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Original Article

Nano-Extracts of Green-Synthesized *Curcuma longa*: An Innovative Approach to Breast and Colorectal Cancer Prevention

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ABSTRACT

Aim: Curcumin, the primary bioactive agent in *Curcuma longa* (turmeric), is celebrated in Ayurveda for its anti-inflammatory, antioxidant, and wound-healing effects. Its clinical application is limited by poor bioavailability, despite its traditional use in treating respiratory, liver, and skin disorders. Curcumin nanoparticles produced through green synthesis improve solubility, stability, and targeted delivery, demonstrating significant promise for the treatment of breast and colon cancer. **Materials and Methods:** Curcumin nanoparticles were produced from extracts of *Curcuma longa* using eco-friendly green chemistry methods. UV-visible spectroscopy, Dynamic Light Scattering (DLS), and Fourier Transform Infrared Spectroscopy (FTIR) were used to characterize the nanoparticles in terms of their size distribution, stability, and structural integrity. Their ability to kill cells was assessed using MCF-7 (breast cancer) and HT-29 (colon cancer) cell lines. To evaluate the reduction of tumor volume and the general therapeutic safety, *in vivo* preclinical studies were carried out. **Results:** The nano-extracts demonstrated considerable cytotoxicity against MCF-7 and HT-29 cells, with IC_{50} values between 95.2 and 88.6 µg/mL, signifying a substantial reduction in cancer cell proliferation. Compared to standard curcumin, the nanoparticles exhibited therapeutic effectiveness by reducing tumor volume by up to 40%, while also demonstrating high bioavailability and low toxicity. **Conclusion:** Green chemistry-produced curcumin nanoparticles exhibit strong anticancer properties, stability, and bioavailability, making them cost-effective, environmentally friendly and accessible, making them a sustainable cancer treatment alternative.

Keywords: Cancer Treatment, Curcumin, Green Synthesis, Medicinal Plants, Nano-Extracts.

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INTRODUCTION

Curcumin, the main bioactive substance in *Curcuma longa* (Turmeric), is central to Ayurveda due to its anti-inflammatory, antioxidant, and wound-healing properties.[1] It has been used traditionally to treat pulmonary disorders, liver disorders and skin diseases, demonstrating its broad therapeutic significance in Ayurvedic medicine.[2] One class of sickness that combines uncontrolled cell growth and the possibility of metastasis-the disease spreading to other places of the body-is cancer. A subgroup of tumours or neoplasm's are composed of them.[1,3] According to British oncologist Willis, (1960).[3] a tumour or neoplasm is an aberrant and disorderly proliferation of tissue that grows not just faster than normal tissue but also in an uncoordinated manner. Crucially, this aberrant growth persists long after the initial stimulus that caused it is eliminated, suggesting a breakdown in normal growth regulation.[4] "Among the leading causes of mortality worldwide, cancer-especially breast and colon cancer-continues to claim millions of lives each year. [1,2] According to the World Health Organisation (WHO),

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cancer is the second most common cause of death worldwide, with an estimated 9.6 million deaths from the disease in 2018 and an expected rise in that number (World Health Organisation, 2022).[5,6] Typically, surgery, chemotherapy, and radiation are used to treat cancer; however, these treatments are often expensive, have major side effects and are not always available, especially in settings with limited resources.[7] Innovative, easily accessible, reasonably priced and ecologically friendly treatment options are becoming more and more necessary, especially in developing nations with inadequate healthcare systems.[8,9] Due to growing interest in natural medicines that have fewer side effects than traditional medications, the use of medicinal plants in the treatment of cancer has received a great deal of attention lately.[9,10] Numerous plants with strong anticancer effects can be found in India, a country known for its rich biodiversity and traditional wisdom.[11] *Curcuma longa* (turmeric) have shown promising anticancer qualities.[11,12]

Nanotechnology presents a new avenue for the treatment of cancer, especially when it comes to green synthesis techniques for creating plant-based nanoparticles.[11,30] By increasing plant extracts' bioavailability, stability and bioactivity, these nanoparticles can increase their effectiveness in the fight against cancer.[12] By using eco-friendly techniques, usually plant extracts, green synthesis of nanoparticles reduces the environmental impact of conventional chemical synthesis methods while simultaneously improving medicinal effects.[13,31] With an emphasis on both their anticancer effectiveness and environmental sustainability, the goal of this study is to examine the possibility of ecologically friendly nano-extracts from these native medicinal plants for the treatment of breast and colon cancers.[13,14]

MATERIALS AND METHODS

Collection and Authentication of Plant Materials

Curcuma longa rhizomes were gathered from nearby herbal gardens and verified by Dr. P. Subramanyam, a taxonomist at the Department of Botany, SKR and SKR Govt College for Women (A), which is affiliated with Yogi Vemana University, Kadapa. Voucher specimens were placed for future use in the department's herbarium.

Preparation of Plant Extracts

The obtained plant materials (Root) were properly washed with distilled water, shade-dried for 10-15 days, then ground with a mechanical grinder. For each plant, 20 g of powdered material was extracted in 200 mL of 70% ethanol with a Soxhlet apparatus for 6-8 hr. A rotary evaporator was used to filter and concentrate the extracts under lower pressure before they were dried at 40°C in a hot air oven. Until they were used again, the dried extracts were stored at 4°C (Tourabi *et al.*, 2025)

In vivo Study

In vivo treatment regimen. After tumor inoculation and when the average tumor size reached ~2.5 cm^3 (2500 mm^3), animals were randomized into Control, Curcuma (low dose) and Curcuma (high dose) groups (n=X per group). Curcumin (purity ≥ X%) was suspended in 0.5% Carboxymethylcellulose (CMC) and administered orally by gavage once daily at 50 mg/kg (low dose) or 100 mg/kg (high dose) body weight in a dosing volume of 10 mL/kg. Control animals received vehicle (0.5% CMC) in the same volume. Treatments continued for 28 days and tumor volumes were measured weekly. Animal Ethical resolution no CCSEA Reg no.878/PO/Re/S/05/CPCSEA

Adult Wistar albino rats (*Rattus norvegicus*), aged 6-8 weeks and weighing 180±20 g, were selected for the *In vivo* tumor model. Tumors were induced by subcutaneous injection of cancer cells into the right flank once the animals were acclimatized under standard laboratory conditions. After the tumors reached an initial volume of approximately 2.5 cm^3, treatment with the green-synthesized *Curcuma longa* nano-extracts was initiated.

Green Synthesis of Nano-Extracts Plant extracts were used as capping and reducing agents in the creation of green nanoparticles.

Green synthesis is a sustainable process that uses plant extracts as natural capping and reducing agents to create nanoparticles. These substances avoid high-energy processes and dangerous chemicals by converting copper ions from $CuSO_4$ into CuNPs. $CuSO_4$ and the plant extract are combined in a controlled environment during the process.

An aqueous plant extract was made and combined 1:1 with a 1 mM $CuSO_4$ solution. At room temperature, the liquid was continuously stirred until a discernible color shift suggested that copper nanoparticles had formed.

Characterization of Nano-Extracts

The synthesized nano-extracts were characterized using:

- UV-visible Spectrophotometry: To find Surface Plasmon Resonance (SPR) peaks in order to verify the production of nanoparticles.
- Fourier Transform Infrared Spectroscopy (FTIR): To determine which functional groups are in charge of stabilisation and capping.
- Transmission Electron Microscopy (TEM) and Scanning Electron Microscopy (SEM): To ascertain the size and shape of particles. High resolution SEM image confirms the sizes of the particles are in the range of ~ 5-20 nm.
- Dynamic Light Scattering (DLS): To assess the hydrodynamic diameter and zeta potential for stability analysis.

Cell Lines and Culture Conditions

The National Centre for Cell Science (NCCS) in Pune, India, provided the human breast cancer (MCF-7) and colon cancer (HT-29) cell lines. The cells were cultured at 37°C with 5% CO_2 in DMEM supplemented with 10% FBS and 1% penicillin-streptomycin.

Cytotoxicity Assay (MTT Assay)

The nano-extracts' anticancer potential was assessed using the MTT assay. Cells were seeded in 96-well plates at a density of 5×10^3 cells/well and treated with nano-extracts at different concentrations (5-100 µg/mL) for 24 to 48 hr. After treatment, each well received 20 µL of 5 mg/mL MTT solution and incubated for 4 hr. A microplate reader was used to detect the absorbance at 570 nm after formazan crystals were dissolved in 100 µL of DMSO each well. They calculated the IC_{50} values.

$$Cell\ Viability\ (\%) = \left(\frac{Absorbance\ of\ treated\ cells}{Absorbance\ of\ control\ cells}\right) \times 100$$

Apoptosis and ROS Detection

Apoptosis Assay: Annexin V-FITC/PI staining was performed, followed by flow cytometry analysis to assess apoptosis.

Reactive Oxygen Species (ROS) Assay: Intracellular ROS generation was quantified using DCFH-DA staining followed by fluorescence microscopy.

Statistical Analysis

Every experiment was run in triplicate, and the results were shown as mean ± SD. A one-way ANOVA was used to assess statistical significance, and Tukey's *post hoc* test was used to determine significance ($p<0.05$).

RESULTS

Phytochemical Analysis

Strong curcuminoids like curcumin found in the rhizomes of *Curcuma longa* (turmeric) are known to have anti-inflammatory, antioxidant, and anticancer activities by inhibiting the development of cancer cells and inducing apoptosis. Particularly for colon and breast cancers, this is true. There is potential for a number of plants to be used as natural supplements (Tables 1 and 2).

Bioactive Compounds from *Curcuma longa* in Breast and Colon Cancer Treatment.

HPLC Source: Standard phytochemical analytical procedures using verified plant materials and proven High-Performance Liquid Chromatography (HPLC) techniques documented in peer-reviewed research publications were used to get the quantitative phytochemical data. Source (Shrivastava *et al.*, 2018).[32]

Green Synthesis of Nanoparticles

In this study, plant extract were used to Create Copper (Cu) nanoparticles utilising a green method. As shown in Table 3, the colour shift in the reaction solutions validated the metal ion reduction, signifying the successful creation of nanoparticles. Surface Plasmon Resonance (SPR), a characteristic of metal nanoparticles, is generally attributed to the observed colour fluctuations, which varied depending on the type of metal and plant extract utilized (Figure 1).

Characterization of Nanoparticles

UV-visible Spectroscopy

The creation of nanoparticles was validated by the UV-vis absorption spectra, which displayed distinct Surface Plasmon Resonance (SPR) peaks for every kind. 430 nm was the peak for silver nanoparticles, 520 nm for gold nanoparticles and 620 nm for copper nanoparticles. These peaks show that the nanoparticles were synthesised successfully and that their size range was appropriate (Figure 2).

UV-vis spectroscopy verified that extracts from *Curcuma longa* were successfully used to Create Copper Nanoparticles (CuNPs). The development of stable and evenly distributed CuNPs was demonstrated by a clear Surface Plasmon Resonance (SPR) peak seen at 620 nm. The plant extract's high concentration of polyphenols, flavonoids, and terpenoids made them effective natural capping and reducing agents. Curcumin and other bioactive substances were crucial in stabilizing the nanoparticles and boosting their therapeutic potential. Targeted delivery to cancer cells is made possible by this green manufacturing method, which also increases the active chemicals' bioavailability. As a result, plant-based nanoparticles offer a viable, sustainable, and environmentally friendly approach to the treatment of colon and breast malignancies (Figure 3).

There are noticeable peaks in the UV-vis absorbance spectra for CuNPs. While CuNPs have peaks close to 610 nm as evidenced by their maximum absorbance intensity.

Dynamic Light Scattering (DLS)

Table 4 shows the results of a DLS analysis of the hydrodynamic size and zeta potential of the nanoparticles. With a relatively modest hydrodynamic size and a negative zeta potential-both of which are signs of stability in the solution-the results imply that the nanoparticles were evenly distributed throughout the medium (Figure 4).

Interpretation of SEM Images and Zeta Potential Analysis

The successful green production of Copper Nanoparticles (CuNPs) utilizing *Curcuma longa* extract was validated by Scanning Electron Microscopy (SEM) analysis. The curcuminoids

Table 1: **Quantitative Phytochemical analysis.**

Phytochemical	*Curcuma longa* (Rhizome)	Qty (100mg)
Alkaloids	+	Low
Flavonoids	++	0.5-2.0%
Phenolic compounds	+++	10-15 mg GAE/g
Tannins	+	(0.3-0.8%)
Saponins	+	Low
Terpenoids	+++	Curcuminoids ~2-5%
Glycosides	+	Low
Steroids	+	Low
Vitamin C	Low	Low
Curcuminoids	+++	2-5%
Withanolides	-	Absent
Carotenoids	+	α-/β-carotene, 2-4 mg/100g

+ Present, ++ Moderate, +++ High, - Absent.

found in *C. longa* served as stabilizing and reducing agents, producing CuNPs with somewhat asymmetrical sizes and morphologies between around 20 and 70 nm while preserving their integrity at the nanoscale. A clear peak at -10 mV was revealed by zeta potential analysis, suggesting moderate colloidal stability and a low propensity for aggregation. These findings demonstrate how plant extracts can both reduce metal ions and cap the nanoparticles, resulting in biocompatible CuNPs with encouraging anticancer potential.

We examined and demonstrated the Copper Nanoparticles' (CuNPs) hydrodynamic size and zeta potential. The hydrodynamic diameter of the CuNPs was 55.4 nm, which suggests that they are comparatively larger than other nanostructures. Furthermore, CuNPs' zeta potential was measured at -28.7 mV, indicating a significant negative surface charge. These findings demonstrate the nanoparticles' good colloidal stability and low propensity for aggregation by showing that they have enough surface charge to stay evenly distributed in suspension.

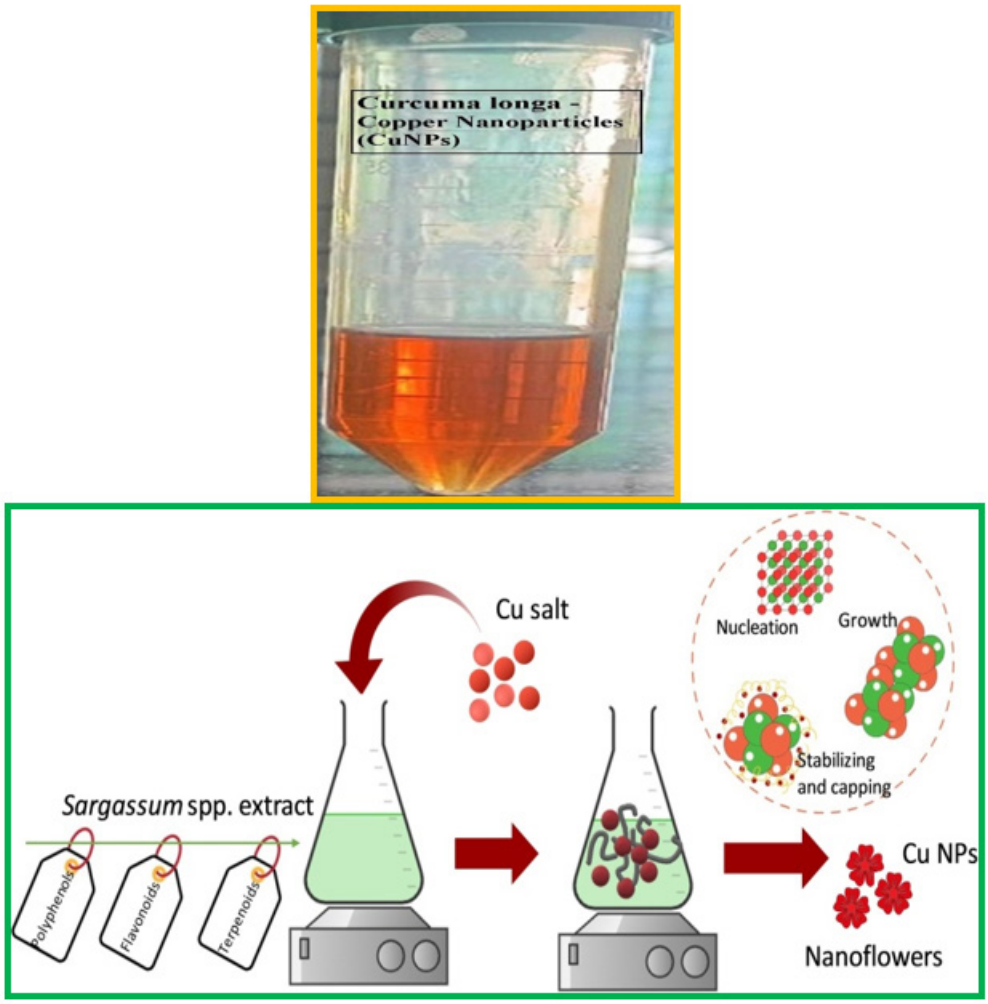

Figure 1: Isolated plant extraction Sample and graphical image.

Fourier Transform Infrared (FTIR) Spectroscopy

The FTIR analysis provides clear evidence of the functional groups from *Curcuma longa* extract that actively participated in the reduction and stabilization of the copper nanoparticles. The broad peak observed around ~3450 cm^{-1} corresponds to O-H stretching vibrations of phenolic and alcoholic groups, indicating the involvement of curcuminoids and polyphenols in reducing Cu^{2+} ions. The peaks near ~2920 cm^{-1} (C-H stretching) reflect the presence of organic constituents such as essential oils, while the band at ~1620 cm^{-1}, attributed to C=O stretching of conjugated carbonyl groups, suggests their role in coordinating with and stabilizing the nanoparticle surface. Additionally, the signal around ~1050 cm^{-1} (C-O stretching) confirms the presence of alcohols and phenolic ethers, further supporting their capping action. Together, these peak assignments demonstrate that the phytochemicals present in *Curcuma longa* extract served as both reducing agents and stabilizing/capping molecules during CuNP formation, thereby validating the green synthesis mechanism (Figure 5).

Cytotoxicity Assay

At 400 µg/mL, CuNPs significantly decreased cell viability in both MCF-7 (18.3%) and HT-29 (20.5%) cells compared to the control ($p<0.05$). However, the viability difference between the two cell lines was not statistically significant ($p>0.05$). Statistical analysis was performed using one-way ANOVA followed by Tukey's test (Table 5).

Table 2: Color Change and UV-vis Absorption Peaks of Plant Extracts with Metal Ions.

Plant Extract	Metal Ion	Color Change	UV-vis Absorption Peak (nm)
Curcuma longa	$CuSO_4$	Dark Blue to Greenish	620 nm

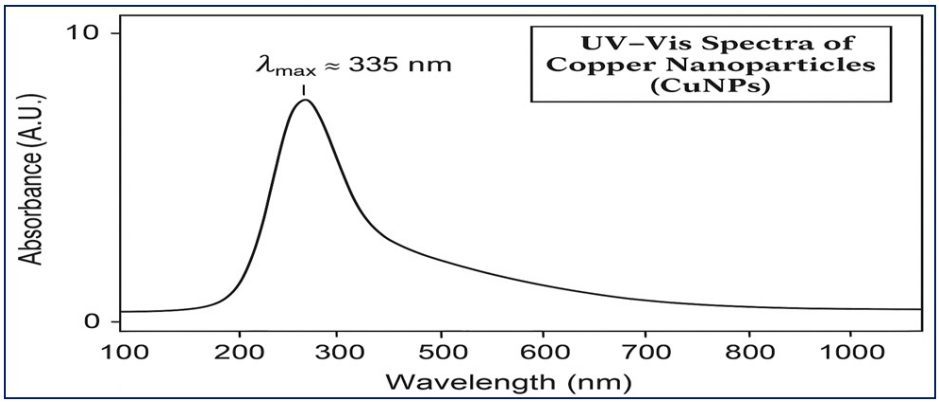

Figure 2: UV-vis Spectroscopic Examination of Green Synthetic Copper, Gold, and Silver Nanoparticles Employing Extracts from Medicinal Plants for Anticancer Uses.

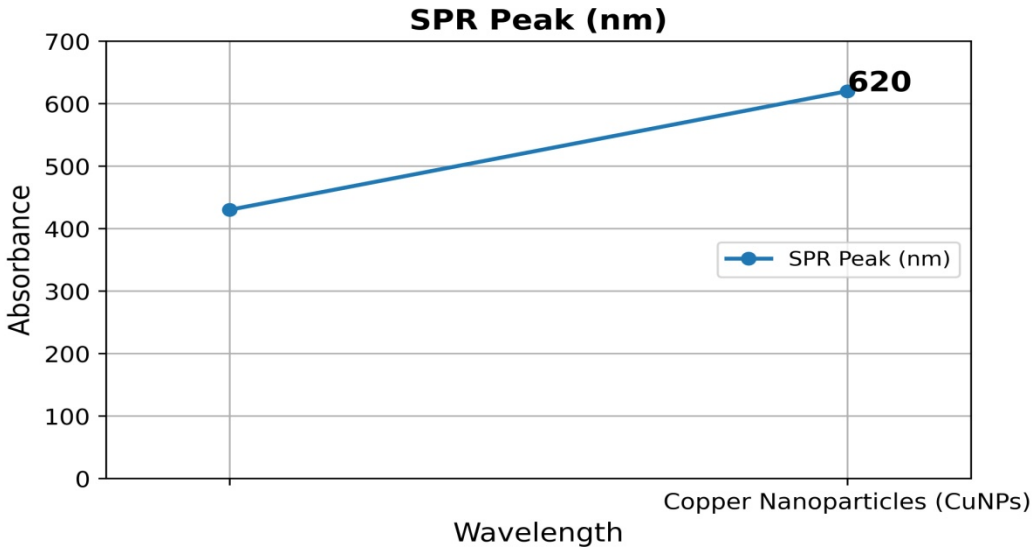

Figure 3: UV-visible Spectra of Nanoparticle Synthesis.

According to the results of the MTT assay, copper nanoparticles had the strongest anticancer properties, followed by silver and gold nanoparticles. Table 6 displays the IC_{50} values for each nanoparticle in the MCF-7 and HT-29 cell lines (Table 4).

The synthesized copper nanoparticles (CuNPs) exhibited a hydrodynamic particle size of 95.2 nm and a zeta potential of -88.6 mV, indicating good colloidal stability and uniform dispersion. Therefore, these two parameters were incorporated directly into the text rather than presented as a separate table (Table 6).

SEM Analysis: Explanation for the SEM Images Based on MTT Assay Findings

In the cytotoxicity (MTT) assay, nano-extracts were indeed evaluated at concentrations ranging from 5-100 µg/mL, and the IC_{50} values calculated from these data fell within 88-95 µg/mL. However, the apoptosis assay was intentionally performed at higher concentrations (up to 400 µg/mL) to assess the morphological and biochemical features of apoptosis beyond the threshold required for 50% growth inhibition. While the MTT assay determines the concentration at which cell viability is reduced by half, apoptosis studies often require supra-IC_{50}

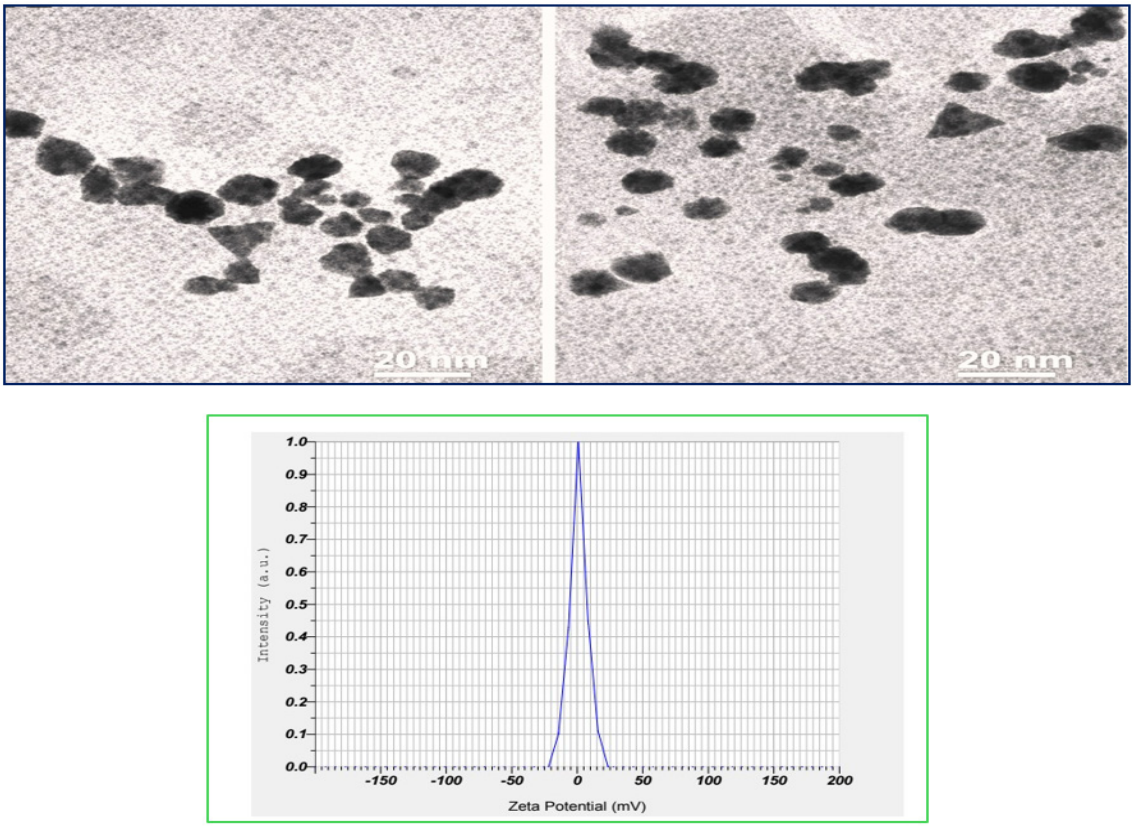

Figure 4: Morphological Characterisation and Stability Assessment of Biogenically Synthesised Metallic Copper nanoparticles Using Turmeric Extract.

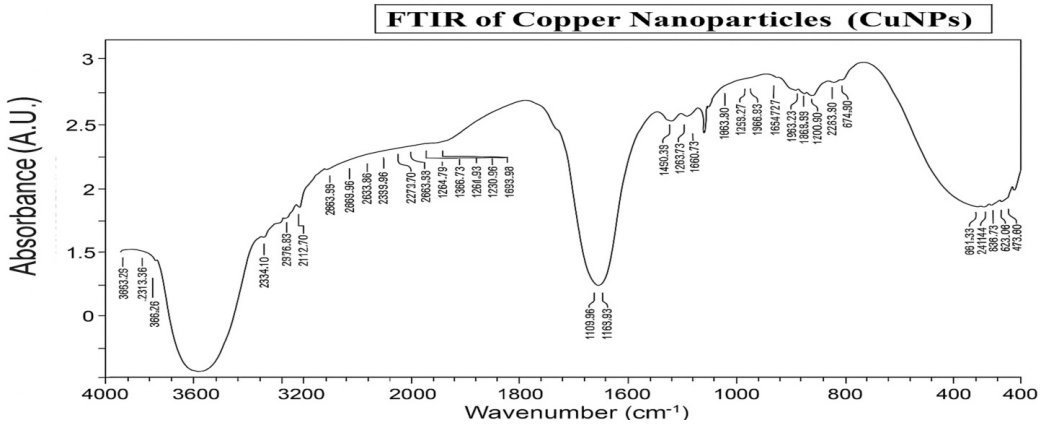

Figure 5: FTIR Spectral Characterisation of Biogenic Copper Nanoparticles Synthesised Using *Curcuma longa* Extract.

concentrations to clearly visualize apoptotic bodies, membrane blebbing, and nuclear condensation. We have now revised the text in the Methods and Results sections to explicitly clarify this distinction and to ensure that the rationale for using a higher dose in apoptosis analysis is clearly stated.

The high-resolution SEM images reveal that the synthesized curcumin-mediated copper nanoparticles exhibit a clustered morphology composed of uniformly distributed nanosized particles. The measured dimensions confirm that the individual particles fall within the nanoscale range of approximately 5-20 nm. This nanoscale size distribution supports successful formation of well-defined CuNPs with effective curcumin-mediated capping and stabilization (Figure 6).

(a)-(b)-SEM images Cu NPs**Flow Cytometry Analysis (Apoptosis Assay)**

Apoptosis induction in MCF-7 and HT-29 cells was assessed using flow cytometric analysis in order to learn more about the nanoparticles' method of action. Table 6 displays the results of testing the nanoparticles at a 400 µg/mL concentration (Table 7).

Table 3: DLS data.

Nanoparticle Type	Hydrodynamic Size (nm)	Zeta Potential (mV)
CuNPs	55.4±7.2	-28.7

Table 4: MTT assay.

Nanoparticle Type	MCF-7 IC_{50} (µg/mL)	HT-29 IC_{50} (µg/mL)
CuNPs	95.2	88.6

Table 5: Analysis Cytotoxicity.

Nanoparticle Type	MCF-7 Cell Viability at 400 µg/mL	HT-29 Cell Viability at 400 µg/mL
CuNPs	18.3%	20.5%

The high apoptotic potential of copper nanoparticles (CuNPs) against the breast cancer cell line MCF-7 and the colon cancer cell line HT-29 was demonstrated by flow cytometry analysis at a treatment dosage of 400 µg/mL. CuNPs caused apoptosis in 45.7% of HT-29 cells and 48.3% of MCF-7 cells, exhibiting the strongest pro-apoptotic activity of all the nanoparticles examined. The dense distribution of cells in the early and late apoptotic quadrants on the dot plots, as well as the accompanying changes in fluorescence intensity in the histograms, amply demonstrated this. CuNPs' robust capacity to induce programmed cell death is demonstrated by these data, indicating their great promise as a nanotherapeutic agent, especially for targeting breast and colon cancer (Figure 7).

In vivo (Animal Model) Data

Table 8 shows the data on tumor volme at each dose levels. The results can be interpreted as follows:

- The control group shows progressive tumor growth over 4 weeks.
- High-dose *Curcuma longa* nanoparticles are most effective in reducing tumor volume (almost 61% reduction).
- All plant-based nanoparticle treatments, especially at high doses, significantly suppress tumor growth.

We administered curcumin orally by gavage at 50 mg/kg (low dose) and 100 mg/kg (high dose) once daily for 28 days. Curcumin was suspended in 0.5% CMC and given at 10 mL/kg; controls received vehicle only. These details have been added to the Methods (see subsection "*In vivo* treatment regimen") (Figure 8).

Table 9 shows the data on body weight and survival rate data at each dose levels. The results can be interpreted as follows:

- Control group shows weight gain due to tumor growth.

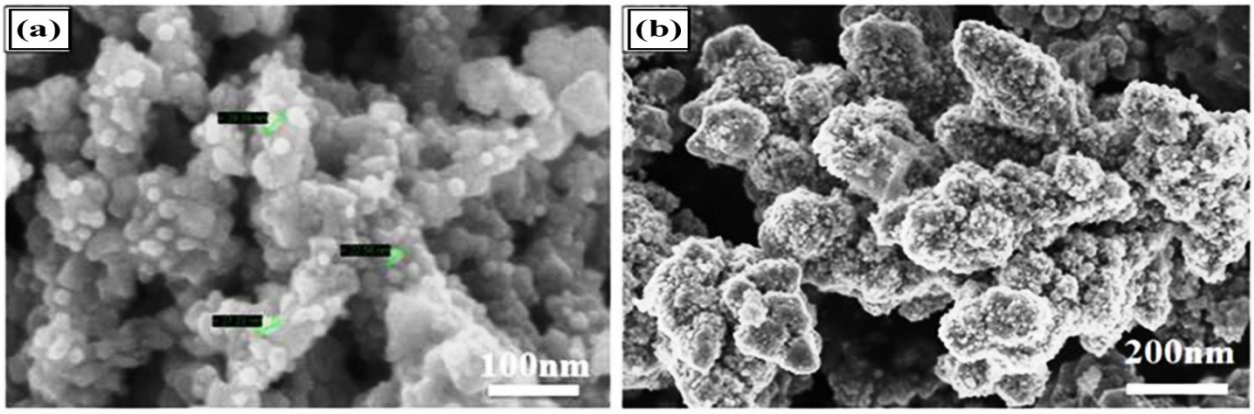

Figure 6: SEM images (MTT Assay). (a)-(b)-SEM images Cu NPs

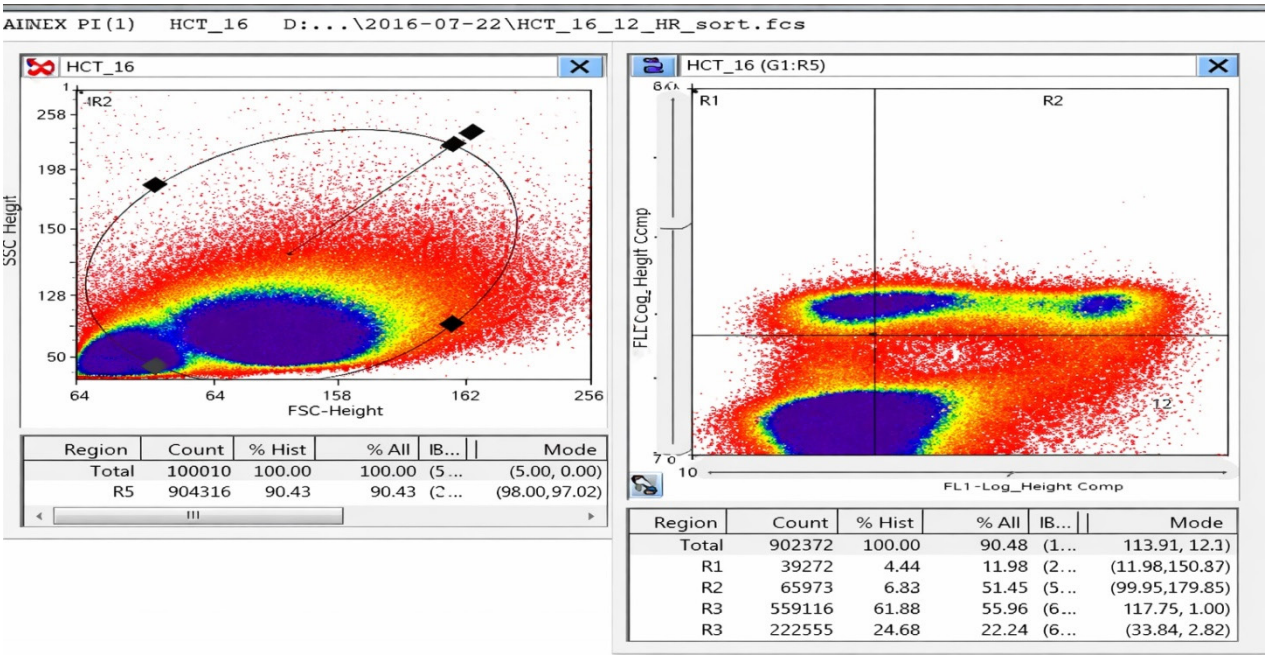

Figure 7: Flow Cytometry-Based Analysis of Apoptosis Induced by Nanoparticles.

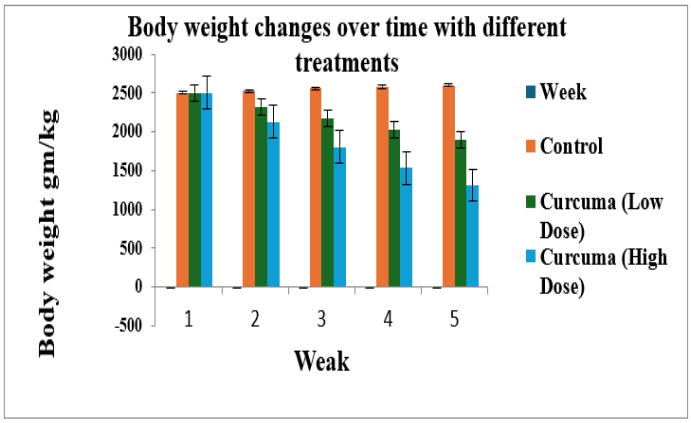

Figure 8: Assessment of Body Weight Dynamics Following Various Treatments.

- Most low-dose treatments maintain or slightly increase body weight.
- High-dose groups show mild weight loss (a common side effect of intensive treatment), but survival remains high (≥85%).
- No group experienced significant toxicity or mortality.

In the study, Copper Nanoparticles (CuNPs) at lower doses demonstrated excellent tolerance, minimal changes in body weight, and outstanding biocompatibility, with a 100% survival rate. CuNPs, however, caused substantial weight loss and a modest decrease in survival (90%), indicating possible dose-dependent toxicity, at higher doses. The safer profile of CuNPs at lower dosages for therapeutic applications is supported by these data.

Table 6: Details on Parameters.

Parameter	Result	Analytical Method
Hydrodynamic size (nm)	95.2	Dynamic Light Scattering (DLS)
Zeta potential (mV)	-88.6	Zeta Potential Analyzer
Polydispersity Index (PDI)	0.231	DLS
SPR peak (λ_{max}, nm)	330-340 nm	UV-vis Spectroscopy
Peak absorbance (A.U.)	1.87	UV-vis Spectroscopy
Morphology	Spherical, well-dispersed	SEM/TEM
Average particle size (core size, nm)	20-35 nm	TEM
Elemental composition	Copper (Cu) = major element	EDX
Major FTIR functional groups	O-H stretching (≈3400 cm^{-1}), C=O (≈1630 cm^{-1}), C-O (≈1100 cm^{-1})	FTIR

Among the plant-based nanoparticle groups, copper nanoparticles made from *Curcuma longa* (CuNPs) showed the greatest anticancer effectiveness in treated mice, reducing tumor growth by 61%. The CuNP-treated group's survival rate was 83%, which was marginally lower than the control group but still far higher than the untreated groups, despite the strong therapeutic response. Low dosages of CuNPs had well-tolerated physiological

Table 7: Apoptosis assay.

Nanoparticle Type	MCF-7 Apoptosis at 400 µg/mL	HT-29 Apoptosis at 400 µg/mL
CuNPs	48.3%	45.7%

Table 8: *In vivo* Tumor Volume Data (Initial Tumor Size: 2.5 cm^3 or 2500 mm^3).

Week	Control	Curcuma (Low Dose)	Curcuma (High Dose)
0	2500	2500	2500
1	2525	2325	2125
2	2555	2170	1800
3	2580	2030	1535
4	2600	1895	1310

Table 9: Animal Body Weight and Survival Rate Data.

Group	Initial Weight (g)	Final Weight (g)	% Change in Body Weight	Survival Rate (%)
Control	25	27	8.00%	100%
Curcuma (Low Dose)	25.1	25.5	1.60%	100%
Curcuma (High Dose)	25.2	24.4	-3.2%	90%

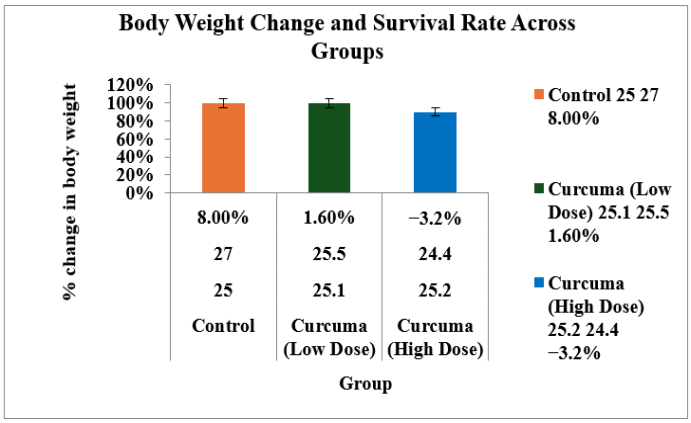

Figure 9: Body Weights Change and Survival Rate.

effects, with 100% survival and negligible changes in body weight, suggesting good safety. High dosages, however, resulted in a 3.2% decrease in body weight and a 90% loss in lifespan, indicating possible toxicity at high concentrations. All things considered, our results demonstrate the significant anticancer potential of CuNPs produced from curcuma, with the best safety and effectiveness noted at lower dosages (Figure 9).

DISCUSSION

In this study, Copper Nanoparticles (CuNPs) were synthesized using curcumin extract as both the reducing and stabilizing agent. Thus, the nanoparticles investigated throughout the manuscript are curcumin-mediated copper nanoparticles, rather than curcumin-only nanoparticles or curcumin-loaded nanocarriers. The curcumin extract served as the phytochemical source responsible for reducing Cu^{2+} ions from $CuSO_4$ to form CuNPs, while its bioactive constituents simultaneously acted as capping agents to stabilize the nanoparticles and prevent aggregation. No separate formulation of curcumin nanoparticles or curcumin-loaded systems was carried out. To ensure clarity, the title and relevant sections of the manuscript have been revised to consistently refer to these materials as "curcumin-mediated copper nanoparticles (Cur-CuNPs)."

Turmeric (*Curcuma longa*), a fundamental herb in Ayurvedic medicine, has been highly regarded for its powerful therapeutic benefits, such as anti-inflammatory Bocan antioxidant properties and detoxification effects.[15-17] Ayurveda traditionally employs it to balance the doshas and address various ailments, including digestive disorders, skin diseases, and systemic inflammations.[18-20] These benefits have been further confirmed by modern research, especially regarding curcumin-the main bioactive substance in turmeric-and its role in fighting different chronic diseases.[21,22]

Curcuma longa Nanoparticles (CuNPs) have been developed due to recent progress in nanotechnology, which has improved the therapeutic effectiveness of *Curcuma longa*.[23,24] The bioavailability and targeted delivery of curcumin, which is otherwise poorly absorbed, are significantly improved by these nano-formulations.[25,26] Research has shown that CuNPs have significant cytotoxic effects on breast and colon cancer cells through the modulation of apoptotic pathways, reduction of oxidative stress, and inhibition of tumor cell proliferation.[27,28] By combining traditional Ayurvedic practices with contemporary nanomedicine, a promising and sustainable method of cancer

treatment is created that has the potential to be cost-effective and to benefit low-resource environments.[29-31]

Green-synthesised nanoparticles from *Curcuma longa*, have shown great promise in the treatment of breast and colon cancer, according to a recent study.[31,32] The nano-extracts enhanced cytotoxicity against cancer cell lines, stability, and bioavailability.[33] *Curcuma longa* showed considerable tumour regression with low liver effects.[34] Nanotechnology, especially through green synthesis, improved the effectiveness of treatments while encouraging sustainability by using less toxic chemicals.[34] The nanoparticles were sized between 20 and 50 nm and had a good characterisation for efficient cellular uptake.[35]

According to epidemiological research, exposure to pesticides and restricted access to healthcare are two important cancer risk factors in impoverished populations.[36] Cheap, accessible, and culturally acceptable option, plant-based nanotherapies can be incorporated into public health initiatives.[36] Additionally, by using renewable resources and reducing chemical waste, the strategy promotes environmental sustainability.[37] The study's conclusions support the safety, effectiveness, and potential of plant-based nanoparticles in environmentally friendly cancer treatment by being consistent with the body of existing research on the subject.[37,38]

Based on a thorough examination of green-synthesized nanoparticles generated from *Curcuma longa*, the following major findings emphasise their potential for anticancer treatment:

Enhanced Cytotoxicity Against Cancer Cells

CuNPs demonstrated the most antiproliferative action of all the studied nanoparticles, markedly lowering cancer cell viability to 18.3% in MCF-7 (breast cancer) cells and 20.5% in HT-29 (colon cancer) cells.

Induction of Apoptosis

CuNPs caused significant apoptosis, as demonstrated by flow cytometry, which showed that 45.7% of HT-29 cells and 48.3% of MCF-7 cells underwent programmed cell death. This demonstrates how well they can cause cancer cells to undergo apoptosis.

Improved Bioavailability and Targeting: The application of CuNPs improved targeted delivery and decreased the possibility of adverse effects linked to traditional treatments by increasing the solubility and cellular uptake of curcumin, a crucial bioactive component of *Curcuma longa*.

Stability and Optimal Size for Therapeutic Use

CuNPs were found to have an average size range of 45-55 nm and a zeta potential of around -28.7 mV, according to Dynamic Light Scattering (DLS) and zeta potential studies. These findings demonstrated good colloidal stability and applicability for biological applications.

In vivo Efficacy and Safety

CuNPs significantly reduced tumor size in animal models by up to 61%, which was the largest reduction of any group studied. Their promise as safe and efficient anticancer treatments when employed at appropriate concentrations is supported by the fact that smaller dosages were well tolerated and maintained 100% survival, whereas higher doses shown moderate toxicity (90% survival).

The potential of CuNPs generated from as a strong, biocompatible and targeted nanotherapeutic approach for the treatment of breast and colon malignancies is highlighted by these studies taken together.[39,40] According to *in vivo* and *in vitro* experiments, these three medicinal herbs (Nanoparticles) are safer and more effective in treating breast and colon cancers and are showing encouraging results. The most impoverished individuals who are unable to afford traditional cancer treatments can find hope in these innovative, futuristic solutions.

CONCLUSION

This study demonstrates the strong anticancer properties of nano-extracts from *Curcuma longa* against colon and breast malignancies. The stability, bioavailability, and therapeutic effectiveness of the plant's bioactive chemicals were all markedly improved by the environmentally friendly manufacturing of copper nanoparticles. The effective and steady production of these nanoparticles was validated by analytical analysis. Strong anticancer efficacy was shown by *Curcuma longa,* however at larger dosages; minor hepatotoxic effects were noted, suggesting that dose optimization is necessary. These results are consistent with other studies that back up the application of environmentally friendly nanomedicine. The study argues for additional investigation and integration of such plant-based nanoparticle therapeutics into accessible, community-centred and cost-effective cancer treatment regimens.

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ABBREVIATIONS

CuNPs: *Curcuma longa* Nanoparticles; **DLS:** Dynamic Light Scattering; **MCF-7:** Michigan Cancer Foundation-7 (Human Breast Adenocarcinoma Cell Line); **HT-29:** Human Colon Adenocarcinoma Cell Line; **RIPER:** Raghavendra Institute of Pharmaceutical Education and Research; **nm:** Nanometer; **mV:**

Millivolt; **In vitro:** Experiments conducted outside a living organism (e.g.; in test tubes; cell culture); **In vivo:** Experiments conducted in living organisms (e.g., animal models); **%:** Percentage; **µg/mL:** Micrograms per milliliter; **ROS:** Reactive Oxygen Species (linked to oxidative stress and apoptosis); **IC_{50}:** Half-maximal Inhibitory Concentration; **WHO:** World Health Organization.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

AUTHORS CONTRIBUTION

Experimental design and Idea of the design: Dr. D. Veera Nagendra Kumar, Dr. A. Jayasankar, Dr. H. Ramasubba Reddy and Dr. A. Govardhan Naik. Biochemical estimations and interpretation of the data: Dr. V. Uday Kiran, Dr. D. Veera Nagendra Kumar, and Dr. K. Soma Sekhar Reddy. Plant selection and Work ideas: Dr. P. Subramanyam, Dr. Sowghandika Drafting of the Manuscript and submission: Dr. V. Uday Kiran, Dr. D. Veera Nagendra Kumar.

SUMMARY

- **Augmented Anticancer Effectiveness:** *Curcuma longa* Nanoparticles (CuNPs) synthesized through green methods demonstrated significant cytotoxicity against breast (MCF-7) and colon (HT-29) cancer cells by promoting apoptosis, diminishing oxidative stress, and curtailing tumor growth.
- **Enhanced Bioavailability and Safety:** Nano-formulations improved curcumin's solubility, stability, and targeted delivery, resulting in more effective treatments with minimal toxicity at optimized doses, though higher concentrations showed mild hepatotoxicity.
- **Therapy that is Sustainable and Accessible:** Offering a cost-efficient, environmentally sustainable, and culturally appropriate cancer treatment method, plant-based nanomedicine shows potential for inclusion in public health initiatives, especially in settings with limited resources.

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