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Radioprotective Potential of Cinnamon Nanoparticles against Gamma Radiation-Induced Oxidative Stress

The current study examines the radioprotective properties of cinnamon-derived nanoparticles to gamma radiation. Aqueous extraction was used to synthesize cinnamon nanoparticles, and UV-Visible spectrophotometry, atomic force microscopy (AFM) and field-emission scanning electron microscopy (FE-SEM) were used to characterize them. The morphology of the particles was quasi-spherical and the average diameter of the particles was 123.4 nm and the particles showed stability in structure. The antioxidant and free radical scavenging activity was evaluated by subjecting deionized water samples to Cs-137 gamma source in different concentrations of nanoparticles. The outcome demonstrated the dose-dependent free radical inhibition up to 60.9 percent at the concentration of 2.5×10^{-3} mg/mL. The present results highlight the potential of cinnamon nanoparticles as natural, plant-based radioprotective agents, which have a great antioxidant capacity and fundamental biological use. These properties indicate that they are promising biomedical uses especially in counteracting radiation-induced oxidative stress and the promotion of protective measures in both clinical radiotherapy and in environmental radiation exposure.

Keyword: Ionizing radiation; Biomolecules; Radiology; Nanomaterials
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1. Introduction

In recent decades, the rapid evolution of technology has significantly increased human exposure to ionizing radiation from various sources, including nuclear energy, space exploration, and medical diagnostics. Radiation, especially ionizing radiation like gamma rays, causes cellular damage by generating reactive oxygen species (ROS) and free radicals in tissues, especially in water-rich organs. These radicals can damage DNA, proteins, and lipids**,** leading to cancer or other health issues [1,2]. Since the human body is largely made up of water, and free radicals can be generated through radiation or other oxidative stressors, while ionizing radiation is invaluable in medicine and industry, its potential to induce cellular damage and genetic mutations raises concerns about its long-term health implications. Consequently, there is a pressing need to develop effective radio protective strategies to mitigate the harmful effects of ionizing radiation on human health.

Water molecule was ionized and generated two ions, i.e., a free electron and an explicitly charged molecule:

$H_2O + \text{radiation} \rightarrow H_2O + e^-$ (1)

The free electron will be added to another water molecule converting it to a negative ion:

$e^- + H_2O \rightarrow H_2O^-$ (2)

The two ions are very excited and separated as equations (3) and (4):

$H_2O^+ \rightarrow H^+ + OH^o$ (3)

$H_2O^- \rightarrow H^o + OH^+$ (4)

Free radicals may react among themselves:

$H^o + H^o \rightarrow H_2$ (5)

$H^o + OH^o \rightarrow H_2O$ (6)

The H^o is free radicals tend to merge with oxygen, producing hydroperoxyed radical, which may cause biological damage directly or break down to form hydrogen peroxide and oxygen:

$H^o + O_2 \rightarrow HO_2^o$ (7)

$2HO_2^o \rightarrow H_2O_2 + O_2$ (8)

Two hydroxyl radicals can merge to produce water molecule:

$OH^o + OH^o \rightarrow H_2O$ (9)

These may interact with other H_2O

$H_2O + H^o \rightarrow H_2 + OH^o$ (10)

or may react with their own reaction products

$H_2O_2 + OH^o \rightarrow H_2O + HO_2^o$ (11)

About two thirds of all biological damages are caused by hydrogen peroxide by such a process.

Also, e^-_{aq} corresponds to free radicals with the subscript aq indicating that the electron is hydrated (aqueous solution). It's a molecular species that has one or more unpaired electrons. In thermal motion, the reactants tend to migrate spontaneously around their original locations. Individual pairs can get closer enough to react chemically as their diffusion in the water progresses. By abstracting hydrogen from organic molecules, which can be symbolized as "RH", these free radicals can generate "organic free radicals (R)":

$RH + OH^o \rightarrow R^o + H_2O$ (12)

$RH + H^o \rightarrow R^o + H_2$ (13)

The organic free radicals can interact and disrupt other molecules that may be part of a more complicated biological system, such as chromosomes, possibly disabling it and causing cell death. Alternatively they can modify the genetic knowledge that is passed onto future generations (genetic mutation).

Synthetic radio protective compounds often present limitations such as toxicity, high cost, and limited bioavailability, thereby encouraging the exploration of natural alternatives. Natural products have gained attention for their potential as radioprotective agents due to their diverse biochemical properties and perceived safety profiles [3,4].

Another study suggested that Turmeric (curcumin) has the potential in reducing oxidative stress related disease as well as for its antimicrobial properties [5]. Another natural substance ginger decreases oxidative stress maker and protects cells from hydrogen peroxide induced oxidative damage. A comparative study identified that methanol extract of cinnamon has DPPH scavenging activity and turmeric followed by Cinnamon and turmeric, in particular, demonstrate potent free radical scavenging activities, making them valuable in mitigating oxidative stress and related pathologies [6].

Among these natural substances, cinnamon nanoparticles due to their phytochemical composition (rich in polyphenols, cinnamaldehyde, eugenol, etc.), act as natural antioxidants and have emerged as a promising candidate for radioprotection. Cinnamon, derived from the bark of various Cinnamomum species, is widely recognized for its antioxidant, anti-inflammatory, and antimicrobial [7]. Recent studies have suggested that these properties may extend to protection against radiation-induced damage at the cellular and molecular levels [8,9]. There are several works using gold, silver and nano natural material as free radical scavengers.

This study explores the potential of cinnamon spice as a natural radio protectant against exposure to gamma radiation. By reviewing current literature and experimental studies, we aim to elucidate the biochemical mechanisms underlying cinnamon's radioprotective effects. Other studies explained the key mechanisms include its antioxidant activity, which neutralizes free radicals generated by ionizing radiation, and its ability to modulate cellular signaling pathways involved in the response to radiation-induced stress [10,11].

This study helps to highlight the practical implications of cinnamon as a dietary supplement or therapeutic adjunct in mitigating radiation-induced damage in human cells and tissues. The insights gained from this research could potentially inform strategies to enhance radiation resistance in clinical settings, such as during cancer radiation therapy, and to protect individuals exposed to environmental sources of ionizing radiation

In summary, this article underscores cinnamon's promising role in enhancing radiation resistance and suggests avenues for future investigations into its application in radiation therapy and environmental exposure scenarios. By advancing our understanding of cinnamon's radioprotective properties, we hope to contribute to the development of novel strategies for safeguarding human health in an increasingly radiation-prone world.

2. Materials and Methods

Deionized water (DIW) was used in this work as a sample for the purpose of studying the abilities of Cinnamon nanoparticles in removing radioactive contamination (scavenging free radicals) because water constitutes a large percentage of the human body (70%).

Table (1) presents all materials used in the preparation of cinnamon nanoparticles, specification and their purpose. The methodology of preparation and characterization of cinnamon nanoparticles as following:

Step 1 – Cleaning and Drying

Cinnamon sticks were well washed with distilled water to remove impurities. Until all moisture is exhausted, they were dried in the sun.

Step 2 – Powdering

The dried sticks have been ground into a fine powder by a laboratory grinder to ensure maximum surface area for extraction.

Step 3 – Extraction

In 200 ml of volumetric flask, 2 g were introduced in 100 ml of deionized water. The mixture was consistently raised with a magnetic sterile at 50 °C for 45-60 minutes. A visible color change in light brown to dark brown indicated the formation of nanoparticles.

Step 4 – Filtration and Stabilization

The solution was filtered using filter paper to remove insoluble residues. The filtrate was stored at 4 °C for 2 days to allow stabilization. A second filtration was performed to obtain a pure hydrous nano-extract.

Step 5 – Preparation of Concentrations

Various concentrations of the nanoparticle extract were prepared: 0.2×10^{-4} g/L, 0.4×10^{-4} g/L, 0.6×10^{-4} g/L, 0.8×10^{-4} g/L, and 1.0×10^{-4} g/L.

UV-visible spectrophotometry was employed in conducting characterization and a clear absorbance peak was observed at the range of 280 to 430 nm. Such observation renders the structural stability of cinnamon nanoparticles and their possible usage in the medical and pharmaceutical sphere, as well as, acting a natural antioxidant with the ability to increase cellular protection.

Experimental Procedure: Gamma Irradiation and DPPH Assay

Step 1 – Preparation of Cinnamon Extract

One gram of finely powdered cinnamon was dissolved in 100 mL of deionized water in a 200 mL volumetric flask. The solution was placed on a Stealer device for 40 minutes at 50 °C with continuous stirring.

The mixture was filtered several times using filter paper to remove insoluble residues. The filtrate was stored in a container at 4 °C for 24 hours, producing the hydrous nano-extract.

Step 2 – Characterization of Nanoparticles

The morphology and particle size of the prepared cinnamon nanoparticles were analyzed using atomic force microscopy (AFM).

Step 3 – Preparation of Samples for Irradiation

Different concentrations of cinnamon nanoparticles were added to deionized water (DIW) samples. These nanoparticle-treated samples were prepared prior to irradiation.

Step 4 – Gamma Irradiation

The DIW samples were exposed to gamma rays using a Cs-137 source. Gamma radiation interacts with water molecules, leading to the generation of free radicals.

Step 5 – Free Radical Scavenging Assay (DPPH Test)

The irradiated samples were mixed with a fixed ratio of ethanolic DPPH solution. DPPH (2,2-diphenyl-1-picrylhydrazyl) is a stable free radical with a strong absorption band at 520 nm. Upon reaction with antioxidants, the solution changes from deep violet to colorless or light yellow.

Step 6 – Measurement of Antioxidant Activity

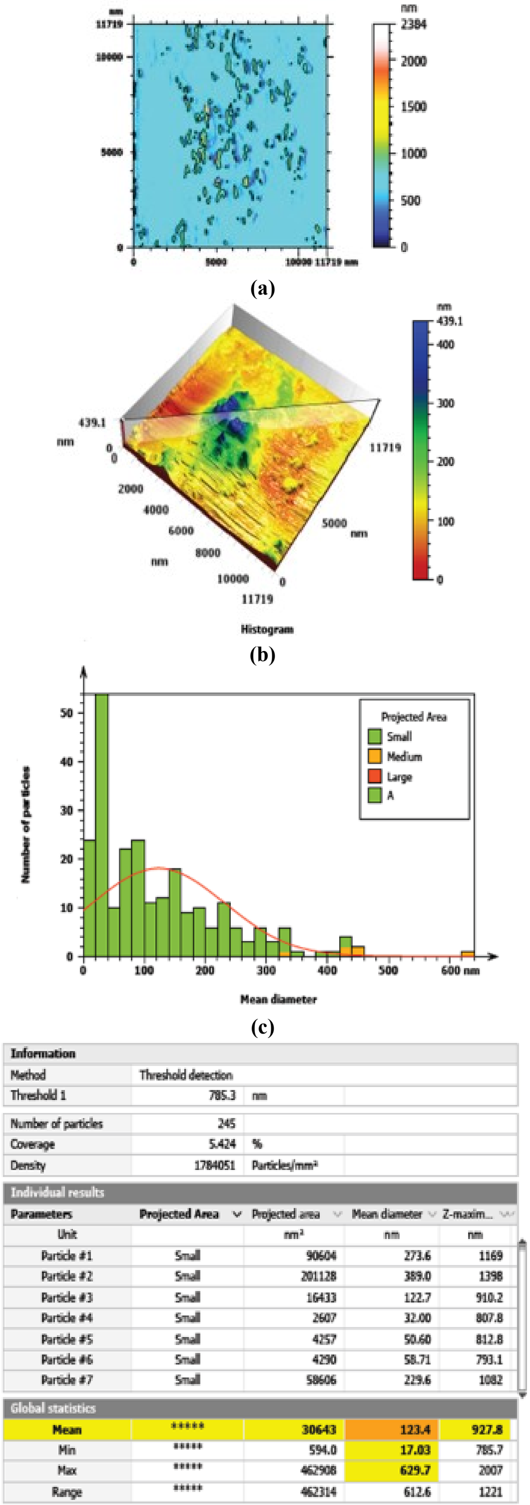
The absorbance of the samples was measured at 520 nm using a UV-visible spectrophotometer. The percentage inhibition of free radicals was calculated using the following formula:

$$I\% = \frac{A_1 - A_2}{A_1} \times 100$$

where A_1 is the absorbance of irradiated DIW samples with DPPH (control), A_2 is the absorbance of samples with various cinnamon nanoparticle concentrations, I% is the percentage of inhibition

3. Results and Discussion

The AFM images together with histograms of the Cinnamon particle size distribution are shown in Figs. (1) and (2). Cinnamon nanoparticles were characterized by AFM and by three-dimensional surface analysis. The 2D particle distribution map indicated 245 particles with surface coverage indicated by 5.42 percent and a high density of 1,784,051 particles/mm ^{2} which indicates efficient nanoscale preparation. It was observed that the 3D surface morphology varied in terms of height of particles, agglomeration was observed, and the average maximum height (Z-max) was 927.8 nm. Particle size analysis showed a mean diameter of 123.4 nm, 17.03 composition with sprinkled large particles.



(a)

(b)

(c)

Information			
Method	Threshold detection		
Threshold 1	785.3	nm	

Number of particles	245		
Coverage	5.424	%	
Density	1784051	Particles/mm²	

Individual results

Parameters	Projected Area	Projected area	Mean diameter	Z-maxim...
Unit		nm²	nm	nm
Particle #1	Small	90604	273.6	1169
Particle #2	Small	201128	389.0	1398
Particle #3	Small	16433	122.7	910.2
Particle #4	Small	2607	32.00	807.8
Particle #5	Small	4257	50.60	812.8
Particle #6	Small	4290	58.71	793.1
Particle #7	Small	58606	229.6	1082

Global statistics

Mean	*****	30643	123.4	927.8
Min	*****	594.0	17.03	785.7
Max	*****	462908	629.7	2007
Range	*****	462314	612.6	1221

Fig. (1) Particle size and surface morphology analysis of nano-cinnamon (average size ~123.4 nm): (a) 2D particle distribution map, (b) 3D surface morphology image, (c) Summary of particle analysis including threshold detection method, particle count, surface coverage, and density. Individual and global statistics show mean diameter, projected area, and Z-maximum, and (Bottom right) Histogram of particle size distribution showing predominance of particles with small projected area. The majority of particles fall within the 50–150 nm range

The nanoparticles were mainly spherical or quasi spherical, which preferred bio absorption and antioxidant. Although there is slight agglomeration, the size distribution and dense concentration of particles assure efficient chemical and biological interactions. Generally, the 3D analysis verified the heterogeneous heights with minimal impact on the overall characteristics of the extract, and the nanoparticles can be used in biology and the industry.

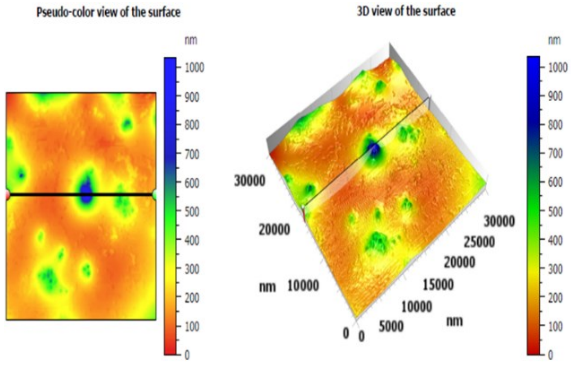


Fig. (2) AFM images of cinnamon nanoparticles at a mean diameter of 123.4 nm

It is observed that the particles are nanosized and spherical in shape. The *in vitro* uses Cinnamon nano-extract to decrease radioactive hazard by removing free radicals which is reasonable to form cancer cell in living tissue. The UV-visible spectrophotometry was used to measure the absorbance of each sample. The absorbance of each sample is shown in Fig. (3) for all samples at a wavelength of 524 nm in different concentrations of Cinnamon nano-extract ($0.5x10^{-3}$, $1.0x10^{-3}$, $1.5x10^{-3}$, $2.0x10^{-3}$ and $2.5x10^{-3}$ mg/mL, respectively as H1-H5).

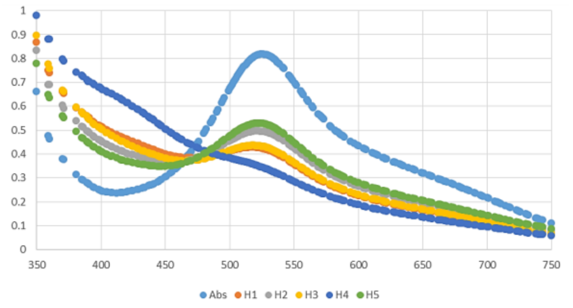


Fig. (3) Absorption spectra of all sample at 524nm with various Cinnamon nano-extract concentrations., where the concentration of nano-Cinnamon are 0.5×10^{-3}, 1.0×10^{-3}, 1.5×10^{-3}, 2.0 and 2.5×10^{-3} mg/ml at Abs, H1, H2, H3, H4 and H5, respectively

The increase in absorbance with the increasing concentration of nanoparticles is in line with Beer-Lambert law implying that the nano-cinnamon particles absorb the light efficiently at this wavelength. This modest curvature to linearity at the maximum concentration (H5) can be an indication of partial saturation or slight aggregation influences. On balance, the data help to confirm the high optical activity of the Cinnamon nano-extract that can be exploited to determine its concentration and bioactivity.

The effect of various concentrations of synthesis Cinnamon added to deionized water samples on increases in efficiency of free radical inhibition prior exposing them to gamma radiation was shown in Fig. (4) and table (2). As shown in table (2), cinnamon nanoparticles exhibited a clear concentration-dependent free radical scavenging activity, where percentage inhibition increased from 31.7% at 0.5×10^{-3} mg/mL to 60.9% at 2.5×10^{-3} mg/mL where the absorbance of irradiated water was 0.82 before adding nanoparticles. This trend highlights the strong antioxidant potential of Cinnamon nano-extract, which becomes more effective at higher concentrations due to an increased capacity to neutralize reactive oxygen species (ROS). The enhanced scavenging ability is closely related to the presence of phenolic compounds and bioactive phytochemicals that remain attached to the nanoparticle surface during green synthesis, thus improving their interaction with free radicals.

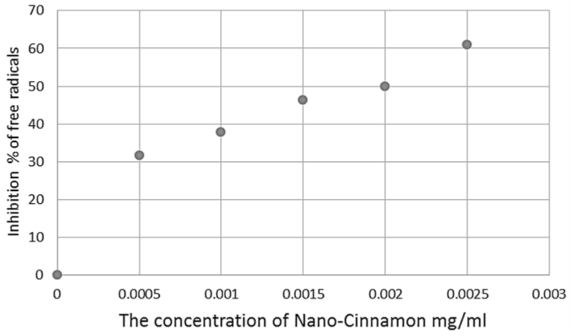


Fig. (4) Percentage inhibitions of free radicals as a function of Cinnamon nano-extracts concentrations. The graph illustrates the dose-dependent antioxidant activity of the extract, showing a steady increase in inhibition percentage with increasing concentrations of nano-cinnamon, reaching a maximum of 60.9% at 2.5×10^{-3} mg/ml

Table (2) The absorbance, concentration, and % inhibition of the nano-Cinnamon extract using DPPH assay

Sample Condition	Concentration ($\times10^{-3}$ mg/ml)	Absorbance	% Inhibition
Irradiated	0.5	0.56	31.7
Irradiated	1.0	0.51	37.8
Irradiated	1.5	0.44	46.3
Irradiated	2.0	0.41	50.0
Irradiated	2.5	0.32	60.9
Irradiation Before adding nanoparticles	—	0.82	—

Comparable findings have been reported for other plant-derived nanomaterials. For example, olive leaf nanoparticles (OLNPs) [9] demonstrated promising antioxidant and radioprotective activity under gamma irradiation at relatively low concentrations. The way that the Cinnamon nanoparticles interacted with free radicals and converted into neutral molecules was what caused the absorption and inhibitory behavior. The interplay of ionizing radiation with biological tissues generates reactive oxygen species and free radicals, which induce oxidative pressure and harm vital biomolecules together with DNA, RNA, proteins, and lipids. This uncontrolled oxidative burden can lead to mutations, genomic instability, and in the long run the initiation of carcinogenic techniques. Eliminating or scavenging these loose radicals is therefore vital to reduce oxidative strain and save you radiation-induced mobile transformation. Natural antioxidants, especially plant-derived nanomaterials, have shown promising efficacy in neutralizing these reactive species. Cinnamon nanoparticles, because of their rich polyphenolic content and excessive surface reactivity, act as effective unfastened radical scavengers. Their activity reduces oxidative potential in dwelling tissues, thereby keeping mobile integrity and blocking off pathways that cause malignant boom. Consequently, the usage of cinnamon nanoparticles highlights a singular radioprotective method in opposition to most cancers development triggered with the aid of ionizing radiation [14].

The field-emission scanning electron microscopy (FE-SEM) analysis was used to find the size and shape of nanoparticles for Cinnamon extract as shown in Fig. (5) using a MIRA3 TESCAN SEM. As can be seen in the micrograph, nanoparticles have an irregular and aggregated morphology implying that clustering should occur naturally upon the synthesis or drying process. The texture of the surface is rough and porous, which may increase the surface area and optimize interactions in possible bioactive or catalytic systems.

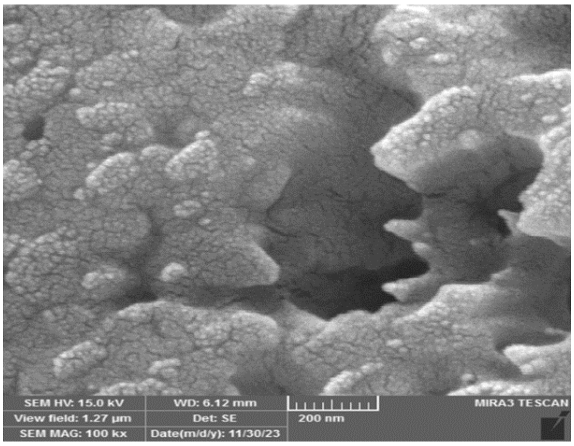


Fig. (5) FE-SEM image of Cinnamon nanoparticles. The image was captured at 100,000x magnification. The nanoparticles exhibit irregular, aggregated morphology with a rough surface texture. The particle size is consistent with nanoscale dimensions, with visible clustering and porous surface features.

The morphology and particle size of the synthesized cinnamon nanoparticles were examined using a JEOL JEM-2100 transmission electron microscope (TEM) operated at an accelerating voltage of 200 kV. For sample preparation, a dilute aqueous suspension of the nanoparticles (0.1 mg/mL) was sonicated for 10 min, and a 10 µL droplet was drop-cast onto a carbon-coated copper grid (300 mesh). The grid was air-dried at room temperature before imaging. Particle size distribution (Fig. 1) was determined by analyzing 200 particles from at least five randomly selected micrographs using ImageJ (v1.54) software. The histogram represents the mean particle size with standard deviation.

The particle sizes are in the anticipated nanoscale and that is in agreement with the previous AFM measurements and the image indicates the existence of clusters and interconnected structures. Such porous and rough surfaces could also support adsorption and chemical reactivity, allowing these nanoparticles to be further used in biological or antioxidant or other functional applications. The heterogeneity of shapes and aggregation form of the particles observed is characteristic of naturally derived nanoparticle extracts and gives a clue to the structural characteristics of nanoparticles in the nanoscale.

4. Conclusions

In conclusion, the Cinnamon nanoparticles have the ability to remove the effect of gamma rays on the exposed water (scavenge free radicals) resulting from gamma rays, which acts as an antioxidant that can donate electrons to free radicals and inhibit them. However, Cinnamon nanoparticles have a high ability to remove radioactive contamination (free radical removal), reaching 60.9%.

References

[1] C. Wilson et al., “A Review of Recent Low-dose Research and Recommendations for Moving Forward”, *Health Phys.,* 126(6) (2024) 386-396.
[2] M.C. Joiner and A. van der Koge, **“Basic Clinical Radiobiology”**, 6th ed., CRC Press (2025).
[3] S.J. Hosseinimehr, “Trends in the development of radioprotective agents”, *Drug Discovery Today,* 19(9) (2014) 1205-1213.
[4] G.C. Jagetia and G.K. Rajanikant, “Role of curcumin, a naturally occurring phenolic compound of turmeric, in accelerating the repair of excisional and irinotecan-induced DNA damage in cultured human cells”, *J. Cancer Res. Therapeut.,* 15(2) (2019) 281-287.
[5] P. Ballester et al, “Antioxidant activity in extracts from Zingiberaceae family: Cardamom, turmeric, and ginger”, *Molecules,* 28(10) (2023) 4024.
[6] S. Balu at el., “Turmeric and cinnamon dominate in antioxidant potential among four major spices”, *J. Spices and Aromatic Crops.,* 26(1) (2017) 27-34. doi: 10.25081/josac.2017.v26.i1.803.

[7] S.K. Roghayeh, I. Baskaran and B.-H. Cheng, "Recent Advances on the Analysis and Biological Functions of Cinnamaldehyde and Its Derivatives", *Antioxidants*, 14(7) (2025) 765.

[8] O.S. Ashour, A.H. Al-Mashhadani and R.M. Yas, "Studying the free radical scavenging activity using low concentration of nanogold particles", *J. Phys.: Conf. Ser.,* 1279(1) (2019) 012066.

[9] O.S. Ashour and A.H. Al-Mashhadani, "Inhibition of free radicals in water using nano olive leaf", *Iraqi J. Appl. Phys.,* 20(1A) (2024) 67-70.

[10] R. Arora et al., "Radioprotective potential of plants and herbs against the effects of ionizing radiation", *J. Clinic. Biochem. Nutrit*., 60(3) (2017) 8-15.

[11] K. Yulan et al., "Roles of the phagocytosis checkpoint in radiotherapy", *Cell Death Dis*., 16(1) (2025) 630.

[12] O.P. Sharma and T.K. Bhat, "DPPH antioxidant assay revisited", *Food Chem*., 113(4) (2009) 1202-1205.

[13] M. Buijnster et al., "Evaluation of antioxidative activity of some antioxidants by means of combined opthothermal window and DPPH free radical colorimetry", *Anal. Sci*., 17 (2001) 544-546.

[14] F. Mokhtar et al., "Effects of cinnamon nanoparticles produced with ultrasonic waves on growth performance, antioxidant status, and hemato-biochemical metabolites of broiler chickens", *Poultry Sci.*, 104(10) (2025) 105615.

Table (1) Materials used in the preparation of Cinnamon NPs

Material	Specification / Source	Purpose
Cinnamon sticks	Locally sourced, cleaned, and sun-dried	Raw material for nanoparticle preparation
Deionized water (DIW)	Laboratory grade	Solvent for extraction and nanoparticle synthesis
Volumetric flask (200 mL)	Borosilicate glass	Container for extraction and mixing
Magnetic stirrer with heater	Adjustable, set at 50°C	Stirring and heating during extraction
Filter paper	Whatmann No. 1 (or equivalent)	Removal of insoluble matter
Refrigerator	4°C	Stabilization of the extract
UV-Visible Spectrophotometer	Range 200–800 nm	Characterization of nanoparticles (absorbance peak)