th>Amoxicillin/ ketoconazole</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fish</td>
<td>E. coli</td>
<td>12.40±0.02</td>
<td>10.30±0.01</td>
<td>17.30±1.20</td>
</tr>
<tr>
<td></td>
<td>P. aeruginosa</td>
<td>6.11±0.00</td>
<td>0.0</td>
<td>12.2±1.64</td>
</tr>
<tr>
<td></td>
<td>P. mirabilis</td>
<td>8.00±0.10</td>
<td>6.00±0.00</td>
<td>10.10±0.00</td>
</tr>
<tr>
<td></td>
<td>K. pneumoniae</td>
<td>8.00±0.30</td>
<td>0.0</td>
<td>8.00±0.01</td>
</tr>
<tr>
<td></td>
<td>K. oxytoca</td>
<td>10.00±0.00</td>
<td>7.00±0.03</td>
<td>12.40±0.02</td>
</tr>
<tr>
<td></td>
<td>C. albicans</td>
<td>9.03±0.20</td>
<td>5.00±0.00</td>
<td>11.30±0.06</td>
</tr>
<tr>
<td>Meat</td>
<td>Bacillus subtilis</td>
<td>12.00±1.20</td>
<td>8.00±0.40</td>
<td>15.30±2.01</td>
</tr>
<tr>
<td></td>
<td>Streptococcus faecalis</td>
<td>9.04±0.52</td>
<td>0.0</td>
<td>12.00±1.05</td>
</tr>
<tr>
<td></td>
<td>Micrococcus luteus</td>
<td>11.00±0.40</td>
<td>6.00±0.01</td>
<td>12.10±1.50</td>
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<tr>
<td></td>
<td>P. aeruginosa</td>
<td>10.30±0.62</td>
<td>0.0</td>
<td>16.10±1.20</td>
</tr>
<tr>
<td></td>
<td>S. aureus</td>
<td>9.00±0.30</td>
<td>6.02±0.01</td>
<td>10.00±0.62</td>
</tr>
<tr>
<td></td>
<td>E. coli</td>
<td>13.30±1.00</td>
<td>0.0</td>
<td>12.00±0.33</td>
</tr>
<tr>
<td></td>
<td>K. pneumoniae</td>
<td>13.00±0.72</td>
<td>8.04±0.33</td>
<td>14.05±0.82</td>
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<tr>
<td></td>
<td>*E. coli</td>
<td>11.00±0.61</td>
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<td>12.10±0.73</td>
</tr>
<tr>
<td></td>
<td>*S. aureus</td>
<td>12.06±1.04</td>
<td>7.00±0.01</td>
<td>10.00±0.62</td>
</tr>
<tr>
<td></td>
<td>*C. albicans</td>
<td>11.01±0.90</td>
<td>6.00±0.04</td>
<td>14.03±1.20</td>
</tr>
</tbody>
</table>

*clinical isolates with multiple drug resistance. 0.0= no zones of inhibition observed at 1000 µg/mL.

Table 4. MIC (µg/mL) of AgNp-C and AgNp-S against tested microorganisms

<table>
<thead>
<tr>
<th>Source</th>
<th>Microorganisms</th>
<th>AgNp-C</th>
<th>AgNp-S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fish</td>
<td>E. coli</td>
<td>125</td>
<td>500</td>
</tr>
<tr>
<td></td>
<td>P. aeruginosa</td>
<td>250</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>P. mirabilis</td>
<td>250</td>
<td>1000</td>
</tr>
<tr>
<td></td>
<td>K. pneumoniae</td>
<td>125</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>K. oxytoca</td>
<td>500</td>
<td>1000</td>
</tr>
<tr>
<td></td>
<td>C. albicans</td>
<td>500</td>
<td>0.0</td>
</tr>
<tr>
<td>Meat</td>
<td>Bacillus subtilis</td>
<td>250</td>
<td>500</td>
</tr>
<tr>
<td></td>
<td>Streptococcus faecalis</td>
<td>500</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>Micrococcus luteus</td>
<td>125</td>
<td>1000</td>
</tr>
<tr>
<td></td>
<td>P. aeruginosa</td>
<td>500</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>S. aureus</td>
<td>125</td>
<td>1000</td>
</tr>
<tr>
<td></td>
<td>E. coli</td>
<td>125</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>*Staphylococcus aureus</td>
<td>125</td>
<td>500</td>
</tr>
<tr>
<td></td>
<td>*C. albicans</td>
<td>500</td>
<td>1000</td>
</tr>
</tbody>
</table>

*clinical isolates with multiple drug resistance. 0.0 = MIC > 1000 µg/mL.

Findings of Almeida et al. (2015) revealed that Escherichia coli, Enterococcus faecalis, Staphylococcus aureus, S. epidermidis, Vibrio cholerae, Pseudomonas aeruginosa, Shigella flexneri, Bacillus anthracis, Vibrio cholerae, Pseudomonas aeruginosa, B. subtilis, B. cereus, Proteus mirabilis, Salmonella enterica typhimurium, Micrococcus luteus, Listeria monocytogenes, and Klebsiella pneumonia were inhibited using nanoparticles. Yakout and Mostafa (2015) ascertained that synthesized green AgNps with soluble starch showed a pronounced antibacterial activity with zones of inhibition ranging from 7.2 mm to 16.3 against Grams positive and negative pathogenic bacteria like Staphylococcus aureus and Streptococcus pyogenes, Salmonella typhi, Shigella sonnei.
and *Pseudomonas aeruginosa*. In this study, AgNps-C exhibited better inhibitory potential than AgNps-S. Silver nanoparticles (AgNps)-cellulose exhibit good biocompatibility and antimicrobial properties because AgNps are tightly immobilized on cellulose materials and bestowing better antibacterial activity (Xu et al., 2018). Silver nanoparticle-cellulose as bio-composite inhibited the growth of *Escherichia coli* ATCC 11229, *Staphylococcus aureus* ATCC 6538, *Pseudomonas aeruginosa* ATCC 27853, multidrug resistant *Staphylococcus aureus* and *Pseudomonas aeruginosa* (Garza-Cervantes et al., 2020). In the findings of Xu et al. (2019), silver nanoparticles (AgNps) with dialdehyde cellulose nanocrystal exhibited antibacterial activities against *Escherichia coli* and *Staphylococcus aureus*, which later added to pulp fibers to obtain hand sheets with strong antibacterial activities. Thigamani et al. (2019) revealed that infusion of AgNps on cellulose-based hybrid nanocomposites maintain its mechanical, thermal and proved to have good antimicrobial activities, which therefore, recommended for active packaging applications. Rozilah et al. (2020) revealed antibacterial activity of nano-composite films containing sugar palm starch and sugar palm nanoparticles crystalline cellulose with inhibited zones ranged from 0.1 mm to 8.0 mm against the growth of *Escherichia coli*, *Staphylococcus aureus*, and *Salmonella cholerasuis*. Silver nanoparticles and silver nanocomposites have a wide spectrum of antimicrobial activity with different mechanism of action against Gram-positive and negative bacteria, fungi, and viruses. Studies of Morones et al. (2005); Sobye et al. (2015); and Simbine et al. (2019) have revealed that nanoparticles in the range of 1 to 10 nm bound to the surface of the cell membrane and drastically disrupt its permeability and respiration, and possibly interact with macromolecules in cells such as proteins, deoxyribonucleic acid (DNA). This reduce the growth and metabolism of bacterial cells and therefore, leading to accelerated lysis (Sobye et al., 2015).

Table 5 shows the minimum inhibitory concentrations (MIC) of AgNps-C and AgNps-S against tested microorganisms. The MIC ranged from 125 μg/mL to 500 μg/mL and 500 μg/mL to 1000 μg/mL for AgNps-C and AgNps-S, respectively. Finding of Badawy et al. (2019) obtained MIC of 200 and 250 mg/L against *E. coli* and *Salmonella typhimurium*, respectively when chitosan-silver nanoparticles used in preservation of minced meat. Table 5 shows the preservative quality of AgNps-C and AgNps-S on fish and meat at different temperature for 4 days. The microbial load obtained on each sample; fish and meat were recorded. At day 1-3, the microbial load (∗10⁵ cfu/g) of fish and meat decreased from 1.4 to 1.0 and 1.5 to 1.3 at 4°C when treated with AgNps-C. AgNps-S did not significantly reduced the microbial load but maintained microbial load of 1.9-2.0 and 2.0-2.3 × 10⁵ cfu/g on fish and meat respectively. At day 4, the untreated fish and meat have higher microbial load with traces of spoilage at day 4. Findings of Badawy et al. (2019) revealed lower microbial load of 8.17 to 14.47 × 10⁵ cfu/g when chitosan-silver nanoparticles was used to preserve minced meat. In the study of Shavisi et al. (2017), microbial population decreased to 1-logCFU/g in treated minced beef with extended shelf life without any unfavourable organoleptic properties when cellulose nanoparticle was combined with *Ziziphora clinopodioides* essential oil.

### Conclusion

Polymers should be incorporated with silver nanoparticles because of their antimicrobial properties against pathogenic organisms which will also go a long way to reduce environmental pollution in our environments. The application of silver nanoparticles (AgNps) with biopolymer from agrowastes for food packages will offer new perspectives to prevent microbial spoilage and increase the shelf life of foods. AgNps can be incorporated to non-degradable (polyethylene, polyvinyl chloride, vinyl alcohol) and biodegradable polymers such as cellulose, starch, chitosan, agarose) to produce food packages.

### Declaration section

**Statement of ethical approval**
Compliance with ethical standards

**Conflict of interest**
All authors declare no conflict of interest.

**References**


