Synthesis of Silver Nanoparticles Using Reactive Water–Ethanol Extracts from *Murraya paniculata*

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**ABSTRACT:** Using the radiation–chemical simulation method of free radical reactions with 2,2-diphenyl-1-picrylhydrazyl, we were able to show high antiradical activity of water–ethanol extracts from *Murraya paniculata*. This will allow for the creation of new bioactive antioxidants based on them. The formation of silver nanoparticles (Ag-NP) was determined using the silver-ion reduction process by *M. paniculata* extracts. A band of electronic plasmon resonance was identified in the optical absorption spectra of hydrosols of Ag-NP using extracts of dried *M. paniculata* leaves. A decrease in the number of *Candida albicans* and *Pseudomonas aeruginosa* cells after introduction into the Ag-NP system synthesized by the reduction of silver cations using *M. paniculata* extracts indicates their moderate antimicrobial activity.

### 1. INTRODUCTION

It is known\(^1\) that preparations containing silver nanoparticles (Ag-NPs) can be used in oncology,\(^4\) cosmetology, the food industry, biosensor development, as substrates for surface-enhanced Raman scattering (SERS)\(^5\)–\(^7\) and in microelectronics. In medicine,\(^8,9\) methods for the “green” synthesis of nanoparticles (NPs) and materials containing NPs as nanofillers and/or additives are of a great practical importance. The presence of biocompatible NP-containing medicinal compounds in a pharmaceutical product provides a possibility for the treatment of complex cancer,\(^10\) as well as treatment of bacterial and viral infections. It should be emphasized that other properties of NPs synthesized using the green method are practically the same as those of analogues synthesized using the traditional methods of nanotechnology.

The synthesis of colloidal Ag-NPs in a solution using extracts from aerial parts of plants is referred to as the biochemical method. It is known\(^11,12\) that medicinal products of plant materials are better absorbed and participate in complex biochemical processes in the body. In the work,\(^13\) an extensive list of plants used as substrates for the extraction of reducing agents, as well as species of microorganisms used in a green synthesis of Ag-NPs are presented. It is shown that the size of the Ag-NPs produced depends on the parts of plants (leaves, flowers, and roots) used in the process, and that the efficiency of exposure depends on the concentration of Ag\(^+\) ions and reducing components in the solution used. There has been a report on the synthesis of dumbbell-shaped Ag-NPs and spherical Au-NPs with the use of *Garcinia mangostana* fruit extracts, which have high antibacterial\(^14\)–\(^16\) and antioxidant activities. Due to their pronounced antimicrobial properties, Ag-NPs are known to destroy fungi and other pathogens.\(^17\)

The conditions of reduction of metal cations and formation of NPs involve the influence of high reduction potentials of the active groups present in the structure of protein and metabolite molecules contained in plants,\(^18\) algae, bacteria, fungi, and yeast cells and/or some residual reduction potential of Ag\(^+\), as well as exposure of the system to other reduction agents (photoirradiation, X-ray, light, ultrasonication and others, various catalysts, and stabilizers), which also are pertinent to the process of NP formation. It is known\(^19\)–\(^21\) that terpenoids, flavonoids, glycosides, amino acids, ketones, aldehydes, and polyphenols in plant extracts can act as reducing agents in the process of the green synthesis of NPs. They contain biologically active hydroxyl and aldehyde groups responsible for the reduction of metal ions and carboxyl groups responsible for the stabilization of the resulting NPs. Simultaneous to metal cation reduction and the formation of NPs, the organic compounds of the kinds listed above, which are isolated from the original biomass, adsorb onto the NP surface. NPs generated with the use of medicinal plant extracts may elicit
a strong therapeutic effect when applied to the treatment of malignant tumors. Biologically active compounds (BAC) with high medicinal potential and reactivity in relation to free radical particles are of particular interest. Many medicinal plants have been shown to have different reactivities.

In this work, Murraya paniculata was used as a green agent for the reduction of silver ions. M. paniculata is a member of Rutaceae, the citrus family. Its healing properties (anti-inflammatory, fungicidal, anticoagulant, anticancer, antiallergic, and capillary strengthening properties) and reactivity are related to its composition; M. paniculata contains alkaloids, tannins, glycosides, saponins, flavonoids, phytocides, and coumarin compounds (umbelliferone, scopoletin, auraptene, todelonene, gleinadiene, paniculacin, and hesperidin) and trace elements. It can be assumed that the anticancer and bactericidal properties of M. paniculata may be enhanced by NPs due to the imbuenment of many of the properties of adsorbed BACs. The purpose of this study was to investigate the possibility of synthesis of hydrosols of Ag-NPs by silver nitrate reduction in water—ethanol solutions of M. paniculata leaf extracts and to study the reactivity of M. paniculata extracts.

2. RESULTS AND DISCUSSION

2.1. Micro- and Macroelement Composition of M. paniculata as Per the Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) Method. Using the ICP-MS analysis method, the maximum content of various metals present in the raw material of M. paniculata was determined (Table 1). The silver content was 0.00133 mg/g. It is known

Table 1. Content of Some Macro- and Microelements in Dried Samples of M. paniculata (mg/g of the Plant Material)

| element | M. paniculata (mg/g) | element | M. paniculata (mg/g) |
|---------|----------------------|---------|----------------------|
| Mg      | 5.61                 | Ge      | 3.58 x 10⁻³          |
| Mn      | 2.61 x 10⁻²          | As      | 2.23 x 10⁻⁹          |
| Sr      | 8.36 x 10⁻²          | Se      | 3.07 x 10⁻⁹          |
| Ba      | 2.45 x 10⁻²          | Mo      | 3.38 x 10⁻⁹          |
| Fe      | 7.45 x 10⁻¹          | Ag      | 1.33 x 10⁻⁹          |
| Ni      | 5.03 x 10⁻³          | Cs      | 3.69 x 10⁻⁹          |
| Cu      | 1.11 x 10⁻²          | TI      | 5.87 x 10⁻⁶          |
| Zn      | 1.53 x 10⁻²          | Pb      | 4.13 x 10⁻⁹          |

that if silver is present in the plant or in the working solution, the process of nanoformation metals proceeds favorably, in general.

2.2. Radiation—Chemical Investigation of Antiradical Reactions Responsible for the Biological Activity of M. paniculata. The optical absorption spectra of 70% (vol %) ethanol extracts of M. paniculata, which were prepared from dried (D) raw material (Figure 1, curve 1) and from fresh (F) leaves raw material (Figure 1, curve 2) are shown in Figure 1. Radiation stability up to a dose of 2 kGy was registered for all samples. After irradiation of extracts (at a dose of 17 kGy), a high radiation sensitivity of components in extract of F was registered, as is presented in Figure 1, curve 4; all extractable substances in the raw material extract (Figure 1, curve 4) are absorbed with the narrowing of optical absorption bands in the region of 250–400 nm. The maximum at 270 nm is attributed to the absorption of compounds possessing a chromophore containing a benzene ring.

2.3. Antiradical Activity of the M. paniculata Extract (on the Base 2,2-Diphenyl-1-picrylhydrazyl (DPPH)). The dependence of change in the effect of inhibition of extracts from M. paniculata in the reaction with 2,2-diphenyl-1-picrylhydrazyl (DPPH) radicals before and after irradiation is presented in reactions 2–4. DPPH produces a stable free radical; it has the property to be reduced and change its color in the presence of phenolic (PhOH) antioxidants from purple to yellow. The reduction rate of DPPH is higher, and the change of the solution color to yellow is more pronounced with higher solution antioxidant activity (AOA) (reaction 2). The compound formed as a result of hydrogen abstraction is involved in reactions 3 or 4 with the formation of products.37

\[
\text{PhOH} + R^* \rightarrow \text{RH} + \text{PhO}^* \tag{1}
\]

\[
\text{PhO}^* + \text{PhO}^* \rightarrow \text{product} \tag{3}
\]

\[
\text{PhO}^* + \text{DPPH}^* \rightarrow \text{product} \tag{4}
\]

It has been demonstrated that the effect of inhibition of DPPH by compounds in extracts from M. paniculata after exposure to radiation (doses of 0.8 and 4.7 kGy) remains high when the extract from M. paniculata is introduced in the volume of 200 μL (Figure 2a–c). It should be noted that in 100% (vol content) ethanol extracts, the value of the inhibition effect is about 30%, and after irradiation (dose of 4.7 kGy) about 10%. As can be seen in Figure 2d, after exposure to 0.27 and 1.08 kGy, the effect of inhibition of DPPH by extracts from M. paniculata decreases in comparison with nonirradiated samples. Also, at doses higher than 6 kGy, we observed an increase in the regenerating ability of extracts from M. paniculata (by the reaction with DPPH). It can be concluded that the recorded higher antiradical properties of the M. paniculata extract in the reaction with DPPH occur due to the products of radiation—chemical transformations in 70% ethanol extracts from M. paniculata.

2.4. Green Synthesis of Ag-NPs Using Extracts from Leaves of M. paniculata. The solution acquired an intense reddish coloring under the action of scattered light after the completion of the reduction of silver ions with M. paniculata extracts. When the solution was stored in the dark, the silver
To prove the formation of Ag-NPs, the optical absorption spectra (Figure 3) were measured using transmission electron microscopy (TEM) (Figure 3, inset). The formation of Ag-NPs in the water−ethanol extract from *M. paniculata* leaves and silver nitrate is accompanied by the appearance of a surface plasmon resonance (SPR) band in the region of 400−600 nm (Figure 3). It was found that the change in the weight of dried *M. paniculata* leaves significantly affects the SPR spectral shape and leads to its long-wave shift (Figure 3).

A detectable change was observed in the characteristics of the SPR band in the optical absorption spectra of light-irradiated water−ethanol solutions of silver nitrate and *M. paniculata* dried leaves extract, the origin of which is associated with the formation of silver hydrosols in the reducing reaction.

On the other hand, since the obtained extract from *M. paniculata* is a mixture of different classes of organic compounds (coumarines, flavonoids, phenols, etc.), we can assume that biomolecules present in the extract from *M. paniculata* leaves are able to act as reducing agent silver cations when exposed to light. An experiment was also carried out with the *Murraya* extract in the presence of silver nitrate (without the action of light), which showed no color change, and the solution of silver nitrate (under action of light) also showed no color change.

Figure 2. Changes in the effect of DPPH inhibition by water−ethanol extracts of *Murraya* depending on the dose: (a) unirradiated extract of *M. paniculata* 1:40 (*v₀ = const = 200 μL), (b) after irradiation at a dose of *D* = 0.8 kGy (*v₀ = const = 200 μL), (c) after irradiation at a dose of *D* = 4.7 kGy (*v₀ = const = 200 μL), and (d) 70% ethanol extract of *Murraya* from its addition to the system after irradiation with doses (kGy): 1–0.2–0.27, 3–1.08, 4–5.94, and 5–6.48.

Figure 3. Change in the spectral shape of the band of SPR of synthesized Ag-NPs using an aqueous *M. paniculata* extract at different concentrations: 1–2.5 mL of the *Murraya* extract (0.5 g of raw materials in 50 mL of 40% ethanol) was added into 50 mL of an aqueous solution of 1 mM silver nitrate in light for 2 days, 2–2.5 mL of the *Murraya* extract (1.5 g of raw materials in 50 mL of 40% ethanol) was added into 50 mL of an aqueous solution of 1 mM silver nitrate in light for 2 days, and 3–2.5 mL of the *Murraya* extract (2.5 g of raw materials in 50 mL of 40% ethanol) was added into 50 mL of an aqueous solution of 1 mM silver nitrate in light for 2 days. Inset: TEM images of Ag-NPs.
After filtration of the colloid solution Ag-NPs through the pores of a nuclear filter (NF) made of a poly(ethylene terephthalate) (PET) film, we used raster electron microscopy to detect the sediment in the form of a layer of Ag-NPs distributed over the filter surface (Figure 4). Consequently, the nature of the absorption band with a maximum of \( \sim 470 \) nm may be related to the plasmon resonance of Ag-NPs formed as a result of photosensitized silver cation reduction.

The function of the distribution by size of Ag-NPs was determined by processing TEM images in ImageJ 1.49 software. It was found that particle size varied from 1 to 100 nm, and the resulting histogram can be approximated by log-normal distribution with a maximum of 1.86 ± 0.18 nm.

The methods of TEM and laser light scattering registered the formation of numerous Ag-NPs (Figures 4 and 5) of mainly spherical and oval shapes sized from 5 nm to several microns (Figure 5). The maximum function of the size distribution of Ag-NPs was 25–30 nm (Figure 6).

2.5. Coulometry in the Study of the Antioxidant Activity (AOA) of Plant Extracts and Ag-NPs. We studied the AOA of extracts from \textit{M. paniculata} in the presence and absence of silver ions using coulometry (Figure 7). It was shown that Ag-NPs affect the AOA of extracts: for extracts without silver ions, it is equal to 35 \( \mu\)g/100 \( \mu\)L, and for those with silver ions, after exposure to light for 2 h and during further storage of the system in the dark or in the light, it decreases and is equal to 20/100 and 14 \( \mu\)g/100 \( \mu\)L, respectively.

It is noted that BACs of \textit{Murraya} are involved in the formation of Ag-NPs. The AOA of colloidal solutions of \textit{Murraya}/Ag-NPs decreases but remains comparable with the AOA of BHT, when at a concentration of 1 mM.

Coulometric studies of antioxidant properties provide information on the behavior of extracts before and after exposure, and are commensurate with other physical and chemical methods of analysis. The solution (\textit{Murraya} (1:20)/Ag\(^{+}\), exposed to light for 2 h and then placed in the dark) was used to determine its antimicrobial activity with respect to \textit{Candida albicans} and \textit{Pseudomonas aeruginosa}.

2.6. Antimicrobial Activity of Synthesized Ag-NPs. The functionalization of NPs with active molecules from plant extracts (which independently affect pathogens) can enhance the antimicrobial properties of green-generated NPs, as has been shown.\(^3,\)\(^5,\)\(^6\)

The mechanism of action of Ag-NPs on microbial cells involves absorption of the NPs by the cell wall, which results in...
the impairment of certain functions in the microbe that act to maintain the normal vitality of the microorganism. The present work contains an analysis of antimicrobial activity of Ag-NPs (Tables 2 and 3) synthesized using aqueous *M. paniculata* leaf extracts against the fungus *C. albicans*. The growth and development of this pathogen in the human body is often observed during antibiotic treatment, nervous shocks, and immunocompromisation. Herein, antimicrobial activity was shown using *P. aeruginosa*, a type of Gram-negative aerobic nonspore-forming bacteria, which lives in soil, water, and plants.

The examined solutions were found to have become turbid (Table 3), while sample 1 was transparent. We plated the contents of samples 2 and 3 (1 mL) into a 2% agar–agar nutrient medium. A bacterial lawn formed (Table 3), with individual complex *C. albicans* colonies visible in sample 2.

It was shown that synthesized Ag-NPs using the *Murraya* extract exhibited antimicrobial action against test cultures of *C. albicans* and *P. aeruginosa*. It was found that the minimum inhibitory concentration (MIC) of Ag-NPs for the yeast *C. albicans* was 0.15% and for the bacteria *P. aeruginosa* was 0.04%. The research results are shown in Table 3.

When Ag-NPs get inside the cells, they influence the processes of adenosine 5′-triphosphate (ATP) synthesis and DNA replication through the formation of singlet oxygen, ozone, hydroxyl radicals, and/or by the direct action of NPs in reactions between silver cations and ATP/DNA. Depending on the shape, size, and concentration of Ag-NPs in a solution and the sensitivity of the pathogens, various effects, growth inhibition, reduction of infectious activity, and, finally, microbial death may be induced.

### 3. CONCLUSIONS

The micro- and macroelement composition of *M. paniculata* has been established; its functional activity and certain reactivity have been associated with certain minerals. A silver presence in the plant that testifies the effective process of nanoformation.

The high reactivity of water–ethanol *M. paniculata* extracts has been demonstrated; we also registered the increase of the regenerating ability of *M. paniculata* extracts reacting with DPPH under exposure to ionizing radiation at a dose of 6 kGy. It can be concluded that the recorded higher antiradical properties of *M. paniculata* in the reaction with DPPH are due to the products of radiation–chemical transformations in the *M. paniculata* extracts.

The effect of silver ions on the optic absorption spectra of *M. paniculata* after exposure to light has been shown, and a new band in the visible region of the spectrum of 460–480 nm was registered. It was found that, as the *M. paniculata* concentration increased, so did the intensity of the 460–480 nm band. The fact of formation and the structure of Ag-NPs was confirmed by the TEM method, where the *M. paniculata* extract was used in a water–ethanol medium. The size of NPs was 20–50 nm.

We studied the AOA of *Murraya* extracts in the presence and absence of silver ions by coulometry. It was shown that Ag-NPs reduce the AOA of solutions: for extracts without silver ions, AOA was equal to 35 μg/100 μL of the bromine reaction, whereas for extracts with silver ions, if the system was stored in the dark, it was equal to 20 μg/100 μL. If the system was stored in the light, it was 14 μg/100 μL.

It was shown that synthesized Ag-NPs using the *M. paniculata* extract exhibited antimicrobial action against test cultures of *C. albicans* and *P. aeruginosa*. It was found that the minimum inhibitory concentration (MIC) of Ag-NPs for the

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**Table 2. Growth of Test Cultures of Microorganisms in a Liquid Nutrient Medium in the Presence of a Silver Colloid Solution Prepared from the *M. paniculata* Extract at Different Concentrations**

| sample | synthesized Ag-NPs using aqueous *M. paniculata* extract at different concentrations (%) | growth of *C. albicans* ATCC 8856/653 | growth of *P. aeruginosa* VKPM-B-8243 |
|--------|----------------------------------------------------------------|-----------------------------------|----------------------------------|
| 0      | 0 (control)                                                   | +                                 | +                                |
| 1      | 0.30                                                          | −                                 | −                                |
| 2      | 0.15                                                          | −                                 | −                                |
| 3      | 0.08                                                          | +                                 | −                                |
| 4      | 0.04                                                          | +                                 | +                                |
| 5      | 0.02                                                          | +                                 | unexamined                       |
| 6      | 0.01                                                          | +                                 | unexamined                       |
| 7      | 0.005                                                         | +                                 | unexamined                       |

*In table, “+” indicates the systems where growth of microorganisms was observed and “−” indicates those with no microbial growth of *C. albicans* and *P. aeruginosa.*
yeast C. albicans was 0.15% and for the bacteria P. aeruginosa was 0.04%. Thus, a decrease in the number of C. albicans and P. aeruginosa cells after introduction into the system of Ag-NPs synthesized by the reduction of M. paniculata extracts indicates their moderate antimicrobial activity.

The use of reactive plant extracts as metal cationic reducers in the green synthesis of Ag-NPs is of practical importance, considering their eventual applications; it is dependent on the use of a particular plant extract with known functional activity and biological safety of samples.

4. EXPERIMENTAL SECTION

Samples of 2,2-diphenyl-1-picrylhydrazyl (DPPH), butylated hydroxytoluene (BHT), and silver nitrate were obtained from Sigma-Aldrich. Pure water was prepared using a Millipore α-Q apparatus, and the resistivity of the apparatus was 18.2 MΩ.

Samples of dry M. paniculata were collected from the Yangon Botanical Garden in the Republic of Myanmar.

4.1. Inductively Coupled Plasma-Mass Spectrometry (ICP-MS). Samples of the dry plants were crushed before analysis. Crushed samples (100 mg) were placed into a fluoroplastic autoclave, and then 4 mL of nitric and 0.10 mL of hydrofluoric acids were added. The autoclave was sealed and kept in a microwave sample preparation system-6 (180 °C, 20 ATM) for 15 min. Samples of solutions diluted with 2% HNO₃ were analyzed by ICP-MS (Thermo Scientific Fisher mass spectrometer iCAP-Qc) using argon as a plasma-forming gas.⁴¹

4.2. Preparation of M. paniculata Extracts for Determination of Antiradical Activities (on the base DPPH). In this paper, we have studied dried (D) and fresh (F) Murraya leaves. Water–ethanol extracts of Murraya in a ratio of 1:20 (2.5 g of raw materials in 50 mL of 70% of ethanol) were prepared.

The antiradical properties of dried water–ethanol extracts in a ratio of 1:40 (2.5 g of raw materials in 100 mL ethanol by volume) of Murraya were estimated in terms of their reactivity with stable radical DPPH by spectrophotometry using 0.2 mM DPPH in ethanol; this composition was brought to a total ethanol content of 50%, and optical density values were measured at $\lambda = 517$ nm relative to ethanol.³⁷ The inhibition percentage of DPPH (inh., %) was calculated using formula 5

$$\text{inh. (\%)} = 100 \times \left(\frac{A_c - A_o}{A_c}\right)$$

where $A_c$ is optical density in the absence of analytes (control) and $A_o$ is optical density in the presence of analytes.

To determine the total antioxidant activity of Murraya, a coulometry method was used. The content of the initial component (dried Murraya leaves) in solution was 1:33 and 1:20 diluted (subsequently diluted 20 times) in water. As comparison standards for AOA, 1 and 10 mM ethanol solutions of BHT were used.

4.3. Biosynthesis of Ag-NPs. To obtain water–ethanol extracts of various concentrations, we added 0.5, 1.0, and 2.5 g of dried M. paniculata leaves placed in 50 mL of 40% ethanol and kept in the dark in the air at room temperature for a week. Then, to 2.5 mL of the M. paniculata extract, 50 mL of 1 mM aqueous AgNO₃ was added with stirring. Then, the solution was kept in the light for 2 days in air at room temperature.

4.4. Characterization of Ag-NPs. The NFs used in this work were obtained from “Hostaphan” (Dubna, Russia). NFs of thickness 12 μm were produced by the irradiation of PET with a stream of accelerated xenon ions. The average size of the...
micropores of the NF was 0.22 µm and the surface density was around 4.6 × 10^7 cm^{-2}.

4.4.1. Transmission Electron Microscopy (TEM) Analysis. TEM analysis was carried out using an FEI Versa 3D Tecnai G2 F20 S-Twin TMP (FEI production Company) at an acceleration voltage of 200 kV under a bright field. The device resolution was 0.14 nm (line resolution). Processing and analysis of electron microscopic images were performed using ImageJ 1.49 software, using the Fracplug plug-in, both of which are publicly available on the Internet.

4.5. Spectrophotometry. The optical absorption spectra of aerated water–ethanol extracts of M. paniculata and colloidal solutions with silver were measured on an SF-2000 spectrophotometer, Russia. The selected solvents served as the reference standard; the optical path length of quartz cells was 1 cm.

4.6. Coulometry. Measurements were made using the Expert-006, Russia, coulometric analyzer, which provides coulometric titrations in a galvanostatic mode with a current interval from 1 to 50 mA. The quantity of electricity was measured with a relative error of no more than ±0.2%. The coulometric assay was performed according to the method.45,46

4.7. 60Co γ-Source. The RCHM-γ-20 plant housing a 60Co γ-ray source (D. Mendeleev University of Chemical Technology of Russia) was used to determine the reactivity of extracts from M. paniculata in the presence of DPPH. A Fricke dosimeter was used to estimate the dose rate of the absorbed radiation. The dose rate was determined to be 0.078 ± 0.002 Gy/s.45,46

4.8. Method for the Determination of the Antimicrobial Activity of Ag-NPs. The antimicrobial activity of Ag-NPs synthesized using extracts of the leaves of M. paniculata was studied using the serial dilution method for the determination of MIC in accordance with the methodological complex “Determination of the sensitivity of microorganisms to antimicrobial drugs.”46,47 C. albicans (ATCC 885-653) P. aeruginosa (VKPM-B-8243) were used as test organisms.

C. albicans cells were grown on a nutrient medium of the following composition, g/L: 10.0 peptone; 40.0 glucose; and 1 L distilled water was brought to 1 L. The pH of the medium was 6.5. To prepare a dense nutrient medium, agar–agar was added in an amount of 20 g/L.

P. aeruginosa cells were grown on a nutrient medium, g/L: 10.0 peptone; 1.5 K2HPO4; 1.5 MgSO4·7H2O; 8 mL glycerin; and 1 L distilled water. The pH of the medium was 7.0. Crops were incubated in a thermostat at 35 °C for 48 h.

The reference solution (control) was prepared without introducing Ag-NPs solutions. The comparison was carried out with the control, which was the growth of test strains of microorganisms in a liquid nutrient medium. The antimicrobial effect of Ag-NPs was assessed visually by the presence or absence of growth of test strains in a liquid nutrient medium. The concentration range of the solution with Ag-NPs was 0.005–0.3%. The samples were sieved after incubation on a solid nutrient medium to exclude errors in the visual assessment of yeast growth of C. albicans in a liquid medium. The samples were kept for a week without exposure to light.

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The manuscript was written through the contributions from all authors. All authors have given approval to the final version of the manuscript.

Notes
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■ ABBREVIATIONS USED
BAC, biologically active compounds; AOA, antioxidant activity; DPPH, 2,2-diphenyl-1-picrylhydrazyl; NP, nanoparticle; Ag-NP, silver nanoparticle; NF, nuclear filter; SPR, surface plasmon resonance; TEM, transmission electron microscopy; PET, poly(ethylene terephthalate)

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