ORIGINAL ARTICLE

The Photocatalytic and Biological Activity of Cuucumin Coated with Lanthanum-doped Copper Oxide Nanoparticles

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Abstract

Aim: The study focuses on the synthesis and evaluation of curcumin-coated lanthanum-doped copper oxide (La-CuO) nanoparticles (NPs), aiming to combine the bioactivity of curcumin with the photocatalytic and antimicrobial properties of La-CuO. **Materials and Methods:** Curcumin-coated La-CuO NPs were characterized using transmission electron microscopy, scanning electron microscopy, Fourier-transform infrared and X-ray diffraction, providing insights into their morphology, size distribution, functional groups, crystalline structure, and phase composition. The study explored the photocatalytic effects of these NPs on thiodicarb pesticide residues in water, revealing that the NPs significantly reduced the pesticides' half-life when exposed to sunlight. In addition, curcumin, a compound in turmeric, is noted for its anti-diabetic properties, including blood sugar control, oxidative stress reduction, and enhanced insulin sensitivity. **Results and Discussion:** Photocatalysis studies show increased efficiency and faster reactions, and the DT50 value, or half-life, is important in environmental chemistry. This study suggests new uses for curcumin-coated La-CuO NPs in environmental remediation and wastewater treatment. Curcumin-coated La-CuO NP's antidiabetic effects were evaluated by inhibiting the α-glucosidase enzyme. **Conclusion:** According to this study, CuO NPs inhibit diabetes by 40.23%. La-CuO NPs coated with curcumin have been shown to have promising antidiabetic properties. According to research, turmeric's polyphenol curcumin may have insulin-sensitizing properties that aid in blood sugar control. Curcumin has been shown to improve β-cell function, reduce insulin resistance, and prevent β-cell death, making it a promising treatment for diabetes.

Key words: Anti-diabetic, catalytic activity, curcumin-coated lanthanum-doped copper oxide nanoparticles, Fourier-transform infrared, scanning electron microscopy, thiodicarb, transmission electron microscopy, X-ray diffraction

INTRODUCTION

Curcumin, a bright yellow polyphenol found in turmeric, has anti-inflammatory and antioxidant properties.[1] It has multiple applications, including food additives, herbal supplements, and cosmetics. Curcumin may benefit your health in a variety of ways, including cancer prevention, brain protection, and diabetes management.[2] Because it does not work well in the body, researchers are looking for ways to improve its effectiveness.[3] Curcumin has long been used in Ayurvedic medicine to treat skin problems, digestive issues, and inflammation. Curcumin, which has earthy, slightly bitter flavors and is used in cooking and supplements. Indian food, stir-fries, golden milk, pickles, sauces, and marinades all frequently use it. Due to its anti-inflammatory, antioxidant, and pain-relieving qualities, curcumin is used in supplements to support the immune system, digestive health, and arthritis.[4]

A metal oxide nanomaterial with improved properties, lanthanum-doped copper oxide (La-CuO) nanoparticles (NPs) find applications in photocatalysis, supercapacitors, and the biomedical industry. They enhance charge transport, stabilize the monoclinic crystal structure of CuO, and exhibit encouraging outcomes in the degradation of organic pollutants

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and water purification.[5] La-CuO NPs coated with curcumin are a promising nanomaterial that may find use in drug delivery, biomedicine, and antimicrobial therapies. These NPs have potent antimicrobial activity against fungi and bacteria, as well as improved stability and bioavailability.[6] Their combination improves their antimicrobial, anti-inflammatory, and antioxidant qualities, which makes them beneficial for therapeutic and drug delivery applications.[7]

La-CuO NPs coated with curcumin exhibit encouraging photocatalytic activity, which makes them valuable for use in biomedical and environmental applications.[8] These NPs can degrade organic pollutants, enhance light absorption, and make charge separation easier. In biomedical applications, they might also support targeted drug delivery and antimicrobial effects.[9]

Thiodicarb, an insecticide of the carbamate class, is used in agriculture to control insect pests by inhibiting acetylcholinesterase, an enzyme essential for nerve function. Due to its broad-spectrum activity against leafhoppers, aphids, beetles, and caterpillars, it provides rapid pest control.[10] It can be used as a crop soil treatment or foliar spray and has less of an impact on beneficial insects. Thiodicarb is governed by strict regulations and is registered with the Environmental Protection Agency (EPA) and other international agencies.[11]

La-CuO NPs coated with curcumin have demonstrated possible anti-diabetic effects.[12-14] The antioxidant and anti-inflammatory properties of curcumin are strengthened by these NPs, which also lower insulin resistance, control blood sugar, lessen oxidative stress, and lessen chronic inflammation that is connected to the development of diabetes.[15] In addition, curcumin's bioavailability is increased by the nanoparticle coating, guaranteeing improved absorption and efficacy in the treatment of diabetes.[16,17]

EXPERIMENTAL

Preparation of La-CuO nanocomposite

Chemically precipitating ammonia and copper nitrate solution makes CuO NPs. To make a one molar solution of copper(II) nitrate, you need to mix 24.16 g of copper nitrate with 100 mL of distilled water. A solution of 25 mL of ammonia and 75 mL of water is made. We put these solutions in separate burettes and add them all at once to a conical flask full of water while stirring. Furthermore, lanthanum oxide solutions with a concentration of 0.1 M are added to the mixture. Cleaning the resulting precipitate with distilled water and acetone gets rid of any impurities. Four to five drops of triethylamine are added to the mixture to keep it from clumping together. After centrifugation, the leftover material is dried in a furnace that can be controlled to stay at 50° for an hour. Copper oxide is formed by annealing the residue for 2 h at 250°C. The samples' coffee-brown hue attests to the existence of lanthanum ions.

Synthesis of curcumin coated with La-CuO NPs

We mixed 1.0 g of La-CuO NPs and 500 mg of curcumin in 100 mL of distilled water and placed it in a 250 mL glass beaker. Then, add 10 mL of dimethyl sulfoxide solvent and heat at 60°C for 4 h. The final mixture was collected after 4 h and centrifuged at 6000 rpm for 10 min. The final product was dried at 40°C for 24 h. Finally, yellowish brown Cu-La-CuO NPs were obtained.

Characterization of synthesis of curcumin coated with La-CuO NPs

The produced NPs were characterized using different kinds of methods, such as X-ray diffraction (Rigaku Smartlab SE Multipurpose XRD), which identified the crystallite size, phase composition, and lattice parameters. The functional groups and bonds found in precursors and products are identified using Fourier-transform infrared spectroscopy (Agilent 4300-FT-IR). The size, shape, distribution, and morphology of curcumin coated with La-CuO NPs can all be seen using scanning electron microscopy (SEM). The synthesis of curcumin coated with La-CuO NPs is examined for size, shape, and crystal structure using transmission electron microscopy (Tescan-TEM).

Tap water collection

Mahatma Gandhi University in Nalgonda, Telangana, 508 254, is where the tap water was gathered. 17.1429° N is the latitude, and 79.2163° E is the longitude.

High-performance liquid chromatography (HPLC) conditions

HPLC was used to determine the Thiodicarb residues under the specified instrument conditions. The instrument was a Shimadzu with a photo diode array (PDA) detector, a Phenomenex C18 column (250 mm × 4.6 mm, 5 µ), a 25:75 v/v mobile phase, a 30°C oven temperature, a Lambda max 235 nm, a 1.0 mL/min flow rate, a 10 µL injection volume, a 10 min run time, and a retention time of about 4.8 min.

METHOD VALIDATION

Method specificity

Untreated control samples of tap water extract, acetonitrile, 0.1% orthophosphoric acid, working standard, and test solutions were assayed for method specificity.

Linearity of response

Weighing 10.06 mg of reference standard into a 50 mL volumetric flask and diluting with acetonitrile yielded a stock solution of triallate standard stock. The correct volume of stock solution was then diluted into various 10 mL volumetric flasks, and acetonitrile was added to bring the flasks to volume, resulting in a series of calibration solutions. The calibration solutions (L1, L2, L3, L4, L5, and L6) were analyzed using HPLC at concentrations of 0.015, 0.05, 0.1, 0.5, 1.0, and 5.0 µg/mL. The correlation coefficient was determined by plotting a linear curve of the standard concentration against the observed peak area.

Assay accuracy and precision

The validation process involves the analysis of fortified samples as well as an untreated (blank) sample. Fortified samples were created by adding a known amount of triallate and working up the sample volume. The HPLC method was then used to extract and quantify the amount of triallate in tap water. The fortified samples' concentration levels were 1 × limit of quantitation (LOQ) = 0.05 µg/mL and 10 × LOQ = 0.5 µg/mL. Method validation was carried out using five replicates at each level of fortification. The response area of the fortified samples was used to calculate the percentage recovery and relative standard deviation.

LOQ

The lowest validated level with adequate recovery is known as the LOQ. Five injections of 0.05 µg/mL fortification level recovery samples of triallate were used to determine the LOQ. For LOQ, low-level recovery solutions were employed.

Photolytic and photocatalytic studies

A concentration of 0.5 µg/mL of each was added to study the photocatalysis of triallate residues in water. At every fortification level, single replications were carried out in addition to control samples for comparison. For the experiments, two sets of spiked concentrations are made. Curcumin-coated La-CuO NPs, the catalyst, were applied to one set of samples while it was not applied to the other. The samples were placed in direct sunlight. At specified intervals, aliquots of the sample were taken. During this time, water samples were taken at temperatures between 26°C and 42°C. Samples collected at different sampling times were filtered using a 0.2 µm PTFE membrane filter. After that, the filtrates were collected into amber-colored vials. Before HPLC analysis, each sample was stored in the dark at 5°C. The samples containing curcumin-coated La-CuO NPs were centrifuged for 5 min at 5°C using a Beckman cooling centrifuge with 3000 rotations/min. To prevent further degradation of the residues, the supernatants were transferred to amber-colored bottles and stored in the dark at 5°C until analysis.

Sample extraction

The representative homogenized 5 mL of the water sample was concentrated to dryness using a vacuum rotary evaporator before being diluted with acetonitrile to the mark. The solution was injected into the HPLC.

Antidiabetic activity

The synthesized NPs were tested for antidiabetic activity using the α-glucosidase enzyme. The α-glucosidase enzyme is derived from crude rat intestinal acetone powder. Sonicating normal saline (100:1, w/v) produced acetone power. The solvent's top layer was removed by centrifugation at 5000 rpm for 20 min at 5°C. It was thought to be a crude version of intestinal α-glucosidase. The enzyme was preincubated in phosphate-buffered saline (pH 6.9) for 5 min. For 5 min, the product reacted with the substrate, p-nitrophenyl-α-D-glucopyranoside, prepared in the same buffer, phosphate buffer saline (pH 6.9). The α-glucosidase enzyme action caused the release of p-nitrophenol, which was detected by spectrophotometry at 400 nm. Acarbose experimented using a working standard. % of inhibition = ([Abs[C]-Abs[S]]/Abs[C]) was the formula used to determine the percentage of inhibition of the α-glucosidase enzyme (at λmax: 400 nm). ×100.

RESULTS AND DISCUSSION

Characterization of curcumin coated with La-CuO NPs

FT-IR analysis

The functional groups of curcumin-coated La-CuO NPs are examined using FT-IR spectroscopy [Figure 1], bringing illumination on the interactions and chemical bonds that

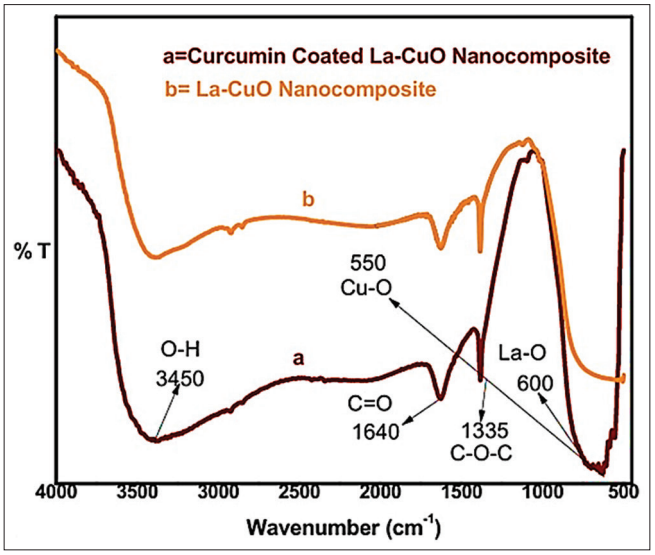

Figure 1: FTIR Spectra of (a)curcumin coated with La-CuONPs(b) La-CuO Nanocomposite

exist between the curcumin and the La-CuO nanocomposite. Curcumin contains O-H stretching, or phenolic hydroxyl groups, which appear between 3200 and 3500 cm^{-1}. Curcumin's diketone structure includes C=O stretching (ketone groups) at approximately 1620-1650 cm^{-1}. C=C Stretching (Aromatic Rings): Curcumin's benzene rings are visible at 1500–1600 cm^{-1}. Cu-O and La-O bonding show peaks in the 400–650 cm^{-1} range, indicating metal–oxygen interactions. Curcumin exhibits C-O-C stretching (ether linkages) at approximately 1200–1350 cm^{-1}. These functional groups increase the stability and bioavailability of La-CuO NPs by confirming that curcumin has been successfully coated on them. This study provides more information on curcumin's FT-IR spectral analysis.

XRD analysis

CuO NPs exhibit distinct XRD peaks at 2θ diffraction angles of 32.45°, 35.54°, 38.70°, 48.90°, 53.50°, 58.15°, 61.50°, 66.15°, and 72.35°, indicating their high crystalline nature [Figure 2]. However, because of the strong interaction between lanthanum and CuO NPs, the peaks were slightly reduced after doping lanthanum with CuO NPs (La-CuO NPs) [Figure 2].

SEM analysis

As shown in Figure 3, larger clusters are the consequence of particles in particular sample regions being more interconnected. This implies that a portion of the particles in the sample act as seed particles, attracting additional particles through condensation. As a result, the sample tends to concentrate in specific areas. SEM can also be used to observe how NPs aggregate. Alginate promotes more effective dispersion of NPs by preventing aggregation.

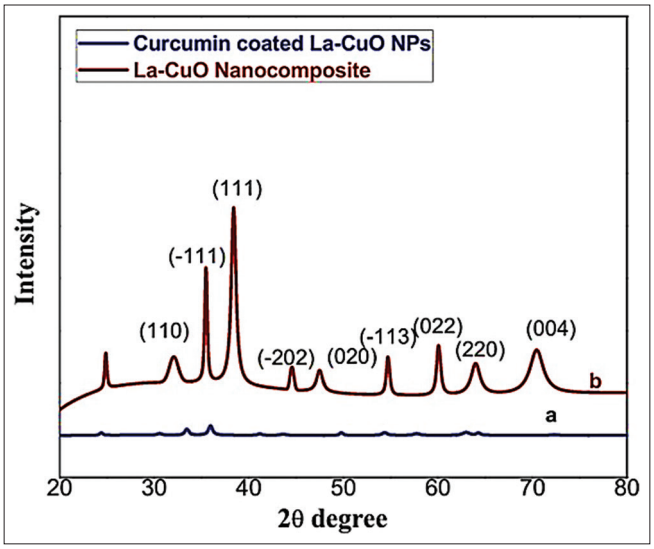

Figure 2: XRD of (a) curcumin coated La-CuO NPs and (b) La-CuO Nanocomposite SEM Analysis

Transmission electron microscopy analysis

Figure 4 shows a transmission electron microscope image of curcumin-coated La-CuO NPs with wavelengths ranging from 20 to 100 nm. The sample has a different cubic structure, high crystallinity, and particle aggregation. La-CuO NP NPs coated with curcumin have a different shape and structure.

METHOD VALIDATION

Specificity

The analytical method was found to be specific. There was no interference observed at the retention time of the thiodicarb peak. The % difference in retention time of the test item and reference standard was found to be within ± 3.0 %.

Linearity

The linearity of the method was established by injecting six different concentrations of thiodicarb reference standard into HPLC-PDA and by plotting their respective standard concentrations (µg/mL) The results of area of concentrations

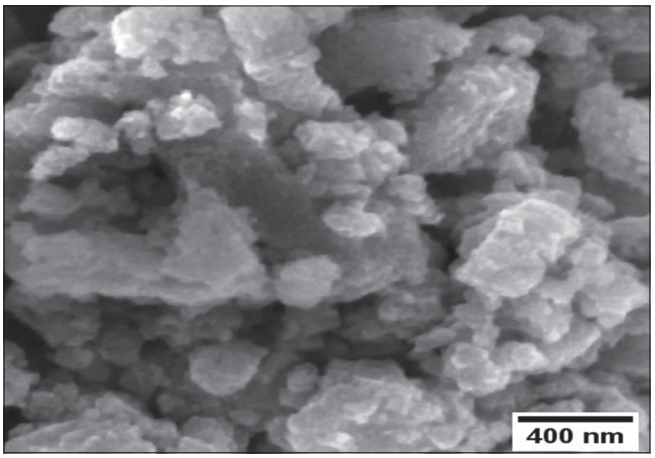

Figure 3: SEM image ofcurcumin coated La-CuO NPs

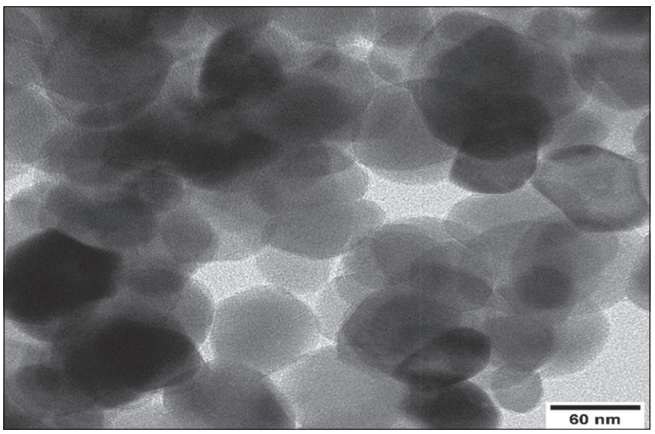

Figure 4: TEM image ofcurcumin coated La-CuO NPs

were presented in Table1. The linearity curve presented in Figure 5. The representative chromatograms were illustrated in Figure 6.

Recovery and repeatability

Multiple recovery control samples (n = 2) at each of 2 fortification levels, equivalent to 0.05 µg/mL and 0.5 µg/mL for tap water. Thiodicarbin, the final solution, was assayed using HPLC-PDA. The results are presented in Table 2.

LOQ

LOQ was established to be 0.05 µg/mL from the lower level recovery test in tap water.

Table 1: Detector linearity test

Standard code	Std. concentration (µg/mL)	Thiodicarb std. area
Linearity-1	0.015	269
Linearity-2	0.05	985
Linearity-3	0.1	1974
Linearity-4	0.5	10014
Linearity-5	1	20412
Linearity-6	5	100896
Intercept		1.79
Slope		20185.94
Correlation of Coefficient (r)		1.00000
Coefficient of determination (r^2)		1.00000

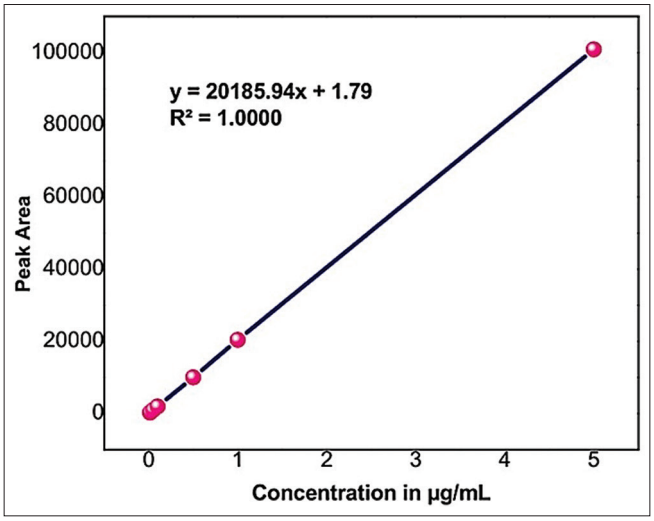

Figure 5: Linearity curve of ThiodicarbStandard

Photolytic studies and photocatalytic studies

The half-life of thiodicarb was 3.86 days in tap water without catalyst shown in Table 3 and Figure 7. Whereas the half-life of thiodicarb in presence of catalyst in tap water was recorded to be 7.44 hours the results were shown in Table 4 and Figure 8.

Antidiabetic activity (α-glucosidase enzyme inhibition activity)

The synthetic curcumin-coated La-CuO NPs were tested for their antidiabetic effects using the α-Glucosidase enzyme. Figure 9 shows the antidiabetic action of curcumin-coated La-CuO NPs. Metformin was used as the standard reference

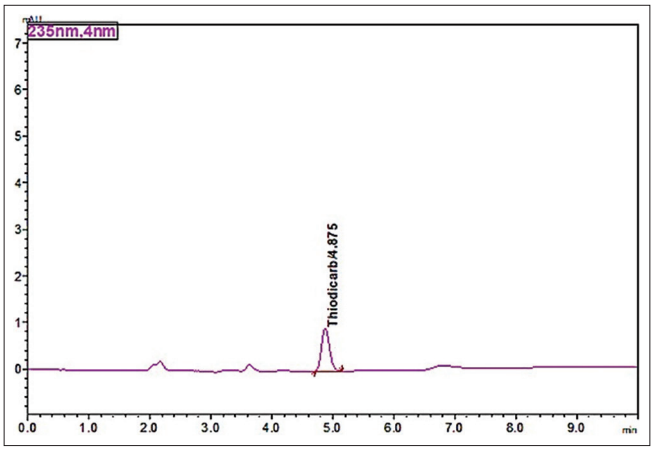

Figure 6: Representativechromatogram of linearity -4 of Thiodicarb

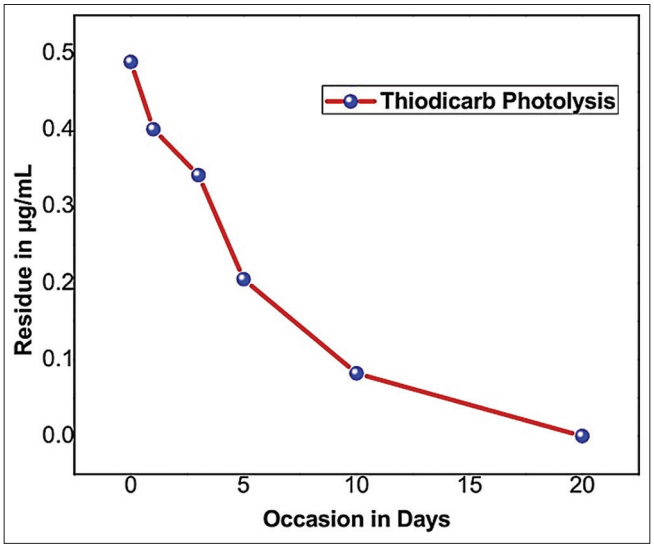

Figure 7: Photolysis Curve of Thiodicarb in Absence of curcumin coated La-CuO NPs in tap water (without catalyst)

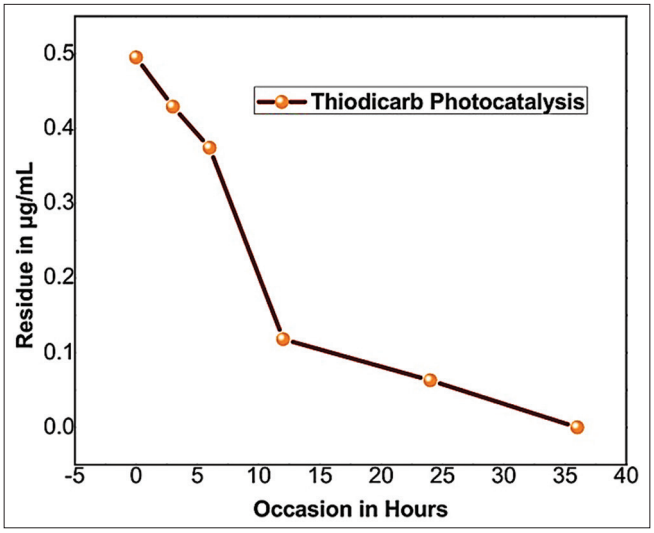

Figure 8: Photocatalysis Curve of Thiodicarbin presence of curcumin coated La-CuO NPs in tap water (with catalyst)

Table 2: Recovery and repeatability of thiodicarb in tap water

Sample code	Recovery (%) of thiodicarb in tap water
LOQ Level_R1	85.21
LOQ Level_R2	86.78
LOQ Level_R3	84.96
LOQ Level_R4	85.36
LOQ Level_R5	86.03
LOQ×10 Level_R1	88.71
LOQ×10 Level_R2	87.23
LOQ×10 Level_R3	88.84
LOQ×10 Level_R4	90.01
LOQ×10 Level_R5	89.45
Average	87.26
Standard deviation	1.88
%RSD	2.15

%RSD: Percent relative standard deviation, LOQ: Limit of quantitation

in this spectrophotometric experiment, which measured absorbance at 400 nm. In this study, we discovered that curcumin-coated La-CuO NPs had a 40.23% antidiabetic effect by inhibiting enzymes. The results were presented as mean ± standard deviation, with $n = 3$.

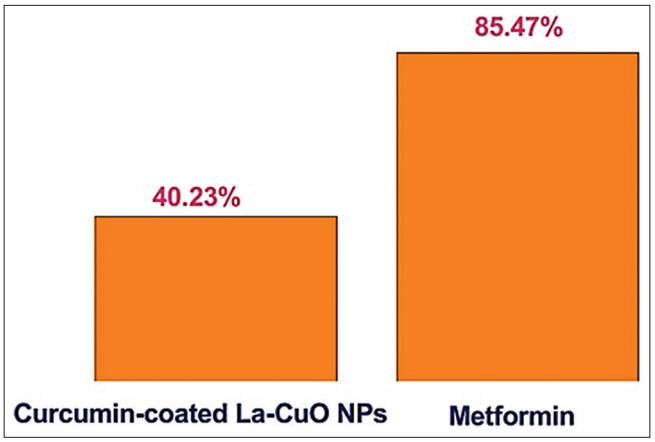

Figure 9: The antidiabetic activity results of curcumin-coated La-CuO NPs

Table 3: Photolysis of thiodicarb under direct sunlight in tap water (without catalyst)

Occasion (Days)	Residue level (µg/mL)	Log	Thiodicarb	
0	0.489	−0.3107	Slope	−0.078
1	0.401	−0.3969	Half-life (DT50)	3.86
3	0.341	−0.4672		
5	0.205	−0.6882		
10	0.082	−1.0862		
20	BDL	BDL	Intercept	−0.294
			CC	0.972

BDL: Below detectable Limit, CC: Correlation Coefficient

Table 4: Photocatalysis of thiodicarbin presence of curcumin-coated lanthanum-doped copper oxide nanoparticles under direct sunlight in tap water

Occasion (Hours)	Residue level (µg/mL)	Log	Thiodicarb	
0	0.495	−0.3054	Slope	−0.040
3	0.429	−0.3675	Half-life (DT50)	7.44
6	0.374	−0.4271		
12	0.118	−0.9281		
24	0.063	−1.2007		
36	BDL	BDL	Intercept	−0.282
			CC	0.983

BDL: Below detectable Limit, CC: Correlation Coefficient

CONCLUSIONS

This analysis presents a fast and efficient analytical strategy employing HPLC-PDA to detect Thiodicarb in residues

across three different buffer types. The mobile phase, which includes Acetonitrile and 0.1% ortho-phosphoric acid, achieved remarkable separation and resolution, with a notably brief analysis time of roughly 10 min for each chromatographic run. Curcumin-coated La-CuO NPs were found to effectively remove Thiodicarb residues from water, which are a significant environmental and public health concern. The superior adsorption performance and stability of the nanomaterial allow for easy recovery and reuse. Photocatalysis studies show increased efficiency and faster reactions, and the DT50 value, or half-life, is important in environmental chemistry. This study suggests new uses for curcumin-coated La-CuO NPs in environmental remediation and wastewater treatment. Curcumin-coated La-CuO NPs' antidiabetic effects were evaluated by inhibiting the α-glucosidase enzyme. According to this study, CuO NPs inhibit diabetes by 40.23%. La-CuO NPs coated with curcumin have been shown to have promising antidiabetic properties. According to research, turmeric's polyphenol curcumin may have insulin-sensitizing properties that aid in blood sugar control. Curcumin has been shown to improve β-cell function, reduce insulin resistance, and prevent β-cell death, making it a promising treatment for diabetes.

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