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OPTICAL AND PHYTOCHEMICAL DETECTION OF DECAYED FOOD ITEMS USING YEAST MEDIATED SILVER NANOPARTICLE

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ABSTRACT. This study emphasized the use of silver nanoparticle (AgNPs) produced from yeast isolate to detect decayed food items like tomatoes, doughnut, and bread. The synthesized AgNPs was monitored via its surface plasmon resonance (SPR) reading with UV-Visible spectrophotometer and later characterized with Fourier transform infrared spectroscopy (FT-IR), X-ray diffractometer (XRD), scanning electron microscope (SEM), and energy dispersed x-ray (EDX). The UV-Visible reading were observed between wavelength of 350 - 450 nm, while XRD diffraction showed three distinct peaks at 38.08°, 44.28° and 64.51° corresponding to the plane of (111), (200) and (220) suggesting the production of AgNPs. The optical potency of the synthesized AgNPs using decayed tomatoes was observed via color change from the initial light orange color of AgNPs to deep brown color after detection of volatile metabolites from decayed food items and this was confirmed with a red shift noticed on the 6th day when the AgNPs wavelength changed from initial range of 350 - 450 nm to 520 nm when monitored with UV-Visible spectrophotometer. The study demonstrates that silver nanoparticles synthesized from yeast isolates can serve as effective nanosensors for detecting volatile metabolites emitted by decaying food items such as tomatoes, doughnuts, and bread.

KEY WORDS: AgNPs, Optical sensor, Food spoilage, Nanoparticles

INTRODUCTION

Food is a fundamental and important need for human survival. Basically, it's anything nourishing to human being, animals, and plants to maintain growth and life [1]. Energy from food aids in the formation and growth of the body and helps in growth of plants [2], and if proper food preservation techniques are not used, foods degrade and spoil, thus, making the purpose to be jeopardized. Food spoilage occurs when a food item develops an unpleasant flavor, smell, or look that makes it unfit for human ingestion [1, 3]. Different kinds of microorganisms and conditions, including

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bacteria, fungi, yeasts, temperature, protozoa, pH, and others are the contributory factors for food spoilage [4]. The physical appearance, the texture and the nutritional values are affected once the food spoils thus making it unfit for human consumption. Any food kept for too long frequently smells bad and seems to be decaying, and when food are stored or kept in storage for a long time and not properly kept, it gets spoilt, germs start growing on it and thus making it unfit for human consumption. Several methods of preserving food are available to prevent waste and save costs. Some of these food preservation techniques includes freezing, boiling, salting, seasoning, sweetening, drying, canning and the addition of chemicals as preservatives [5].

Contamination by microorganisms a poses problem to food industries with an effect on public health and as well the cost of wastes involved when there is spoilage [7]. Perishable food contains vital elements for bacteria and fungi such nutrients include water, glucose, and amino acids [8]. The microorganism that develops on food releases toxins, altering its physical and chemical composition and contributing to illness on whosoever eats it. Mostly appearance of food indicate spoilage even before tasting or perceiving the odour, when the food's physical appearance is no longer fresh then it is said to be spoilt.

According to Food and Agricultural Organization (FAO) of the United Nation, about 30 percent (approximately 1.3 billion tons) of foods are lost annually due to spoilage or decays in several forms [8, 9]. Approximately two out of three of the food produced is used for human consumption and the other one-third is either wasted or spoilt, thus making food spoilage a global concern [8]. It was also reported that the amount of food wasted per person in Nigeria is the greatest in Africa, in which an average Nigerian is estimated to throw away at least 189 kilograms of food yearly or 37.9 million (37,941,470) tons, according to the survey by FAO of the united nation [8]. Therefore, food security and safety face a significant challenge from food loss and wastage (FLW), economy and environmental sustainability. Two major factors affect food spoilage, these are internal and external factors. The external factor is influenced by the food products' external environment, which has an impact on how well bacteria flourish. Storage, temperature, moisture content, and atmospheric conditions (aerobic, anaerobic, and modified atmospheric packaging) are the relevant variables [9]. Time and temperature are the key elements promoting the growth of microbes, understanding how to manage them to prevent food deterioration is crucial for extending the shelf life of food products. The internal condition of food products that helps the growth of bacteria, fungi, mold are the substrate's physical and chemical composition, water activity, pH, availability of nutrients, starting microbiota, and the presence of naturally occurring antibacterial compounds [10].

Sensory evaluation and chemical studies are used to observe food deterioration [11] but in the past ten years, researchers have been developing different methods of detecting food spoilage by utilizing color indicator to track the microbial metabolites in food. It is advantageous for food-spoilage observation to substitute for the traditional approach, which can result in human errors due to its inefficiency and low precision. Song *et al.* [12] reported that plastics made from non-renewable resources used for packaging foods releases petrochemicals leading to some serious problems because they are not biodegradable and cause serious environmental worries in customers, biodegradable packaging is frequently utilized as food packaging in place of these materials. Traditional methods used for detecting spoilage involve the use of sensory evaluations, while sensitive methods of detecting spoilage include, using nanotechnology, DNA biosensor, smart phone biosensor, DNA micro array, E- nose and Gas chromatography methods to mention but few [13]. All these methods have their disadvantages such as high cost of operation and complex in mode of operation which affect the consumer either directly or indirectly. They also have disadvantage due to the usage of specific gas, signal interpretation, complex calculation, and material medium which sometimes are difficult to get. Some of these chemical methods of detecting spoilage in food affects the environment because many of the components used are not biodegradable [14]. Furthermore, it is advantageous for the purpose of observing food spoilage to

substitute the traditional approach, which can result in human errors because of its ineffectiveness and low precision.

This study is justified by the need to develop an alternative approach for detecting food spoilage that offers greater effectiveness, precision, environmental sustainability, and cost efficiency. By introducing a more advanced method, this research aims to improve the accuracy and reliability of spoilage detection while addressing the demands of modern food safety standards. This method is more stable, less, cost effective and environmentally friendly, and can be achieved by the continued usage of optical, chemical and bio- sensors reaping from the opportunity offered from nanoparticles. Kuswandi *et al*. [15] for instance, used color indicator to identify the contamination in beef when the pH was varied. The use of nanoparticles to detect spoilage of food items is safe, cheap and less hazardous method that can be achieved via green chemistry. The 2020 review by Abolghasem *et al*. [16] categorized the optical methods into four main types - spectrophotometry, spectrofluorimetry, scattering techniques and chemiluminescence and provides a comprehensive analysis of silver nanoparticle (AgNP)-based optical sensors used in pharmaceutical analysis from 2010 to 2020. In each category, Abolghasem *et al*. [16] portrayed AgNPs distinct roles within various sensing platforms, enhancing the detection capabilities for pharmaceutical compounds and further highlights the advantages of Ag NP-based optical sensors, such as low cost and simplicity, due to the absence of complex or expensive instrumentation. The review work by Beck *et al*. [17] examines the unique properties of silver nanoparticles (AgNPs) and their application in biosensing technologies, particularly for point-of-care (POC) diagnostics and also focused on the integration of AgNPs in optical biosensors, such as those utilizing localized surface plasmon resonance (LSPR), and electrochemical biosensors, highlighting their potential to improve sensor performance and enable the detection of analytes at low concentrations. Their review underscores the potential of AgNPs in enhancing the sensitivity and specificity of biosensors for point-of-care diagnostics. In the review study carried out by Kshitij *et al*. [18] explores the synthesis and application of bioinspired silver nanoparticles (AgNPs) in optical sensing and focusing on some environmentally friendly methods for producing AgNPs using plant extracts and biomolecules, which offer advantages such as stability, cost-effectiveness, and reduced environmental impact. The authors discussed how tuning the optical properties of AgNPs enhances their effectiveness in optical biosensors, which are increasingly utilized in biomedical, agricultural, environmental, and energy sectors.

The purpose of this study is to isolate yeast from dough and thereafter deployed its cells in the green synthesis of the silver nanoparticles under different experimental conditions. The prepared AgNPs would be characterized with different analytical methods like FT-IR, XRD, SEM and EDX. The optical activity of the prepared AgNPs in detecting decayed food items was investigated using tomatoes, doughnut and bread by measuring the volatile gas released after 8 days.

EXPERIMENTAL

Preparation of yeast isolate

The yeast was grown after preparing dough made with flour, sugar, milk, water, and baker's yeast. The dough was left for 48 hours to allow the manifestation of yeast which was cultured using saboraud dextrose agar and incubated for 48 hours at 25 °C. The serial dilution (SD) broth was prepared aseptically following the procedure in Van *et al*. [19]. The spoilt dough after being kept for 48 hours was taken with an inoculating loop and introduced into the SD broth, all processes were carried out in the lamina flow hood to prevent contamination. These were kept in the oven for incubation between the temperature range of 25 - 30 °C for 48 hours. The yeast growth was isolated and subculture following direct method of isolation which was done by directly placing the spoilt dough on the saboraud dextrose agar on the plate. Gram staining of the isolate was

carried out to determine if the isolate is gram positive or gram negative. Further biochemical characterization of the isolate was done to confirm the carbon utilization of the isolate.

Synthesis and characterization of yeast isolated AgNPs

The synthesis of the yeast strained AgNPs was done according to the method of Daphne *et al*. [20] with little modification. The yeast isolates in SD broth at pH 7.1 was incubated for 48 hours at 30 °C under agitation of 120 rpm. The broth culture of the yeast isolate was centrifuged at 4000 rpm for 10 min after which 5 mL each of the cell free extract (CFE) was measured and 1 mL of aqueous solution of 1 mM $AgNO_3$ and 3 mM$AgNO_3$ were added in a separate flask and the mixture agitated at 120 rpm for another 72 hours in the dark. The control flask used to monitor the biosynthesis of the AgNP contained only the CFE without the $AgNO_3$. The biosynthesized Ag-NPs was verified within 7 days using UV-Visible spectrophotometric analysis (SM 7504). The reduction of the Ag^+ was monitored by taking readings everyday within the range of 200 – 600 nm wavelength. The yeast strained AgNPs was further characterized using scanning electron microscope (SEM), FT- IR, X-ray diffraction analysis (XRD), particle size analyzer and energy dispersive X-spectroscopy (EDX). The variation in pH of the synthesized yeast silver nanoparticles was monitored to confirm the stability of the AgNPs produced. The pH of the AgNPs was monitored from pH 7.1 to pH 10 and the UV- Visible spectrophotometric reading was taken and recorded. Similarly, the temperature impact on the AgNPs produced was also measured by varying the temperature of the AgNPs and taking the UV-Visible spectrophotometric readings from the range of 40 to 60 °C.

Optical applications of the synthesized AgNPs

The yeast isolated AgNPs were deployed in sensing decayed food items such as tomatoes, bread and doughnut for 8 days. The color changes observed together with the changes in surface plasma resonance of the AgNPs were also measured using UV-Visible Spectrophotometer. The AgNPs medium after sensing the decayed food item was further characterized using GC-MS and FT-IR.

RESULTS AND DISCUSSION

Characterization of yeast isolate

The yeast isolate produced was done using the direct isolation method whereby the dough produced was kept for 48 hours before the isolation of the yeast. The yeast was grown on saboraud dextrose agar and the isolate was taken for gram staining and viewed under microscope. Gram staining of the isolate was done on a slide and viewed under microscope revealed the shape of the yeast isolate to be spherical which is a confirmation of the isolated yeast to be *Saccharomyces cerevisiae* as seen in Figure 1, which agrees with the work done by Olobayotan and Akin-Osonaiye [21]. The biochemical test to reconfirm the type of yeast isolate procedure followed the principle used by Hutzler *et al.* [22] and Tomowa *et al*. [23] where five different carbohydrates were used to incubate yeast isolate for 5 days. The five carbohydrates used were galactose, maltose, fructose, sucrose and lactose and the results revealed that every other sugar except lactose had growth of yeast, and this further confirms the isolate to be *S. cerevisiae* [24].

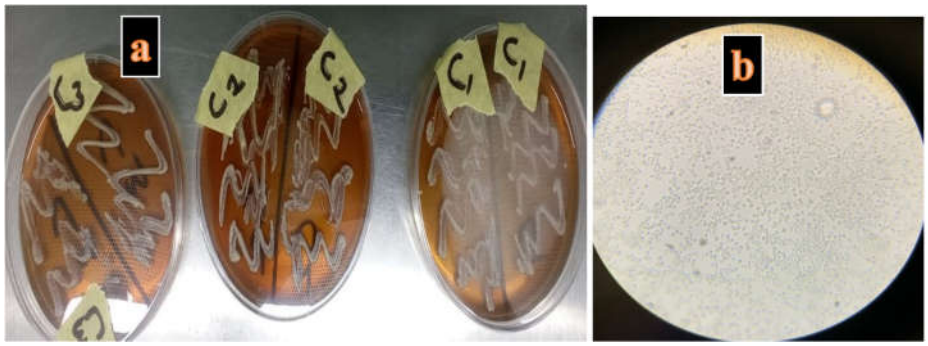


Figure 1. (a) Picture of direct method of yeast isolate from decayed dough and (b) microscopic view of the yeast isolate after gram staining.

Characterization of the synthesized AgNPs

Synthetization of AgNPs was done and characterized with UV-Visible spectrophotometer and there was an optical difference in the color of the AgNPs after it has been formed from the original light cream color of the CFE in Figure 2a to reddish brown in Figure 2b and subsequently to deep brown color in Figure 2c after 72 hours. The characterization was monitored by (1) varying the concentration, (2) varying the pH and (3) varying the temperature. The surface plasmon resonance (SPR) was observed after the addition of either 1 mM $AgNO_3$ or 3 mM $AgNO_3$ to the yeast isolate following the same procedure of Olobayotan and Akin-Osanaiye [18]. The surface plasmon resonance value of AgNPs synthesized from 3 mM AgNPs appeared between wavelength of 350 - 450 nm (Figure 3a), whereas, when 1 mM $AgNO_3$ was used, the wavelength was observed at 300 nm (Figure 3b). This is an indication that the increase in concentration of the $AgNO_3$ has significant effect on the absorbance of the two nanoparticles, and the result was in good comparison with the work done by Skalickova *et al.* [25]. The pH variation of the yeast strained synthesized AgNPs prepared from 3 mM $AgNO_3$ was also carried out ranging from 7.1 to 10 and the SPR was also monitored as depicted in Figure 3c. The SPR values was observed at 350 – 450 nm indicating no substantial impact on the SPR of the AgNPs at varied pH, this confirms the stability of the AgNPs at alkaline range of pH according to Husseiny *et al*. [26]. The SPR readings of the yeast strained AgNPs at varying temperature range of 40 – 60 °C is shown in Figure 3b. It was observed that temperature variation has no major impact on the AgNPs, and this further confirms the stability of the AgNPs even at different temperature. The SPR was still observed at the wavelength range of 350 – 450 nm and similar report was documented by Omole *et al*. [27]. The results of the FT-IR analysis from Figure 4indicates the presence of some functional groups. In the case of the 1 mM $AgNO_3$ synthesized AgNPs, peaks seen at 1635.19 cm^{-1} indicating the presence of either medium or strong C=O stretch or medium or strong N-H bend. The second peak appeared at 2135.65 cm^{-1}, this is an indication of the presence of medium C=C stretch. The appearance of the triple bond is an indication of the presence of alkyne having a chemical formula R-C=C-H. While the third peak seen at 3295.78 cm^{-1} indicating the presence of weak or medium N-H symmetric. The presence of nitrogen bonded to the hydrogen is due to the protein constituents of the yeast used for the synthesis of the AgNPs [28]. For the 3 mM $AgNO_3$ synthesized NPs, the peaks found at 1636.13 cm^{-1} indicate the presence of a medium or strong C=O stretch of the amide group having functional formula of R-C (O)-NR'R'', the second peak at 2156.45 cm^{-1} is an indication of a strong N=N=N stretch, a strong S-C=C stretch or a medium C=C stretch [25]. The N=N=N functional group is an indication of the element present from the constituent of the nanoparticles which is likely obtainable from the protein nature of the yeast strain used in

production of the nanoparticles [28]. While the third prominent peak was found to be at 3277.69 cm^{-1} indicating the presence of a very strong =C-H stretch. The presence of these functional groups is an indication that compounds such as thiocyanate, amide and alkyne were present in the extract. The X-ray diffractometric analysis of the two yeast strained nanoparticles confirms the crystalline nature of the AgNPs produced as shown in Figure 5. The scanning range was done at $2\theta = 10° - 70°$ and peaks formed were indexed using the Joint Committee of Powder Diffraction Standard (JCPDS). From the result obtained in Figure 5, three distinct peaks of AgNPs were recorded at 38.08, 44.28 and 64.51° corresponding to (111), (200) and (220) planes respectively. This confirms the production of AgNPs from the yeast strained [29]. According to Simbine *et al*. [30], nanoparticles size should be between 1-100 nm and from this present work, majority of the particle size of 1 mM $AgNO_3$ and 3 mM $AgNO_3$ synthesized NPs is an average of 56.43 nm (Figure 6a and b) and this further confirms the synthetization of AgNPs from the yeast isolate. The purpose of the EDX is to determine the elements present in the yeast strained AgNPs produced as depicted in Figure 6c. The elemental analysis showed that silver has the highest percentage of 87%, followed by nitrogen with 8%, chlorine 5.32% and oxygen has the least values of 2.90%. The elemental composition confirmed the N=N=N functional group seen in the FT-IR results of both AgNPs produced and this agrees with the report by Almatroudi [28]. The morphology result obtained according to Figure 6c and d, and for 1 mM $AgNO_3$ and 3 mM $AgNO_3$ prepared NPs, the results showed agglomerated spherical shapes of AgNPs and this is in agreement with the report given by Almatroudi [31].

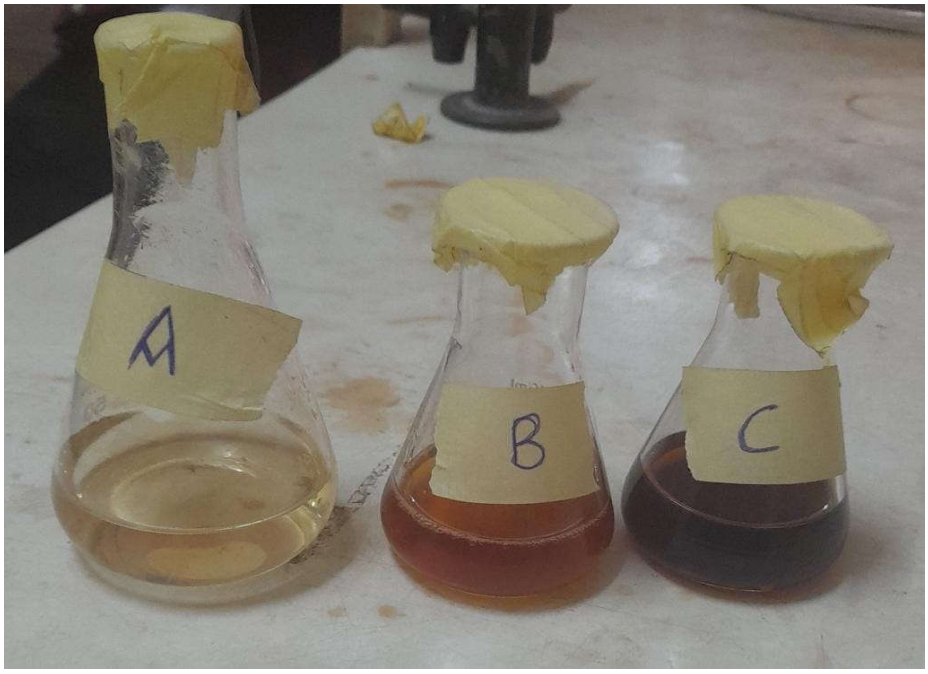


Figure 2. (a) CFE of the yeast isolate after agitation of broth for 48 hours, (b) CFE with 3 mM $AgNO_3$ at 12 hours and (c) Synthesized silver nanoparticles after 72 hours.

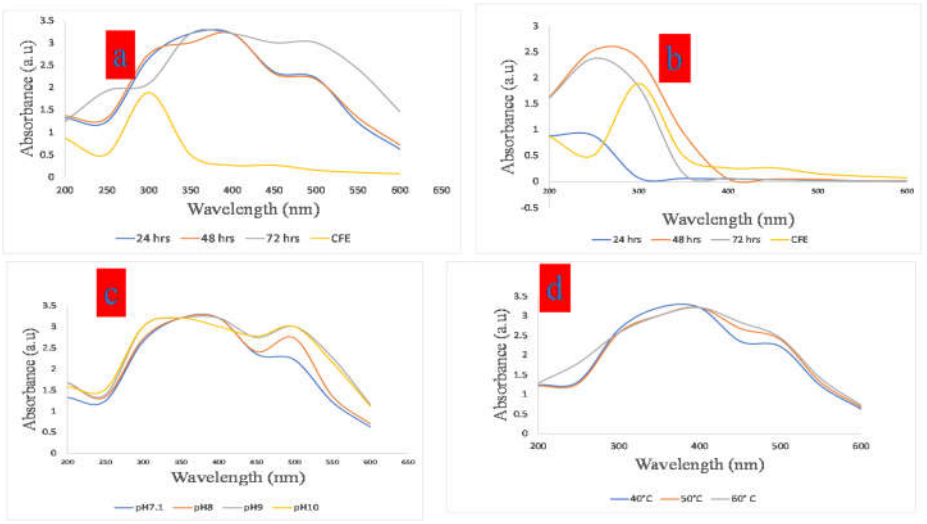


Figure 3. UV - Visible Spectra of synthesized AgNPs from (a) 3 mM $AgNO_3$, (b) 1 mM $AgNO_3$ at different time intervals, (c) AgNPs from 3 mM $AgNO_3$ at pH 7.1 – 10, and (d) AgNPs from 3 mM $AgNO_3$ at temperature.

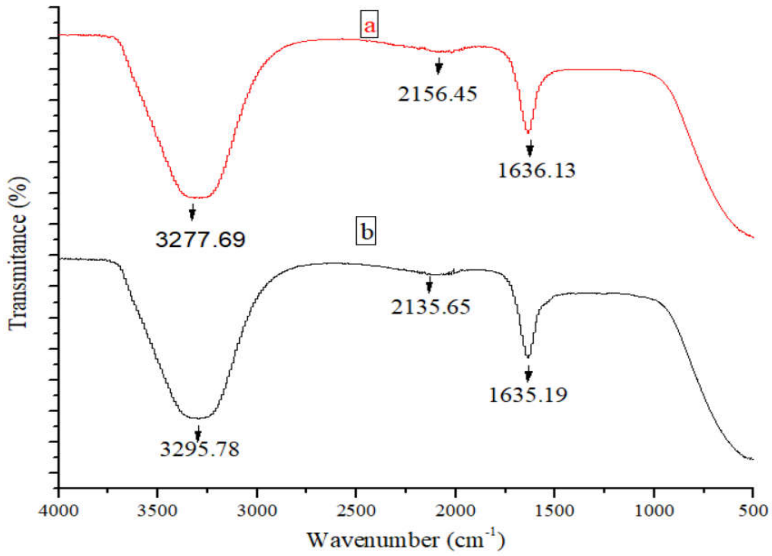


Figure 4. FT-IR spectra of AgNPs synthesized using (a) 3 mM $AgNO_3$ and (b) 1 mM $AgNO_3$

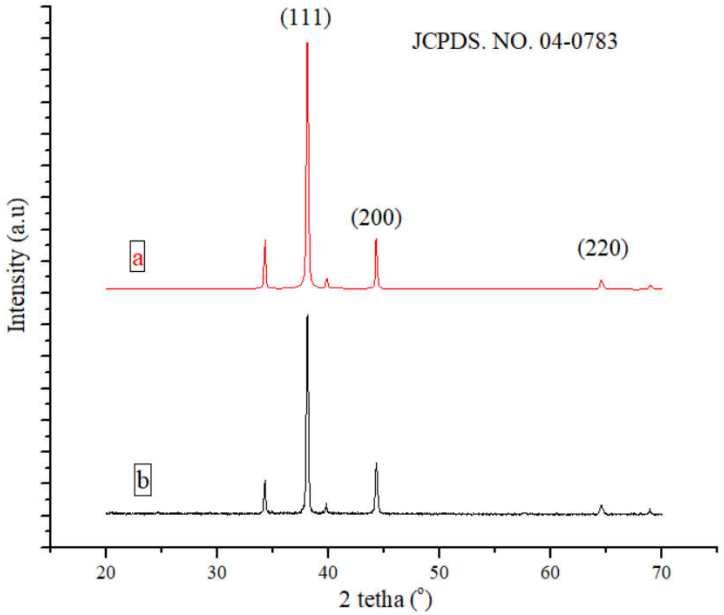


Figure 5. Plot of XRD of AgNPs synthesized using (a) 3 mM $AgNO_3$ and (b) 1 mM $AgNO_3$.

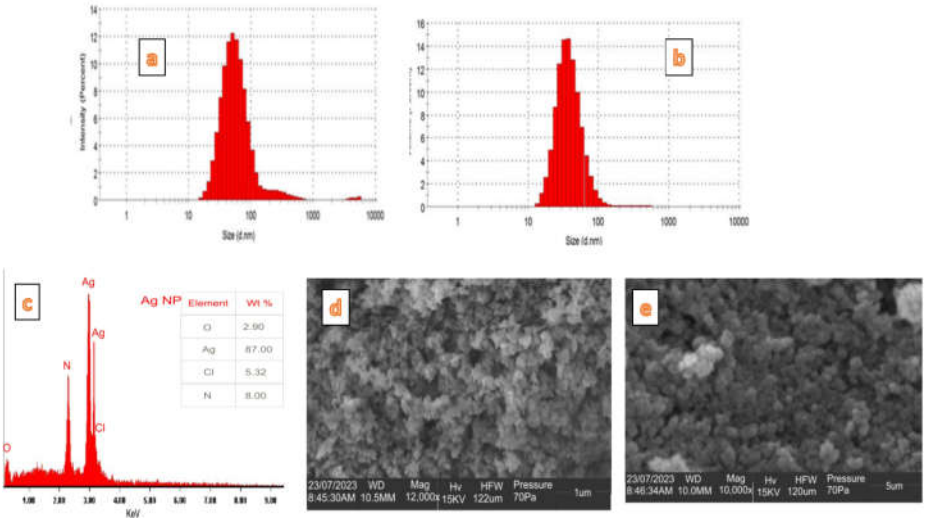


Figure 6. AgNPs synthesized (a) particle size when 1 mM $AgNO_3$ was used, (b) particle size when 3 mM $AgNO_3$, was used, (c) elemental compositions, (d) SEM of AgNPs when 1 mM and (e) SEM when 3 mM $AgNO_3$ were used.

Optical applications of synthesized AgNPs in sensing decayed food items

The yeast isolated AgNPs was deployed in sensing damaged food items for 8 days using so as to be able to detect volatile substances released from the decayed food items. The changes in colour were measured using UV- Visible spectrophotometer and the results obtained are as represented in Figures 7, while the various color changes observed are shown in Figure 8. The AgNPs medium after sensing the decayed food item was further characterized using GC-MS and FT-IR and the results obtained are depicted in Figure 9. The set up was left for 8 days and absorbance reading was monitored. The reading according to Figure 7a showed the SPR of the AgNPs maintaining its wavelength range of 350 - 450 nm for the first 3 days when tomatoes was used. However, the wavelength shifted to 600 nm as from the 4th day indicating its' optical ability to sensed volatile metabolites from the decayed tomatoes. This is an indication that volatile substances have been trapped by the AgNPs. The spectra in Figure 7b showed a shift in the direction of the red area of the SPR as from day 4, while the release of volatile metabolites from decayed doughnut was also sensed on the 7th day by the AgNPs. The AgNPs was employed for detection of the release of volatile substances from decayed bread (Figure 7c). The absorbance monitored with UV-Visible spectrophotometer for 8 days showed the wavelength range of 350 – 450 nm to remain unchanged for the first 5 days after which a red shift was noticed on the 6th day (Figure 7c). The wavelength changed from initial range of 350 - 450 nm to 520 nm on the 6th day. The silver nanosensor prepared performed its functions by changing from reddish brown color to deep brown colour after sensing volatile compounds from the decayed foods as seen in Figure 8, where the colour variations are shown to confirm the presence of trapped volatile substances from decayed foods. This is in agreement with the research work done by Omole *et al*. [27] where the release of volatile metabolites was monitored, detected and reported from bunch of bananas using silver nanoparticles for a period of 10 days. It was reported that the concentration of volatile component produced from the banana grew with the number of days the banana was monitored for spoilage, however the absorption spectrum at 400 nm was maintained for a few days despite a fall in absorbance value making the absorption peak at 400 nm not noticeable as the surface plasmon band became very broad [27]. They concluded that a shift in surface plasmon band from 425 to 547 nm was observed instead with significant decrease in the intensity of the peak at 400 nm indicating the aggregation of the silver nanoparticles [27]. Similarly, Sachdev *et al*. [32] reported the variations in the silver nanoparticles' synthesized SPR absorbance peak value at 425 nm which was deployed to detect spoilage in onions.

To be able to identify the metabolites from the food items which got trapped by the prepared silver nanosensor, the tomatoes extract without and with AgNPs (after trapping the metabolites from the tomatoes extract) was analyzed using GC-MS to further confirm the migration of some phytochemicals from the tomato juice extract and the results are shown in Figure 9a&b. It was observed that some phytochemical compounds were found in both the tomatoes extract and the AgNPs loaded with metabolites from the tomatoes extract which is an indication of the migration of some volatile compound from the tomatoes juice extract into the AgNPs during spoilage causing the optical changes in the AgNPs to take place. The chromatogram of tomatoes juice extract alone indicated the presence of some compounds like nonanoic acid, tridecanoic acid, n-hexadecanoic acid, 1-decanol, 1-octanedecanesulphonylchloride, 12-hydroxydodecanoic acid, 1,5,9-cyclododecanetriol, carbonic acid, oxalic acid, and dodecanoic acid as listed in Table 1. Similarly, the GC-MS chromatogram of loaded AgNPs with decayed tomatoes showed the existence of some compounds such as 1-octanedecanesulphonylchloride, decanoic acid, nonanoic acid, n-hexadecanoic acid, dodecanoic acid, tetradecenoic acid, 1-decanol, oxalic acid, oleic acid, and 9,12,15-octadecatrienoic acid as listed in Table 1. When the two chromatograms were compared (see Table 1), some carboxylic acids such as nonanoic acid, tridecanoic acid, hexadecanoic acid, oxalic acid, dodecanoic acid, and decanoic were present in both chromatograms which is an indication of the migration of some volatile metabolites from tomato

juice extracts into the AgNPs media causing the colour to change and their presence were detected by the nano sensor. It was observed that majority of the compounds that migrated from the tomatoes juice extract to the AgNPs media contained carboxylic functional group. A reaction mechanism can therefore be proposed which involves the reaction between the reduced silver nanoparticles with the carboxylic functional group (-COOH) of the tomatoes juice extract as indicated below:

$$Ag^0 + CH_3(CH_2)_n CO_2H \rightarrow CH_3(CH_2)_n CO_2Ag + H \quad (1)$$

$$-RCOOH + Ag^0 \rightarrow RCOOAg + H \quad (2)$$

where 'R' could be an alkyl, alkyne, aryl or other group attached to the carboxylic group. Reaction of synthesized AgNPs can be intracellular or extracellular, the most important and necessary factor is the availability of enzyme which play a leading role in the electron shuttle that moves electrons from the nitrate molecule to the metal ion for the synthesis of nanoparticles, the majority of studies concur that it plays a key role in the AgNP formation of NADH-dependent nitrate reductase Mikhailova [33].

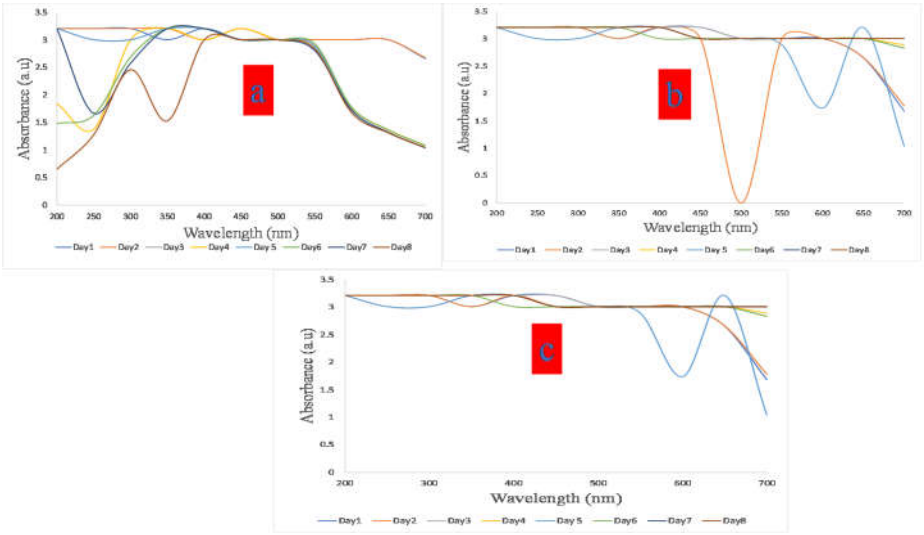


Figure 7. UV-Visible spectra of loaded AgNPs with decayed (a) tomatoes, (b) doughnut and (c) bread at different time intervals.

The interaction between the AgNPs and the tomatoes extract was further studied by taking the FT-IR analysis of the AgNPs loaded with the metabolites from the tomato juice extract and compared with the FT-IR spectral of the AgNPs and the result is shown in Figure 9c. The AgNPs loaded with tomatoes juice extract gave absorption band at 1080.9 cm^{-1} which indicates the presence of C-O which could belong to R-CH_2-OH (1°) or C=C-CH(R)-OH, the second peak was obtained at 1416.4 cm^{-1} which is an indication of a weak C=C of aromatic functional group, the third peak appeared at 1636.3 cm^{-1} which is an indication of the presence of strong C=O stretch in the amide group of the type R-C(O)-NR'R". The fourth peak appeared at 3298.7 cm^{-1} which could be a weak or medium N-H symmetric stretch of the type R-C(O)-NH_2. The FT-IR spectra showed indication of migration of some compounds from the tomatoes juice extract to the AgNPs solution. Thus, the production of new absorption bands in the FT-IR analysis after sensing. This

is supported by the research work done by Omole *et al*. [27] where silver nanoparticles were deployed to detect the spoilage in spoilt banana bunch. The original colour of the AgNPs which was reddish brown changed to deep brown on the 4th day but later turned transparent on the 10th days, the three colour changes were tested using UV-Visible spectrophotometer and the results obtained confirms the use of AgNPs as a colourimetric sensor for detection of spoilage in spoilt banana. The disappearance of specific phytochemicals in GC-MS analysis after sensing with AgNPs is likely due to their involvement in the reduction of silver ions, adsorption onto nanoparticle surfaces, oxidation, or conversion into other metabolites.

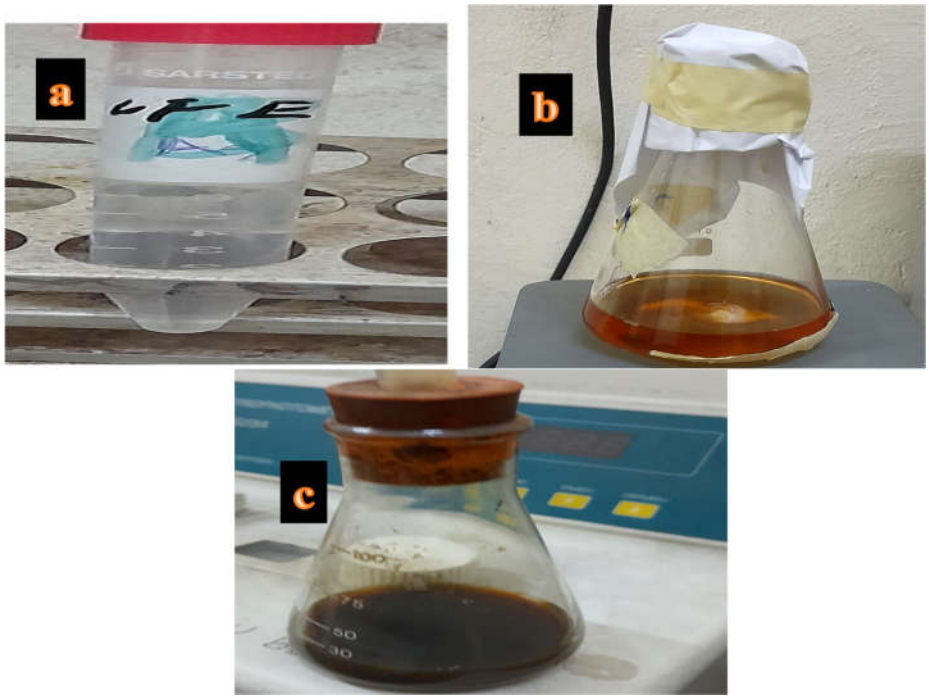


Figure 8. Physical appearance of (a) CFE before addition of $AgNO_3$, (b) CFE+ $AgNO_3$ after agitation for 72 hours and (c) AgNPs after sensing decayed foods.

Limitations and Potential Improvements

While the study demonstrates promising findings, some limitations were identified and the potential improvements as well.

Sensitivity and Specificity

The study indicates that the optical nanosensor detected spoilage in tomatoes, doughnuts, and bread within eight days, marked by a color change and a red shift in absorbance. However, the sensitivity and specificity of this detection method across a broader range of food items and spoilage conditions remain unquantified. Variations in spoilage metabolites among different foods could affect the sensor's performance. Evaluating the sensor's efficacy across a wider variety of food products and spoilage conditions would help determine its versatility and robustness. This includes testing with different spoilage microorganisms and varying storage environments.

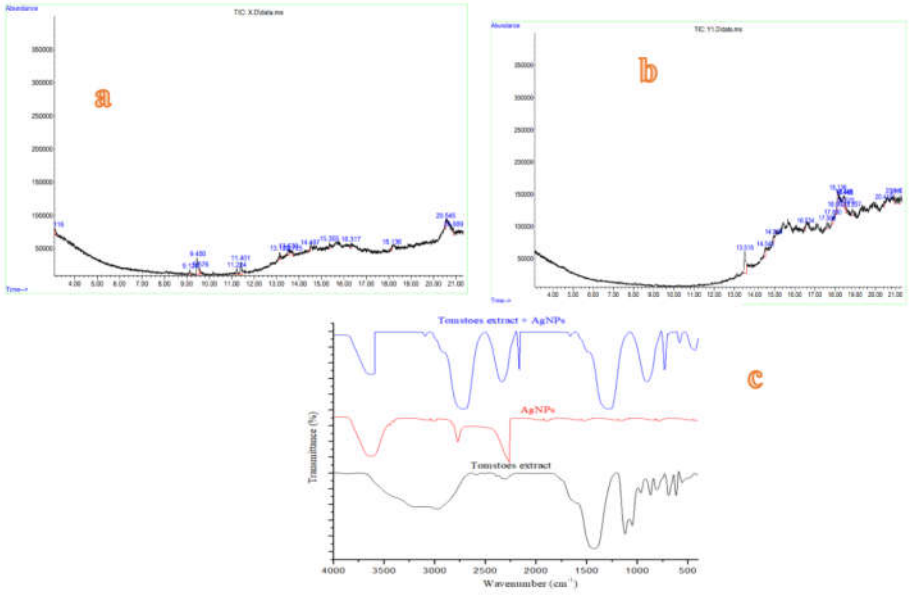
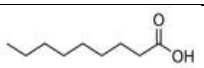
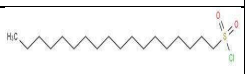
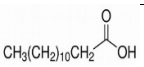
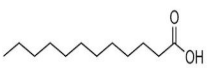
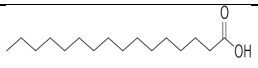
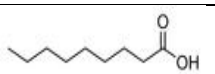
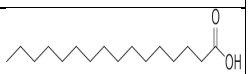
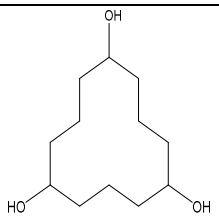
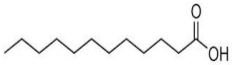
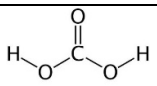
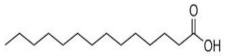
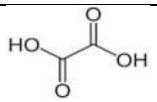
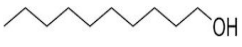
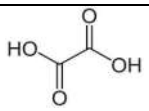


Figure 9. GC-MS chromatogram of (a) tomato juice extract alone before sensing, (b) GC-MS chromatogram of AgNPs + tomato juice extract after sensing, and (c) FT-IR spectral of AgNPs, tomato juice extract alone and tomato juice extract + AgNPs after sensing.

Table 1. Comparison of the dominant phytochemicals found in GC-MS analysis tomatoes extract alone and the load AgNPs+tomatoes extract.

Decayed tomatoes extract alone			AgNPs with decayed tomatoes extract		
RT	Name	Structure	RT	Name	Structure
13.424	Nonanoic acid		9.124	1-Octanedecanesulphonylchloride	
13.443	Tridecanoic acid		9.450	Decanoic acid	
13.518	n-Hexadecanoic acid		9.576	Nonanoic acid	
14.543	1-Decanol		11.401	n-Hexadecanoic acid	

17.598	1,5,9-Cyclododecanetriol		13.129	Dodecanoic acid	
18.062	Carbonic acid		13.530	Tetradecenoic acid	
18.445	Oxalic acid		13.725	1-Decanol	
18.525	Dodeca-noic acid		13.735	Oxalic acid	

Quantitative analysis

The research primarily reports qualitative changes (e.g., color change) without providing quantitative metrics on the concentration of spoilage metabolites or the degree of spoilage. Developing methods to quantify the concentration of spoilage metabolites detected by the sensor could enable a more precise assessment of food quality and safety.

CONCLUSION

Saccharomyces cerevisiae was successfully isolated from spoilt dough, and its cells were utilized for the production of silver nanoparticles (AgNPs). UV-Visible spectrophotometric analysis revealed that AgNPs formation was more efficient with 3 mM $AgNO_3$ compared to 1 mM $AgNO_3$. The absorbance peak for 1 mM $AgNO_3$ occurred at a wavelength of 300 nm, while for 3 mM $AgNO_3$, it shifted to the range of 350–450 nm. The findings indicated that pH and temperature had minimal impact on the synthesized AgNPs. FT-IR analysis confirmed the presence of functional groups such as C=O, N=N=N, C-H, and C=C, while XRD revealed prominent peaks characteristic of AgNPs. The synthesized optical nanosensor effectively detected spoilage in tested food samples, including tomatoes, doughnuts, and bread, indicated by a color change within eight days of exposure. This was accompanied by a red shift in the absorbance wavelength. The GC-MS analysis of tomato extracts, both with and without silver nanoparticles (AgNPs), identified several phytochemicals including nonanoic acid, tridecanoic acid, hexadecanoic acid, oxalic acid, dodecanoic acid, and decanoic acid in both samples suggesting that volatile metabolites from the tomato juice migrated into the AgNPs medium, causing a detectable color change in the prepared nanosensor. Consequently, the developed optical sensor shows potential as a virtual tool for detecting food spoilage.

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Declarations

Competing interest

Authors do declare that no competing interest exists.

Ethical approval

Not applicable.

Author contributions

All authors have equal contributions.

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Data availability

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

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