

Original Research Article

Green Synthesis of Selenium Nanoparticles Using *Kyllinga Brevifolia* Rottb and their Antioxidant Activity

Daikun Chen^{1*}, Dong Li¹¹School of Food and Liquor Engineering, Sichuan University of Science and Engineering, Yibin 644000, China**Article History**

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Abstract: This study aimed to develop a novel method for the green synthesis of selenium nanoparticles (SeNPs) using an aqueous extract of *Kyllinga brevifolia*, providing a safe and efficient nanomaterial preparation technology for food preservation. The extract was prepared by the water extraction method and reacted with sodium selenite solution at 100°C. After 48 h of incubation, the product was purified by centrifugation and freeze-dried to obtain SeNPs. The nanoparticles were characterized using gas chromatography-mass spectrometry (GC-MS), ultraviolet-visible (UV-Vis) spectroscopy, scanning electron microscopy (SEM), Fourier transform infrared (FT-IR) spectroscopy, X-ray diffraction (XRD), and dynamic light scattering (DLS). Their antioxidant activity was evaluated by DPPH and ABTS radical scavenging assays. The results showed that the reaction solution changed from transparent brownish-red to turbid brick-red, with a maximum absorption peak at 407 nm. SEM revealed uniform spherical nanoparticles. XRD patterns exhibited diffraction peaks at 2θ angles of 21.80°, 23.74°, and 29.92°, consistent with the JCPDS standard. DLS measurements indicated an average particle size of 66.44 nm, a polydispersity index (PDI) of 0.1153, and a zeta potential of -16.69 mV. GC-MS identified 17 active components, among which linoleic acid, oleic acid, and 4-hydroxy-2,5-dimethylfuran-3(2H)-one-containing C=C bonds and -OH groups-reduced Se⁴⁺ to Se⁰ and exerted capping and stabilizing effects. The DPPH and ABTS radical scavenging assays demonstrated concentration-dependent antioxidant activity of the SeNPs. This study successfully transformed an invasive weed into functional nanomaterials. The established green synthesis method is simple, environmentally friendly, and low-cost, laying a theoretical foundation for the application of SeNPs in fruit and vegetable preservation and functional food development.

Keyword: *Kyllinga Brevifolia* Rottb, Selenium Nanoparticles, Green Synthesis, Antioxidant Activity, Food Preservation.

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INTRODUCTION

Selenium (Se) is a trace element present in certain microorganisms, humans, and animals that plays a crucial role in maintaining normal physiological functions and is considered an essential cofactor for antioxidant enzymes (Duță, Muscurel, Dogaru, & Stoian, 2025). In the natural environment, selenium exists in various chemical forms, mainly including selenate (SeO₄²⁻, +6 valence), selenite (SeO₃²⁻, +4 valence), elemental selenium (Se⁰, 0 valence), and selenide (Se²⁻, -2 valence). Among these, selenium oxides (SeO₄²⁻ and SeO₃²⁻) pose serious threats to environmental and human health due to their high water solubility, bioaccumulation, and toxicity (Hadrup & Ravn-Haren,

2023). Studies have shown that Se(IV) is considered to be the most toxic form among all selenium species, exerting toxic effects on cells through mechanisms including inhibition of cellular respiration, interference with enzyme activity, disruption of antioxidant systems, and impediment of DNA repair (Peng, Fu, Ye, & Tang, 2021). In recent years, the rapid development of nanotechnology has provided new insights for selenium bioavailability. Selenium nanoparticles (SeNPs), with their large specific surface area and small size effects, exhibit higher biosafety and bioavailability (T. Zhang *et al.*, 2023). SeNPs not only possess significant antitumor, antioxidant, and antibacterial properties, but also exhibit acute toxicity far lower than other selenium species. Studies have shown that the median lethal dose (LD50)

*Corresponding Author: Daikun Chen

School of Food and Liquor Engineering, Sichuan University of Science and Engineering, Yibin 644000, China

of selenium nanoparticles in mice is 92.1 mg/kg, which is 3.5 and 7 times higher than that of selenomethionine (LD50 of 25.6 mg/kg) and sodium selenite (LD50 of 15.7 mg/kg), respectively (J. S. Zhang, Gao, Zhang, & Bao, 2001).

Physical, chemical, biological, and hybrid methods are commonly employed for the synthesis of various types of nanomaterials. However, physical and chemical production methods are subject to various limitations. Specifically, the use of toxic chemicals during the synthesis process greatly restricts their applications in biomedical and agricultural fields (Yilmaz, İspirli, Taylan, & Dertli, 2021). On the other hand, these methods are characterized by complex procedures, high costs, and the generation of hazardous toxic by-products, which not only pose threats to ecosystems but also cause potential harm to human health (Sadeghi *et al.*, 2024). In recent years, bio-based green synthesis methods have gradually emerged as a new research focus for the preparation of selenium nanoparticles. Green synthesis methods successfully prepare selenium nanoparticles by utilizing natural biological materials such as bacteria, fungi, algae, and plants as stabilizing and reducing agents (Das *et al.*, 2017; Joshi, De Britto, Jogaiah, & Ito, 2019). According to previous studies, compared with traditional physicochemical preparation methods, selenium nanoparticles synthesized by green methods using biological materials not only avoid the use of toxic reagents during the preparation process, making them more environmentally friendly, but also possess advantages such as low production costs and high biocompatibility (Das *et al.*, 2017). Among various green synthesis methods, plant extract-mediated synthesis has attracted more attention than microorganism-mediated synthesis, which is attributed to the advantages of using plant extracts as reducing and stabilizing agents compared to other biological sources. Plant extracts typically contain bioactive molecules such as proteins, flavonoids, terpenoids, sterols, polysaccharides, vitamins, phenolic compounds, organic acids, and natural surfactants, which provide high stability and strong dispersibility for the synthesized SeNPs (Abdelnour *et al.*, 2021; Ikram, Javed, Raja, & Mashwani, 2021). Plant extract-mediated synthesis facilitates the regulation of nanoparticle size, morphology, and nanomaterial assembly. Sheikhlou *et al.*, (Sheikhlou, Allahyari, Sabouri, Najian, & Jafarizadeh-Malmiri, 2020) successfully synthesized SeNPs with an average particle size of 375 nm using walnut leaf extract as a reducing and stabilizing agent. Yilmaz *et al.*, (Yilmaz *et al.*, 2021) successfully prepared SeNPs with particle sizes ranging from 20 nm to 50 nm using tarragon extract. These studies demonstrate that plant extract-mediated green synthesis methods have broad application prospects in SeNPs preparation.

Kyllinga brevifolia Rottb. is a perennial herb belonging to the family Cyperaceae and genus *Kyllinga*,

also known as Lanfucuo or Nuejicao (malaria grass). It has a pungent, slightly bitter, and sweet taste with neutral properties, possessing significant medicinal and ecological value. It is mainly distributed in southern China, southwestern China, and the Yangtze River basin (Jianfei, Shumei, & Leng, 2021). The whole plant of *Kyllinga brevifolia* can be used as medicine. In traditional medicine, it is commonly used for symptoms such as common cold with wind-cold, malaria, jaundice, dysentery, sores and swellings, and has effects including dispelling wind and releasing the exterior, clearing heat and promoting diuresis, relieving cough and resolving phlegm, and removing blood stasis and reducing swelling (Jianfei *et al.*, 2021). *Kyllinga brevifolia* is rich in various active components. Its extract contains volatile oils, flavonoids, phenols, anthraquinones, sterols, and organic acids, which confer various biological activities including anti-inflammatory, antibacterial, and antioxidant properties (Jianfei, Shumei, & Leng, 2020; Zhenghua, Zhongqin, Xiaowei, Lianjie, & Dehua, 1995). Chanyal *et al.*, (Chanyal *et al.*, 2026) synthesized iron oxide nanoparticles using an aqueous extract of safflower (*Carthamus tinctorius*) and found that phenols, aldehydes, and alcohols in the extract acted as reducing and stabilizing agents. Cherian *et al.*, (Cherian, Merlin, Rajendran, & Thomas, 2025) found that flavonoids, catechins, and other substances acted as reducing and stabilizing agents when synthesizing SeNPs using an aqueous extract of white mulberry (*Morus alba*). Therefore, *Kyllinga brevifolia* can serve as a natural reducing and stabilizing agent for selenium nanoparticles.

In the present study, sodium selenite (Na_2SeO_3) served as the selenium source for the green synthesis of selenium nanoparticles (SeNPs), utilizing active compounds including glycosides, phenols, and flavonoids from *Kyllinga brevifolia* extract. Gas chromatography-mass spectrometry (GC-MS) was utilized to identify the components in the extract that function as reducing and stabilizing agents. The synthesized SeNPs were systematically characterized regarding morphology, particle size, stability, surface functional groups, and crystalline structure using scanning electron microscopy (SEM), nanoparticle size and Zeta potential analysis, UV-Vis spectroscopy, Fourier transform infrared spectroscopy (FT-IR), and X-ray diffraction (XRD). Furthermore, the antioxidant activity of the biosynthesized SeNPs was assessed through their scavenging capacity against 2,2-diphenyl-1-picrylhydrazyl (DPPH) and 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) diammonium salt (ABTS) free radicals. This research aims to establish a novel green synthesis approach for SeNPs and provide a theoretical basis for applications in food preservation.

1. MATERIALS AND METHODS

1.1 Materials and Reagents

Kyllinga brevifolia was provided by the Plant Resource Development and Utilization Laboratory,

Sichuan University of Science & Engineering. Sodium selenite (Na_2SeO_3) was purchased from Shanghai Aladdin Biochemical Technology Co., Ltd.

1.2 Instrumentation

D2PHASER X-ray diffractometer, Bruker AXS GmbH, Germany; Nano ZS90 nanoparticle size and Zeta potential analyzer, Malvern Instruments Ltd., UK; Spectrum Two N Fourier transform infrared spectrometer, PerkinElmer Inc., USA; VEGA 3 SBU scanning electron microscope, Tescan a.s., Czech Republic; UV-1900i UV-Vis spectrophotometer, Shimadzu Corporation, Japan; SCIENTZ-12N vacuum freeze dryer, Ningbo Scientz Biotechnology Co., Ltd., China.

1.3 Preparation of *Kyllinga brevifolia* Rottb Extract

Freshly harvested *Kyllinga brevifolia* was washed to remove dust and impurities, then dried at 30°C until constant weight was achieved. The dried *Kyllinga brevifolia* was ground into powder using a pulverizer. Ten grams of *Kyllinga brevifolia* powder was added to 100 mL of distilled water, mixed thoroughly, and heated to boiling on an electric furnace for 10 min. The mixture was then extracted at 70°C for 2 h, cooled to room temperature, and filtered to obtain the *Kyllinga brevifolia* extract, which was stored at 4°C in the dark for further use.

1.4 Biosynthesis of Selenium Nanoparticles (SeNPs)

Based on the method described by Hashem *et al.*, (Hashem & Salem, 2021) with minor modifications. A total of 0.6 g of Na_2SeO_3 was weighed and dissolved in 250 mL of distilled water. After incubating in a water bath at 80°C for 30 min, 20 mL of *Kyllinga brevifolia* extract was added and heated to boiling until the solution changed from brownish-red to brick-red. The solution was then incubated in a shaker at 150 rpm for 48 h. After incubation, the mixture was centrifuged at 8000 rpm for 20 min at 4°C, followed by repeated washing and centrifugation with distilled water until the supernatant became clear. The red precipitate was collected to obtain SeNPs. Finally, the synthesized SeNPs were placed in a freeze dryer for 24 h to obtain SeNPs powder.

1.5 GC-MS Analysis of *Kyllinga brevifolia* Extract

Ten grams of *Kyllinga brevifolia* powder was added to 100 mL of distilled water and extracted at 100°C for 2 h. The supernatant was collected and filtered through a 0.45 μm PTFE filter. GC-MS was used to compare the *Kyllinga brevifolia* extract before and after SeNPs synthesis, in order to identify the major active compounds in the extract that served as reducing and stabilizing agents.

Based on the method described by Siddique *et al.*, (Siddique, Al-Samman, & Kakhshan, 2024) with minor modifications. Samples were analyzed using a TSQ 8000 GC-MS system equipped with a split/splitless injector. Samples were injected in splitless mode with the

injector temperature set at 350°C and an injection volume of 1 μL . A TG-5MS fused silica capillary column (30 m \times 0.25 mm \times 0.25 μm) (USD306454) was employed. The GC temperature program was as follows: initial temperature 40°C (held for 0 min), ramped at 8°C/min to 275°C (held for 10 min), then ramped at 8°C/min to 300°C (held for 2 min), with a total run time of 45 min. For the MS system, mass spectra were recorded in electron impact (EI) ionization mode at 70 eV with a mass range of 40-400 m/z. Compounds were identified by comparing mass spectra with those in the mass spectral libraries (WILEY 6.0 and NIST 2.0).

1.6 Characterization of SeNPs Synthesized by *Kyllinga brevifolia* Extract

1.6.1 UV-Vis Spectroscopy Analysis

One hundred microliters of SeNPs solution was transferred to a 10 mL volumetric flask and diluted to the mark with distilled water. The absorbance of the selenium nanoparticles was measured using a UV-Vis spectrophotometer against the extract as a blank. The wavelength scan was performed in the range of 380-800 nm.

1.6.2 Scanning Electron Microscopy (SEM) Analysis

A total of 0.05 g of SeNPs powder was mixed with 1 mL of 2.5% glutaraldehyde and fixed overnight at 4°C. The sample was dehydrated with absolute ethanol three times for 15 min each, followed by freeze-drying. After gold sputtering using an SBC-2 ion sputtering apparatus under vacuum, the morphology of SeNPs was analyzed by scanning electron microscopy.

1.6.3 Fourier Transform Infrared (FT-IR) Spectroscopy Analysis

One milligram of SeNPs powder was thoroughly ground and mixed with potassium bromide (KBr) pellets, then compressed into a thin disk under high pressure. Fourier transform infrared (FT-IR) spectra were recorded in the wavenumber range of 4000-400 cm^{-1} with a data acquisition interval of 1 s to analyze the characteristic chemical bonds and functional groups.

1.6.4 X-ray Diffraction (XRD) Analysis

The freeze-dried SeNPs sample was thoroughly ground. The crystalline structure of SeNPs was evaluated using an X-ray diffractometer. The measurements were performed with a copper target ($\text{Cu K}\alpha$) in the 2θ range of 15-80°, with a step size of 0.02° and a dwell time of 0.1 s per step.

1.6.5 Particle Size Distribution (DLS) and Zeta Potential Measurement

The obtained SeNPs powder was dispersed in ultrapure water and sonicated for 20 min prior to measurement to ensure good aqueous dispersion. The particle size and zeta potential of the SeNPs sample were analyzed using a nanoparticle size and Zeta potential analyzer.

1.7 Determination of Antioxidant Activity

The antioxidant activities of SeNPs were evaluated using DPPH and ABTS assay kits.

2. RESULTS AND DISCUSSION

2.1 GC-MS Analysis

Numerous studies have demonstrated that plant extracts can be used for the green synthesis of nanoparticles. The compounds present in *Kyllinga brevifolia* extract before and after green synthesis of SeNPs were identified by GC-MS. As shown in Fig. 1, the GC-MS chromatogram revealed the major compounds present in *Kyllinga brevifolia* extract. Table 1 lists 17 active components with their retention times (RT), compound names, and structures.

As shown in Table 1, alcohols, phenols, acids, and esters were the major chemical constituents identified in the basic extract obtained from *Kyllinga brevifolia*. Among them, linoleic acid (C₁₈H₃₂O₂), oleic acid (C₁₈H₃₄O₂), *cis*-8,11,14-eicosatrienoic acid (C₂₀H₃₄O₂), and methyl arachidonate (C₂₁H₃₄O₂) are biomolecules containing carbon-carbon double bonds (C=C), which act as capping agents during the green synthesis process. The C=C bonds serving as capping agents can successfully reduce the oxidation of nanoparticles, thereby enhancing their stability (Guan *et al.*, 2024). Secondly, biomolecules such as 4-hydroxy-2,5-dimethyl-3(2H)-furanone (C₆H₈O₃), methyl eugenol

(C₁₁H₁₄O₂), 2,4-di-*tert*-butylphenol (C₁₄H₂₂O), 3,7,11-trimethyl-1-dodecanol (C₁₅H₃₂O), (±)-3-hydroxylauric acid (C₁₂H₂₄O₃), and tocopherol (C₂₉H₅₀O₂) contain both C=C bonds and hydroxyl groups (-OH), which act as both reducing agents and capping agents (Palanivel, Muthumanickam, chinnathambi, & subbiah, 2024). When these active components reduce sodium selenite (Se⁴⁺) to elemental selenium (Se⁰), their hydroxyl groups (-OH) and aldehyde groups (-CHO) from other substances are oxidized to carboxyl groups (-COOH), while the C=C bonds are capped on the surface of the nanoparticles. In addition, components such as methyl palmitate (C₁₇H₃₄O₂), palmitic acid (C₁₆H₃₂O₂), allyl caprate (C₁₃H₂₄O₂), and phytosterol (C₂₉H₅₀O) may form a protective coating layer on the nanoparticle surface through hydrophobic interactions and steric hindrance effects, further enhancing the dispersion stability of SeNPs (Nain, Kaur, Nagre, Tiwari, & Yadav, 2026).

Numerous studies have also reported that alcohols, phenols, and acids participate in the bioreduction, formation, and stabilization of nanoparticles. Furthermore, by comparing the information shown in Fig. 1(a) and Fig. 1(b), a decrease in the content of some biomolecules in *Kyllinga brevifolia* extract was observed after biosynthesis of SeNPs. These results suggest that alcohols, phenols, acids, and esters in *Kyllinga brevifolia* extract may act as reducing and stabilizing agents and are responsible for the formation of SeNPs.

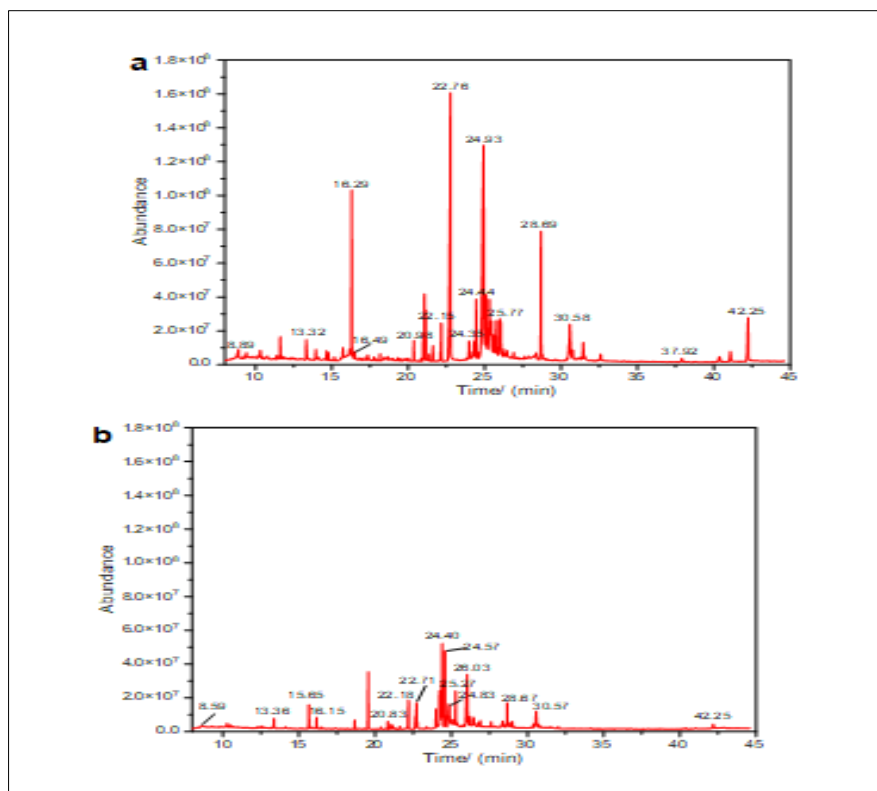
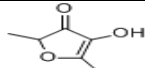
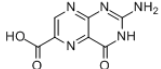
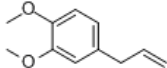
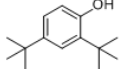
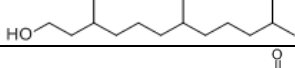
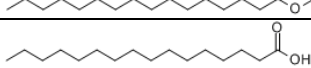
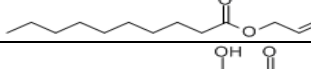
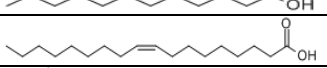
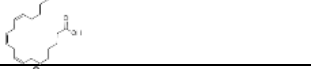
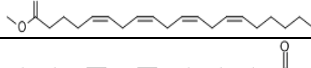
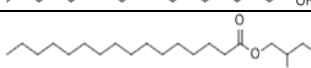
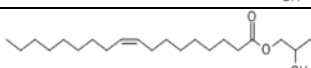
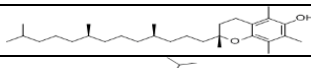
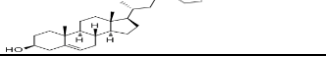
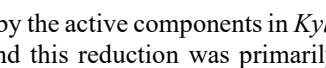
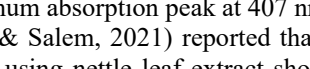
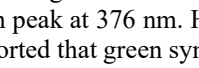


Fig. 1: GC-MS analysis of extracts from *Kyllinga brevifolia* before and after reaction

Note: a, GC-MS analysis of *Kyllinga brevifolia* extract before reaction; b, GC-MS analysis of *Kyllinga brevifolia* extract after reaction.

Table 1: The active principles in the extract of *Kyllinga brevifolia*

Compound Name	Molecular Formula	Structural Formula	Retention Time
4-Hydroxy-2,5-dimethyl-3(2H)-furanone	C ₆ H ₈ O ₃		8.89
2-Amino-1,4-dihydro-4-oxopteridine-6-carboxylic acid	C ₇ H ₅ N ₃ O ₃		13.32
Methyl eugenol	C ₁₁ H ₁₄ O ₂		16.29
2,4-Di-tert-butylphenol	C ₁₄ H ₂₂ O		16.49
3,7,11-Trimethyl-1-dodecanol	C ₁₅ H ₃₂ O		20.98
Methyl hexadecanoate	C ₁₇ H ₃₄ O ₂		22.15
Palmitic acid	C ₁₆ H ₃₂ O ₂		22.76
Decanoic acid,2-propen-1-yl ester	C ₁₃ H ₂₄ O ₂		24.35
Dodecanoic acid,3-hydroxy-	C ₁₂ H ₂₄ O ₃		24.44
Oleic acid	C ₁₈ H ₃₄ O ₂		24.93
8,11,14-Eicosatrienoicacid, (8Z,11Z,14Z)-	C ₂₀ H ₃₄ O ₂		25.1
5,8,11,14-Eicosatetraenoicacid	C ₂₁ H ₃₄ O ₂		25.77
Linoleic acid	C ₁₈ H ₃₂ O ₂		25.99
2-hydroxy-1-(hydroxymethyl)ethyl ester	C ₁₉ H ₃₈ O ₄		28.69
Glyceryl monooleate	C ₂₁ H ₄₀ O ₄		30.58
Vitamin E	C ₂₉ H ₅₀ O ₂		37.92
beta-Sitosterol	C ₂₉ H ₅₀ O		42.25

2.2 Characterization of SeNPs

2.2.1 UV-Vis Spectroscopy Analysis

UV-Vis spectroscopy was used to measure the absorption spectra of SeNPs biosynthesized using *Kyllinga brevifolia* extract and Na₂SeO₃ solution in the wavelength range of 350-800 nm. As shown in Fig. 2, the color change of the Na₂SeO₃ solution before and after reaction with *Kyllinga brevifolia* extract for 48 h is presented. After the reaction, the solution color changed from transparent orange-red to turbid brick-red, with an absorption peak appearing at 407 nm. This color change indicated that selenium in sodium selenite was reduced

to SeNPs by the active components in *Kyllinga brevifolia* extract, and this reduction was primarily confirmed by the maximum absorption peak at 407 nm. Hashem *et al.*, (Hashem & Salem, 2021) reported that green synthesis of SeNPs using nettle leaf extract showed a maximum absorption peak at 376 nm. Hassan *et al.*, (Hassan *et al.*, 2022) reported that green synthesis of SeNPs using *Olea europaea* (olive) fruit extract showed a maximum absorption peak at 258 nm. These results indicate that *Kyllinga brevifolia* extract successfully synthesized SeNPs.

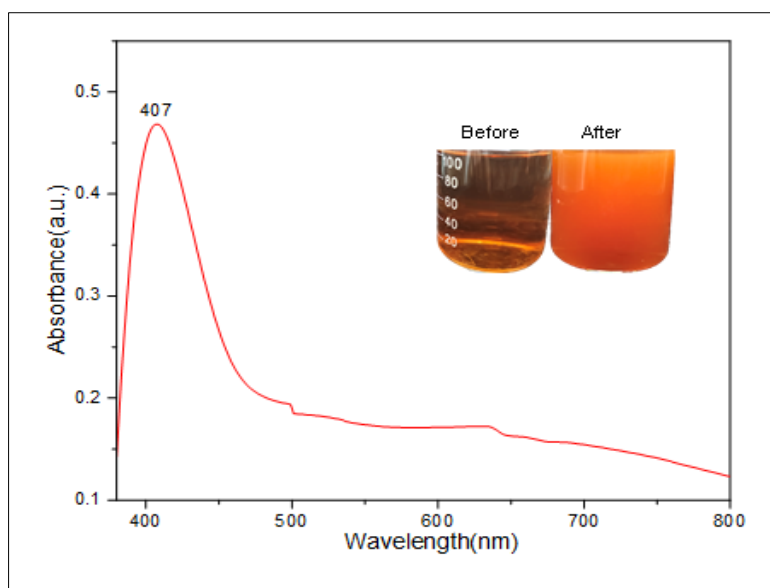


Fig. 2: UV-Vis spectrum of SeNPs

2.2.2 SEM Analysis of SeNPs

To observe the morphology of SeNPs synthesized by *Kyllinga brevifolia* extract, SEM analysis was performed. As shown in Fig. 3(a), the SEM image of SeNPs at 15 kV revealed that the synthesized SeNPs were spherical, uniformly sized, and well-dispersed. The EDS spectrum analysis of SeNPs is shown in Fig. 3(b).

The synthesized SeNPs exhibited strong elemental peaks for C, O, and Se, with mass percentages of C (75.31%), O (11.24%), and Se (10.73%), respectively. In addition, the strong peak observed at 1.41 KeV was a typical absorption signal of Se, indicating that the synthesized SeNPs possessed high purity.

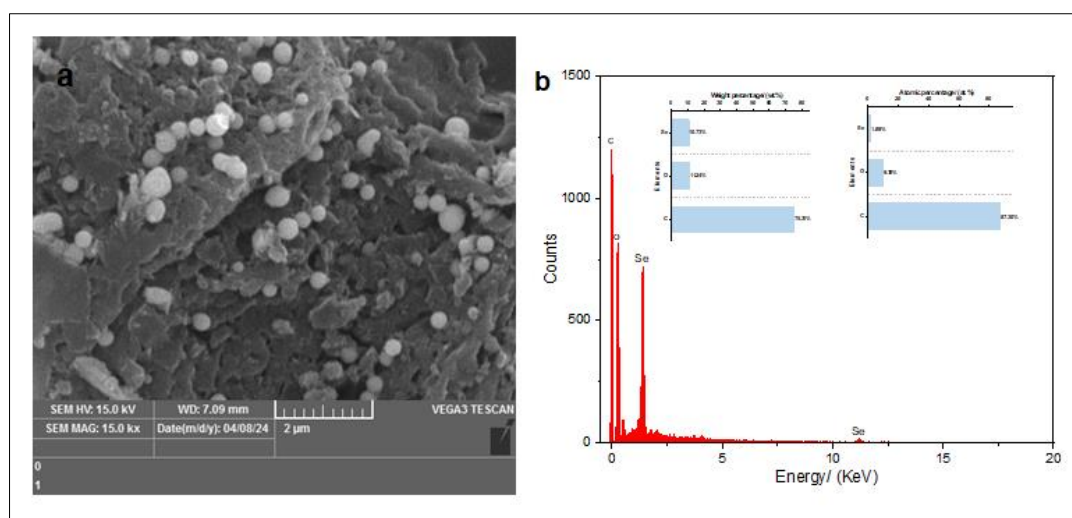


Fig. 3: SEM scan (a) and EDS spectrum (b) of SeNPs

2.2.3 FT-IR Analysis

FT-IR spectroscopy was further employed to identify the functional groups and biomolecules responsible for the synthesis and capping during SeNPs formation. The FT-IR spectrum of SeNPs synthesized using *Kyllinga brevifolia* extract as reducing and stabilizing agents is shown in Fig. 4. The FT-IR spectrum recorded at 3431, 2918, 2345, 1631, 1047, and 575 cm^{-1} exhibited stretching and vibrational bands. The absorption peak at 3431 cm^{-1} is characteristic of -OH group and N-H bond stretching vibrations, indicating the presence of alcohols and phenolic compounds. The peak

at 2918 cm^{-1} corresponds to C-H stretching, suggesting the presence of aromatic compounds. The absorption peak at 2345 cm^{-1} is attributed to C=O bonds, possibly indicating carboxyl groups. The peak at 1631 cm^{-1} may be associated with C=C aromatic bonds (Dang-Bao *et al.*, 2022). The absorption peak at 1047 cm^{-1} corresponds to C-O stretching, indicating the possible presence of aldehyde or ketone groups. The absorption peak at 575 cm^{-1} is attributed to C-N bonds, which may be associated with proteins (Hernández-Díaz *et al.*, 2021; Lomelí-Rosales *et al.*, 2022). Based on the obtained FT-IR spectral results, these functional groups may form

phenols, amines, carbohydrates, alcohols, and carboxylic acids, acting as reducing agents, capping agents, and stabilizers for SeNPs. This preliminarily confirmed that

Kyllinga brevifolia extract contains various reducing and stabilizing agents that successfully participated in the green synthesis of SeNPs.

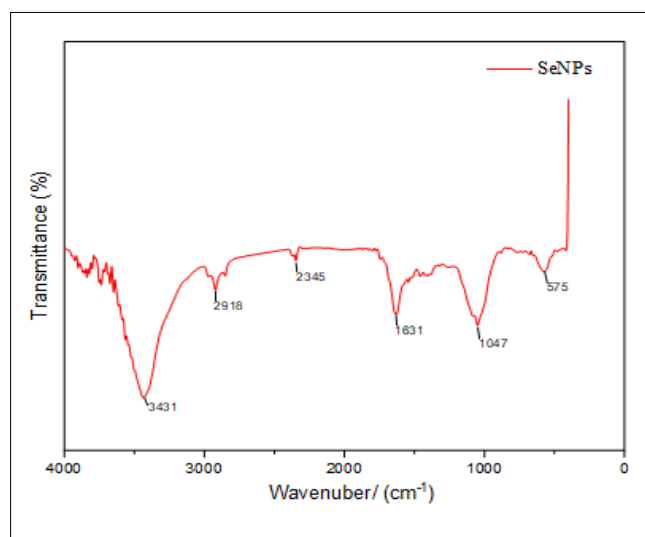


Fig. 4: FT-IR spectrum of SeNPs

2.2.4 XRD Analysis

The crystalline properties and spherical structure of SeNPs were investigated by XRD. The XRD pattern of SeNPs synthesized by *Kyllinga brevifolia* extract is shown in Fig. 5. The X-ray diffraction pattern of SeNPs exhibited diffraction peaks at 2θ values of 21.80° , 23.74° , 29.92° , 43.89° , 45.81° , 51.93° , 56.15° , 61.75° , and 65.54° , corresponding to the (100), (101), (102), (111), (201), (112), (202), and (210) crystal

planes. The XRD pattern of SeNPs was in complete accordance with the pure phase of selenium (JCPDS card No. 86-2246). This result is consistent with those reported by Salem and Alam *et al.*, (Alam, Khatoon, Raza, Ghosh, & Sardar, 2018; Salem *et al.*, 2020) for the synthesis of selenium nanoparticles, confirming that the synthesized SeNPs possess high crystallinity, better morphological structure, and enhanced application.

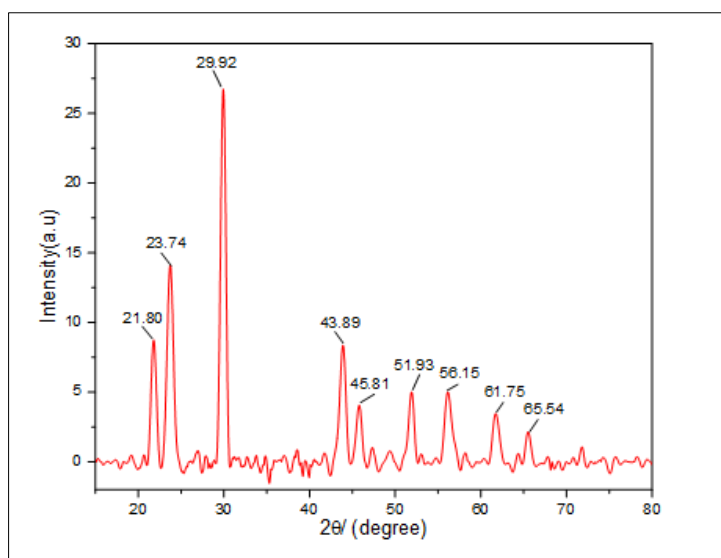


Fig. 5: XRD spectrum of SeNPs

2.2.5 DLS/Zeta Potential Analysis

The stability, size distribution, and polydispersity index (PDI) of the synthesized SeNPs were evaluated by Zeta potential and DLS analysis. As shown in Fig. 6(a), the prepared SeNPs exhibited an average particle size of 66.44 nm with a PDI value of

0.1153. Higher absolute values of Zeta potential represent better stability of the solution. As shown in Fig. 6(b), the Zeta potential of the synthesized SeNPs was -16.69 mV, indicating that the SeNPs nanoparticles possessed a negatively charged surface with high stability. Hashem *et al.*, (Hashem & Salem, 2021)

reported that SeNPs synthesized using nettle leaf extract had an average size of 107.7 nm and a negative charge of -14.5 mV. These findings demonstrate that SeNPs

synthesized by *Kyllinga brevifolia* extract exhibited uniform particle size distribution, good dispersion, and excellent solution stability.

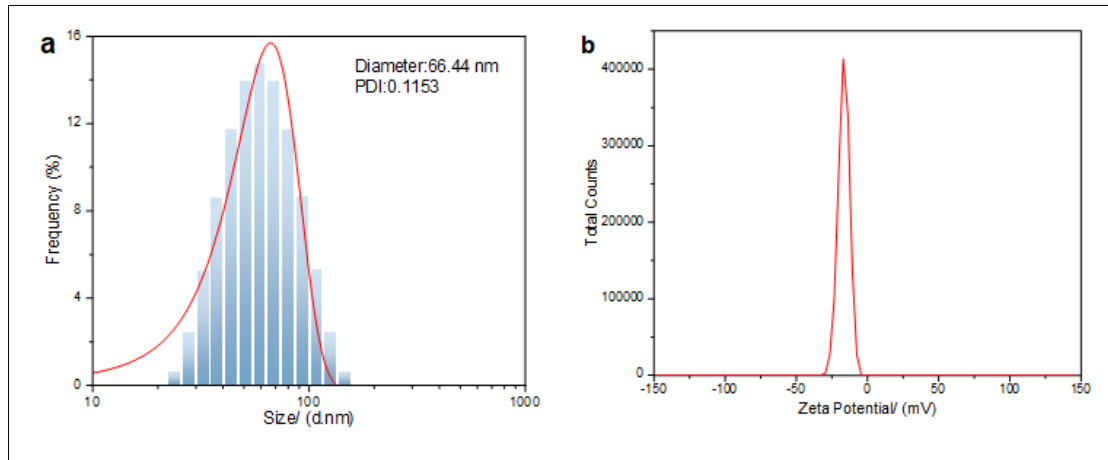


Fig. 6: Particle size distribution and zeta potential of SeNPs
Note: a, Particle size distribution of SeNPs; b, Zeta potential of SeNPs.

2.3 Antioxidant Activity of SeNPs

DPPH and ABTS free radical scavenging assays were employed to evaluate the antioxidant capacity of SeNPs. In the antioxidant activity analysis, dose-dependent tests were conducted on the antioxidant capacities of SeNPs and a standard antioxidant (ascorbic acid). As shown in Fig. 7, the DPPH and ABTS free radical scavenging abilities of SeNPs increased with increasing concentration, demonstrating the dose-dependency of the antioxidant effect. At a SeNPs concentration of 640 mg/L, the free radical scavenging

rates of SeNPs against DPPH and ABTS reached maximum values of 87.31% and 84.29%, respectively, which were comparable to the scavenging ability of ascorbic acid. These results demonstrated that SeNPs can serve as effective free radical scavengers. Studies have shown that Se groups in SeNPs can activate hydrogen atoms of isomerized carbon, thereby enhancing the scavenging ability against free radicals (Gao *et al.*, 2020). These results indicate that SeNPs synthesized using *Kyllinga brevifolia* extract possess strong antioxidant.

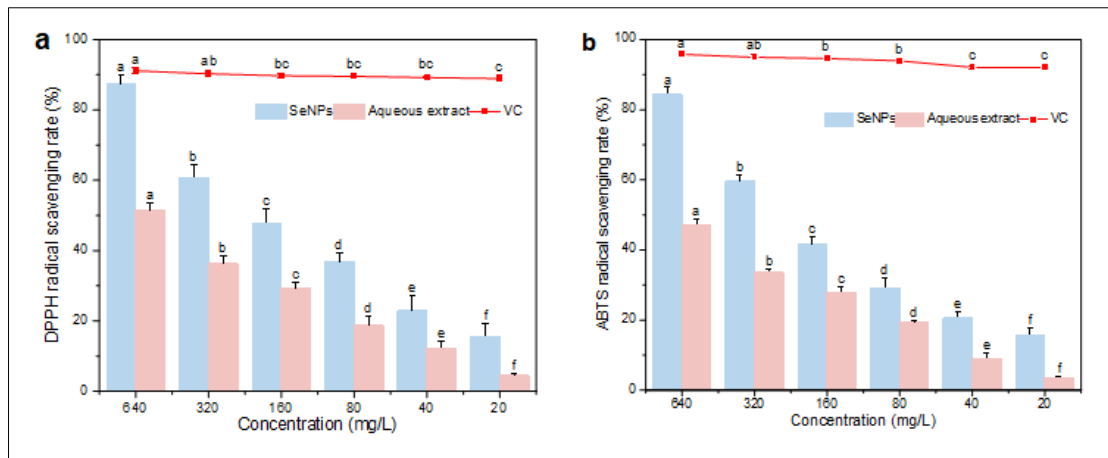


Fig. 7: Antioxidant properties of SeNPs at different concentrations

Note: a, DPPH free radical scavenging rate of SeNPs at different concentrations; b, ABTS free radical scavenging rate of SeNPs at different concentrations. Different lowercase letters indicate significant differences between groups ($P < 0.05$).

3. CONCLUSION

This study successfully established a green synthesis method for selenium nanoparticles using *Kyllinga brevifolia* extract as both reducing and stabilizing agents. Systematic characterization by GC-MS, UV-Vis, SEM, FT-IR, XRD, and DLS confirmed that the prepared selenium nanoparticles were spherical

and uniform in size, with an average particle diameter of 66.44 nm, a PDI value of 0.1153, and a Zeta potential of -16.69 mV, demonstrating good dispersion stability. XRD analysis indicated that their crystalline structure was consistent with standard JCPDS cards. FTIR and GC-MS results revealed that 17 active components in the extract, including alcohols, phenols, acids, and esters,

participated in the conversion of Se⁴⁺ to Se⁰ and the stabilization of nanoparticles through C=C bond capping and -OH group redox mechanisms. DPPH and ABTS free radical scavenging assays demonstrated that the selenium nanoparticles exhibited concentration-dependent antioxidant activity. The core value of this study lies in transforming the invasive weed *Kyllinga brevifolia* into high-value-added nanomaterials, achieving resource utilization through waste-to-wealth conversion, thereby providing theoretical foundation and technical support for the large-scale green preparation of selenium nanoparticles and their application in fruit and vegetable preservation. However, this study has certain limitations: the long-term stability of selenium nanoparticles and their preservation efficacy in real food systems remain unvalidated, and their biosafety evaluation and in vivo metabolic mechanisms also require further investigation. Future research could focus on postharvest preservation application trials of selenium nanoparticles on typical fruits and vegetables, establishing efficacy evaluation systems, and assessing their biocompatibility and safety through cell models and animal experiments, while elucidating the absorption, distribution, and metabolic patterns of selenium nanoparticles in biological systems, thereby laying a solid foundation for their development and application as novel food functional factors.

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