ORIGINAL ARTICLE

Characterization and Utilization of Latex of *Plumeria alba* for Various Bioactive Studies and Nanoparticle Production for Drug Delivery

Antony V Samrot[1]*, Anita Mirarmandy[2], Rajalakshmi D[3], Shobana N[3], Sneha Xavier[3], Krithika Shree S[3], Sanjay Preeth R[3]

[1] Department of Microbiology, Faculty of Medicine, Manipal University College Malaysia, Jalan Padang Jambu, Bukit Baru, 75150 Melaka, Malaysia
[2] School of Bioscience; Faculty of Medicine, Bioscience and Nursing, MAHSA University, Jalan SP2, Bandar Saujana Putra, 42610, Jenjarom, Selangor, Malaysia
[3] Department of Biotechnology, School of Bio and Chemical Engineering, Sathyabama Institute of Science and Technology, Sholiganallur, Rajiv Gandhi Salai, Chennai, Tamil Nadu, 600119, India

ABSTRACT

Introduction: The use of plant latex provides an environment friendly alternative for the synthesis of nanocarriers compared to conventional physical and chemical methods. **Methods:** In this study, latex from *Plumeria alba* was subjected to chloroform extraction to isolate lipid components. The extract was characterized using UV-Vis Spectroscopy (UV- Vis), Fourier Transform Infrared Spectroscopy (FTIR) and Gas Chromatography–Mass Spectrometry (GC-MS). The Antibacterial and antioxidant activities of the extracts were evaluated. Drug loaded nanocarriers were then prepared by a microemulsion approach and analyzed using UV-Vis, FTIR and Scanning Electron Microscopy (SEM). Their drug-release performance was subsequently assessed. **Results:** The chloroform based extract exhibited both antibacterial and antioxidant activities. The synthesized nanocarriers had particle sizes ranging from approximately 450 nm to 920 nm. Among these, the drug-loaded nanocarriers demonstrated notable antibacterial activity, while the formulation on based on chloroform extract showing the highest drug release efficiency in ethanol. **Conclusion:** *Plumeria alba*- derived nanocarriers exhibit promising potential for drug delivery applications due to their biodegradable nature and inherent antioxidant and antibacterial properties, indicating their suitability for future therapeutic use.
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Keywords: Plant latex, nanocarrier; *Plumeria alba*; Antioxidant activity; Antibacterial Activity; GC-MS.

Corresponding Author:
Antony V Samrot, PhD
Email: antonysamrot@gmail.com
Tel: +601160938026

INTRODUCTION

A wide range of medical diagnostic and therapeutic interventions such as diagnostic imaging, photothermal therapy, nucleic acid delivery, tissue engineering, implantable devices and controlled drug and gene delivery have the potential to be revolutionized by the use of nanoparticles (1-5). Nanoparticle based therapies have been widely used for the treatment of several complications such as cancer, diabetes, allergy, infection and inflammation (6-7). Nanoparticles have become increasingly prominent in therapeutic applications largely because their size closely resembles that of proteins. Thus, they have a large surface area which allows the display of a variety of surface functional groups such as ligands and their diffusion and volume change allow for rapid absorption and release (8). A variety of materials such as organic, inorganic, organic/inorganic hybrids can be used for the formation of nanoparticles. Polymeric nanoparticles are mainly utilized as biomaterials for the delivery of various therapeutic agents such as drugs and genes, as well as for tissue engineering scaffolds (8-10). Polymeric nanoparticles have gained increasing attention due to their ability to deliver bioactive compounds precisely to targeted tissues, cells, and even specific cellular compartments. Moreover, they are advantageous over ceramic or metal nanoparticles due to their ability to be synthesized in various sizes and to maintain localized drug release for extended periods (11). Natural and synthetic nanomaterials may possess their own favorable features; however the biocompatibility, biodegradability and low immunogenicity of naturally derived nanomaterials make them particularly advantageous (8). The assembly of one or more biopolymer molecules into a colloidal structure forms a biopolymer particle (12). In general, proteins, polysaccharides and their derivatives can be utilized

for the synthesis of biopolymers (13). The US Food and Drug Administration (FDA) has approved biopolymer nanoparticles as pharmaceutical and food nano-carriers (13-14). The renewability, natural abundance and cost effectiveness of biopolymer makes them ideal candidates for use in the food and pharmaceutical industries (15). Additionally, properties such as gelation, emulsification and water holding ability are among other useful functional properties exhibited by biopolymers (16). Tailoring biopolymer nanoparticles can enable them to exhibit stimuli-responsive activity for targeted delivery of bioactive molecules to specific sites (17-19). These tailored nanoparticles are able to retain their stability within various biological fluids such as blood and gastrointestinal juices (13). Globally, only about 10% of angiosperms produce latex which is the natural source of natural rubber (20). Latex is a milky sap consisting of polymer microparticles dispersed in an aqueous medium that is produced by laticifers upon physical damage (21). Therole of latex in plants is not fully explained but some studies suggest that it acts as a first line of defence, protecting plants from herbivores and pathogens (22). Latex contains a wide range of metabolites, including alkaloids, terpenoids, phenolics and cardenolides which have medicinal value and exhibit bioactivities such as antibacterial, antifungal, antioxidant, insecticidal, cytotoxic and anti-inflammatory effects (22-23). Due to its coagulating properties, latex has been used in pharmaceuticals for healing of wounds, treating joint pain and controlling parasitic infections (24). It has been found that ethanol extracts have the highest antioxidant capacity, whereas acetic acid extracts have the lowest antioxidant capacity (25). Latex can serve as a valuable material for nanocarrier synthesis when combined with a suitable surfactant. In the present study, latex extracted from the *Plumeria alba* tree was utilized to investigate its biological activities, its role in nanocarrier synthesis, as well as its encapsulation efficiency and controlled drug release behavior.

MATERIALS AND METHODS

Materials

Chloroform, Triton X, Curcumin, 2,2-Diphenylpicrylhydrazyl (DPPH), dimethyl sulfoxide, ethanol, methanol, acetone were obtained from Qualigens, India. Nutrient agar and nutrient broth were purchased from HiMedia, India. All the reagents used in this study were of analytical grade. All experiments were performed in triplicates and expressed as mean ± SD.

Collection of Plant Latex

Latex was extracted from bark of the *Plumeria alba* tree through precise incisions at MAHSA University, Bandar Saujana Putra, Malaysia. The plant specimen was authenticated based on organoleptic and macroscopic analysis of a fresh herbarium sample by Prof. P. Jayaraman at the Plant Anatomy Research Center, West Tambaram, Chennai. The registration number is PARC/2020/4255.

Chloroform extraction of the Plant Latex

The collected latex was dried at room temperature. 10g of dried latex were dissolved in 50 mL of chloroform and centrifuged at 5000 rpm. The supernatant was collected and dried in a fume hood at room temperature to evaporate the chloroform. The resulting extract was stored at 4 ^{0}C until further use.

Characterization of the Plant Latex Extracts

The chloroform extract was characterized using UV-Visible spectroscopy in the wavelength range of 200-800 nm. Functional groups were identified using Fourier Transform Infrared Spectroscopy (FTIR), and chemical constituents were analyzed using Gas Chromatography–Mass Spectrometry (GC–MS) (Pegasus BT 4D, LECO, USA).

Bioactivities of the Plant Latex Extracts

Antibacterial Activity

Nutrient agar was prepared and poured into sterile Petri dishes. After solidification, wells were made using a sterile cork borer and the agar surface was inoculated with a 24 hour bacterial broth culture. Using the agar well diffusion method, various concentrations of the plant latex extract were tested for antibacterial activity against *Bacillus sp., Klebsiella sp., Staphylococcus aureus*, and *Escherichia coli*. The inoculated plates were incubated at 37˚C for 18 - 24 hours, after which the zones of inhibition were measured and recorded (26).

Minimum Inhibitory Concentration (MIC)

A series of dilution containing different concentrations of the plant latex in nutrient broth was prepared in 96-well microtiter plates. Bacterial inocula were added to each wells and after overnight incubation, the Minimum Inhibitory Concentration (MIC) was determined using turbidometry method by comparing the turbidity of treated wells with that of the control (26).

Biofilm Assay

Stock solutions of the latex extracts were serially diluted in sterile Mueller–Hinton (MH) broth to obtain a range of concentrations. Each well of a 96-well plate received a specific volume of these extract dilution. Single colonies of the bacterial strains were inoculated into sterile MH broth and incubated at 37 °C until mid-logarithmic phase. The suspensions were adjusted to a standardized optical density (OD) at 600 nm using a spectrophotometer. The plates were then incubated statically at 37 °C for 48 hours to allow for sufficient biofilm formation on the well surfaces. Wells containing only MH broth and bacterial suspension served as control. After incubation, planktonic cells were removed by gentle aspiration, and the wells were washed three times with sterile physiological saline (0.9% NaCl). The biofilms were stained with 0.1% (w/v) crystal violet, incubated for 20 minutes at room

temperature, and washed with distilled water. Finally, 200 µL of 96% ethanol was added to each well, and absorbance was measured at 630 nm (27). Percentage inhibition was calculated using the formula:

$$\text{Percentage Inhibition} = \frac{\text{OD 630 control - OD 630 treated}}{\text{OD 630 control}} \times 100$$

Antioxidant Activity

Antioxidant activity was assessed using TLC bioautography and DPPH radical scavenging assays. For TLC bioautography, silica gel–coated plates were loaded with the extracts and developed using water and ethanol as solvents. After solvent migration ceased, the solvent front was marked. Plates were sprayed with DPPH solution, and retention factor (Rf) values were calculated (23). The extracts were also tested for DPPH free radical scavenging activity as described by standard protocols (28).

Synthesis of the Nanocarriers

Synthesis of chloroform extract nanocarriers

100 mg chloroform extract was dissolved in 10 mL chloroform and added dropwise to water under vigorous stirring. Simultaneously, 5 mL of 2% Triton X solution was added dropwise. The mixture was stirred for 3 h at room temperature, refrigerated overnight at 0 °C, and lyophilized.

Synthesis of drug loaded nanocarriers

100 mg of the synthesized unloaded nanocarriers were mixed with 0.6 g of curcumin dissolved in 10 mL ethanol and agitated for 3 h. The pH was adjusted to 5.0 with 0.1 M HCl, and the mixture was stirred overnight. After centrifugation at 10,000 rpm for 5 min, the supernatant was discarded, and the pellet was lyophilized (24).

Characterization of Synthesized Nanocarriers

The nanocarriers and drug-loaded nanocarriers were dispersed in water and absorbance were recorded between 200- 800 nm using UV–Vis spectroscopy. FTIR analysis (Spectrum Two, PerkinElmer, Waltham, MA, USA) was carried out in transmission mode within the range 4000–450 cm^{-1}. SEM analysis was performed using a Gemini SEM (ZEISS, Germany), and AFM analysis was conducted for both drug-loaded and unloaded nanocarriers (23–24).

Antibacterial Activity of the Nanocarriers

The antibacterial activity of the curcumin-loaded nanocarriers was evaluated against *Bacillus sp., Klebsiella sp., Staphylococcus aureus* (*S. aureus*), and *Escherichia coli* (*E. coli*). The drug-loaded nanocarriers were dispersed in sterile olvents(acetone, ethanol, or chloroform), to prepare the desired test concentrations. Wells were made on sterile Mueller-Hinton agar plates, uniformly inoculated with bacterial suspensions using a sterile swab to create a bacterial lawn and incubated.

Drug Release Efficiency

Nanocarriers loaded with curcumin (1 mg/mL) were dispersed in water and subjected to dialysis against 100 mL of 10 % ethanol in water. Readings were taken at every 15 min using a spectrophotometer at 420 nm (Genesys 10s, Thermo Scientific, Waltham, MA, USA) (24).

RESULTS

Characterization of the Extracts

The chloroform extract of *Plumeria alba* latex was characterized using UV–Vis, FTIR, and GC–MS analyses to identify its key functional and chemical constituents. UV-Vis spectral analysis showed two prominent absorption peaks at 232 nm and 323 nm, indicating the presence of conjugated systems and aromatic compounds within the extracts (Fig 1a). FTIR spectra (Fig 1b) revealed several characteristic functional groups, including O–H and N–H stretching vibrations, C=O and S=O stretching, as well as C–O, CO–O–CO, and C=C stretching bands. These features confirm a high abundance of carbon-based and nitrogen-containing compounds, suggesting the presence of diverse bioactive molecules in both water and chloroform fractions of the latex. GC–MS analysis (Fig. 1c; Table I) further identified ten major peaks corresponding mainly to hydrocarbons, esters, and alcohols. Pentadecane, 4-methyl was the predominant constituent, followed by flavone, 12-methyl-E,E-2,13-octadecadien-1-ol, and 4H-1-benzopyran-4-one,5,7-dihydroxy-2-(4-hydroxyphenyl). The presence of these compounds, particularly flavonoids and long-chain hydrocarbons, supports the potential antioxidant and antibacterial properties of the chloroform extract observed in subsequent bioactivity assays.

Bioactivities of the Extracts

The bioactivities of the *Plumeria alba* chloroform extract were evaluated through antibacterial, antibiofilm, and antioxidant assays. As shown in Table II, the extract exhibited antibacterial activity specifically against *Staphylococcus aureus* at concentrations of 6 mg and 8 mg, while no inhibition was observed against *E. coli* or other tested strains. The minimum

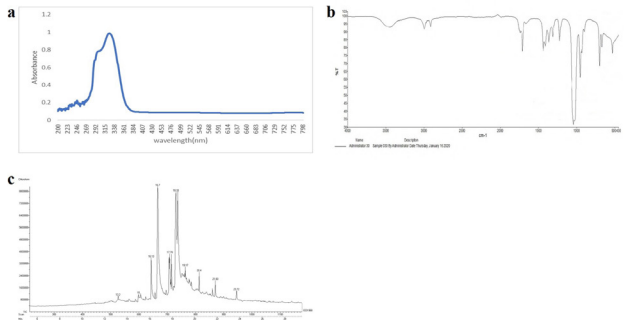

Figure 1: Chloroform extract: a. UV-Vis analysis, b. FTIR analysis, c. GCMS analysis

Table I: Compounds found in the GC-MS analysis of chloroform extract

Name of the component	RT	Base (%)FS
Pentadecane,4 methyl	16.7	58.9
Flavone	16.13	52.6
12-Methyl-E,E-2,13-octadecadien-1-ol	18.33	49.2
4H-1-Benzopyran-4-one,5,7- dihydroxy-2-(4-hydroxyphenyl)	17.78	21.7
9,15- Octadecadienoic acid, methyl ester, [Z,Z]	19.17	18.4
Elaidic acid, isopropyl ester	20.4	17.2
6,13-Pentacenedione,5,14-dihydroxy	21.83	14
Estra-1,35(10),6-tetraene-3,17-diol, diacetate, (17 6)	23.72	8.7
1H-pyrazole,4,5-dihydro-1- phenyl	13.2	8
3-Buten-2-one,4(2,5,6,6-tetramethyl-2-cyclohexen-1-yl)	15	6.8

Table II: Antibacterial activity of chloroform extract

Organism	Zone of inhibition (cm)					
	DMSO	Antibiotic	2mg	4mg	6mg	8mg
E.coli	0.00	2.00	0.00	0.00	0.00	0.00
S. aureus	0.00	2.50	0.00	0.00	0.3	1.2
Klebsiella	0.00	3.00	0.00	0.00	0.00	0.00
Bacillus sp	0.00	1.50	0.00	0.00	0.00	0.00

inhibitory concentration (MIC) assay confirmed a dose-dependent inhibition pattern, where increasing extract concentrations progressively reduced *S.aureus* growth, as illustrated in Fig. 2a. The biofilm inhibition assay further demonstrated that biofilm formation by *S.aureus* decreased with increasing concentrations of the chloroform extract, achieving partial but significant inhibition at higher doses (Fig. 2b). This result indicates that while the extract can disrupt biofilm development, complete eradication was not achieved at the concentrations tested. The incomplete inhibition may be due to limited penetration of the phytoconstituents through the *S.aureus* biofilm matrix. Hence, higher extract concentrations, longer exposure time, or nanoparticle-based formulations may be required to achieve complete biofilm disruption. In addition, the antioxidant potential of the extracts was assessed using the DPPH radical scavenging assay, where the chloroform extract exhibited markedly stronger scavenging activity than the water extract (Fig. 2c and 2d). The presence of flavonoids and long-chain hydrocarbons identified in the GC–MS analysis likely contributed to both the antibacterial and

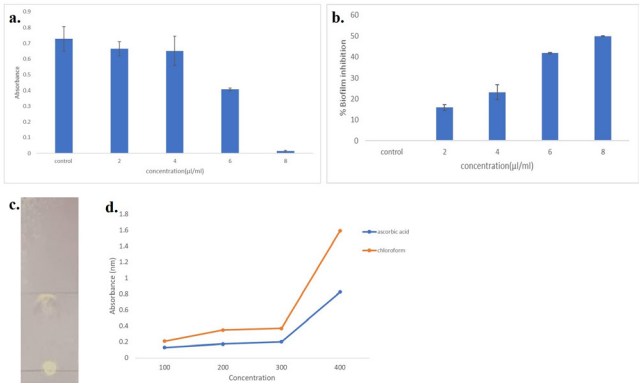

Figure 2: a. MIC of Latex against *S.aureus*, b. Percentage biofilm inhibition of latex against *S.aureus*, c.TLC bioautography for antioxidant activity of latex, d. DPPH radical scavenging activity of chloroform extract of latex

antioxidant effects observed, supporting the extract's potential as a source of bioactive compounds for further nanocarrier formulation.

Characterization of the Nanocarriers

The characterization of the nanocarriers revealed distinct optical, structural and morphological features. The unloaded nanocarrier exhibited a peak absorbance at 229 nm, while the chloroform based nanocarrier showed a maximum at 230 nm as illustrated in Fig 3b. In contrast, the drug loaded nanocarriers have prominent absorbance peaks at 220 nm, 270nm and around 400 nm (Fig 3a), indicating successful curcumin incorporation. FTIR spectra (Fig. 3c and d) showed characteristic N-H stretching in both unloaded and drug-loaded nanocarriers, with additional C-C stretching bands evident in the unloaded form. Morphological analysis by SEM (Fig. 3e and f) demonstrated that the unloaded nanocarriers ranged from approximately 150 to 250 nm in size, while the drug-loaded nanocarriers were larger, around 800 nm. AFM images recorded in this work (Fig. 3g and h) further supported the SEM findings, confirming an increase in nanoparticle size and surface roughness following drug loading, with clear visualization of the three-dimensional topography of the nanocarriers. The mean zeta potentials of the unloaded and drug-loaded nanocarriers were –17 mV and –16 mV, respectively (Fig. 3i and j), suggesting that drug encapsulation did not significantly alter the surface charge, and both formulations retained moderate colloidal stability.

Antibacterial Activity of the Nanocarrier

The antibacterial evaluation of the nanocarriers revealed selective but measurable activity against the tested bacterial strains. As shown in Table III, the drug-loaded nanocarriers exhibited distinct antibacterial activity against *Staphylococcus aureus*, whereas the chloroform-based nanocarriers also demonstrated effectiveness against *Klebsiella* species. No inhibitory effect was detected against *E. coli* or *Bacillus* species. This selective response is consistent with the results obtained for the

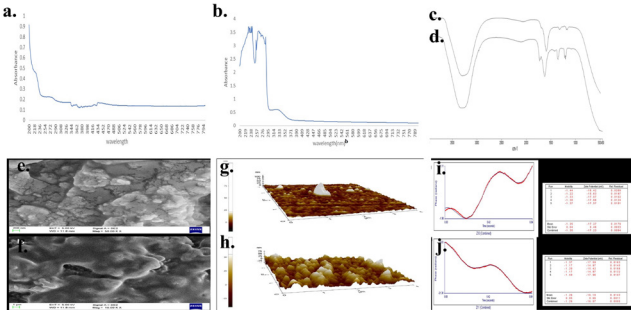

Figure 3: a. UV – vis analysis of nanocarrier produced using chloroform extract- Curcumin loaded nanocarrier, b. UV – vis analysis of nanocarrier produced using chloroform extract - unloaded nanocarrier, c. FTIR analysis of nanocarrier produced using chloroform extract - unloaded nanocarrier, d. FTIR analysis of nanocarrier produced using chloroform extract - curcumin loaded nanocarrier, e. SEM analysis of nanocarrier produced using chloroform extract - unloaded nanocarrier, f- SEM analysis of nanocarrier produced using chloroform extract curcumin loaded nanocarrier, g -AFM analysis of nanocarrier produced using chloroform extract - unloaded nanocarrier, h. AFM analysis of nanocarrier produced using chloroform extract - curcumin loaded nanocarrier, i. Zeta potential analysis of nanocarrier produced using chloroform extract - unloaded nanocarrier, j. Zeta potential analysis of nanocarrier produced using chloroform extract - curcumin loaded nanocarrier

chloroform extract, which showed activity only against *S. aureus* (Table II). The enhanced antibacterial effect of the drug-loaded nanocarriers confirms successful curcumin encapsulation and sustained release, leading to improved localized antimicrobial activity. The stronger inhibition of Gram-positive bacteria may be attributed to their more permeable peptidoglycan layer, whereas the outer lipopolysaccharide barrier in Gram-negative bacteria restricts nanoparticle penetration and hydrophobic compound diffusion. These findings indicate that *Plumeria alba*-derived nanocarriers can act as effective carriers for targeted antimicrobial delivery, particularly against Gram-positive pathogens.

Drug Release Efficiency

The drug release efficiency of all nanocarriers was further evaluated in ethanol and water to examine the effect of solvent polarity on curcumin diffusion. As depicted in Fig. 4a and 4b, the chloroform-based drug-loaded nanocarriers exhibited a markedly higher release rate in ethanol than in water, indicating enhanced solubility and diffusion of curcumin in a less polar environment. This solvent-dependent release behavior suggests that the lipid-rich composition of the *Plumeria alba* latex matrix facilitates more efficient drug liberation under hydrophobic conditions. The results collectively indicate that, although antibacterial activity remains moderate, the nanocarrier system demonstrates stable encapsulation, selective bioactivity, and favorable release kinetics suitable for localized therapeutic applications.

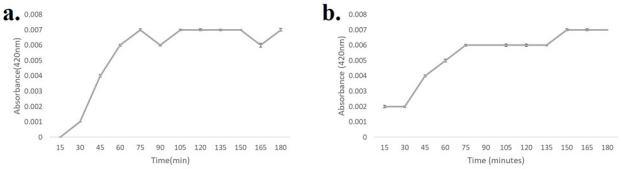

Figure 4: Drug release efficiency of nanocarriers a) Ethanol, b) Water

DISCUSSION

Characterization of the Extracts

The absorbance maxima between 220 - 250nm regions is an indication of presence of carboxylic acid groups (29). This observation is further supported by the work by Kalita and Saikia (30) on *Plumeria alba*, which reported an average composition of carbon, hydrogen, and nitrogen as 44.89%, 6.72%, and 1.26%, respectively. Both the chloroform and water extracts exhibited N–H groups, characteristic of polypeptide chains, suggesting the presence of proteins. Similarly, Mata et al. (31) reported that *Plumeria alba* showed vibrational stretching bands at 3211 cm^{-1} corresponding to C–O stretching of carboxylic acids and at 1411 cm^{-1} for C=C aromatic ring stretching. The GC–MS results revealed flavone as one of the major compounds, known for its antioxidant and antimicrobial properties. The synthesis of flavonoids is common in vascular plants and represents an important secondary metabolic pathway essential for their adaptation to terrestrial environments (32). Flavonoids

Table III: Antibacterial activity of nanocarriers

	inhibition zone (cm)											
	Bacillus			*E.coli*			*S. aureus*			*Klebsiella*		
	etha-nol	ace-tone	chloro-form	etha-nol	ace-tone	chloro-form	etha-nol	ace-tone	chloro-form	etha-nol	ace-tone	chloro-form
Negative control	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Positive control	1.3	0.0	0.0	1.0	0.5	1.0	1.5	1.0	1.3	1.4	0.3	1.5
2µL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4µL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6µL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0
8µL	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.2	0.0	0.2

serve multiple biological functions in plants, including electron transport during photosynthesis, antioxidant defense against UV radiation, and antimicrobial protection against bacteria, fungi, and viruses. They also act as natural deterrents to herbivores and, in humans, have been reported to prevent various chronic diseases (33).

Bioactivities of the Extracts

The antibacterial activity of the chloroform extract may be attributed to the presence of phytochemicals such as alkaloids, flavonoids, tannins and phenolic compounds. Phytochemicals are non-nutritive bioactive molecules that contribute to disease prevention and protection (34). The chloroform extract which contained a high percentage of flavones, showed antibacterial activity specifically against *S.aureus*. However, the extract only showed bacteriostatic effects within the tested concentrations, suggesting growth inhibition rather than complete bacterial killing. Since *S.aureus* is capable of forming biofilms that contribute to persistent infections (35), the biofilm assay results are significant. The extract concentrations tested did not completely inhibit biofilm formation, indicating that the current formulation or dosage was insufficient for full eradication. This partial inhibition could be due to the limited diffusion of flavonoid and phenolic constituents through the dense extracellular polymeric matrix of *S.aureus* biofilms. Increasing the extract concentration, extending the exposure time, or employing nanoparticle-based delivery systems may enhance biofilm penetration and achieve complete inhibition.

The observed antioxidant activity of the latex extracts can be attributed to their flavonoids content. Braca et al. (36), reported similar antioxidant potential of flavonoids from *Licania licaniaeflora* by DPPH assay. In this study, one-dimensional TLC with water and ethanol as solvents helped dissolve both polar and non-polar components, and silica gel enabled the successful separation of compounds with varying polarity (37). These results indicate that both the water and chloroform extracts exhibited antioxidant potential, confirming the bioactive nature of the latex constituents.

Characterization of the Nanocarriers

The optical and structural characterization carried out in the present study revealed important insights. The maximum absorbance observed between 200-300nm suggests the presence of non-conjugated carbonyl groups and non-conjugated fatty acids (38). FTIR spectra confirmed the presence of O–H and C=O functional groups along with ester and alcohol bands, indicating that lipids were incorporated in the ethanol-based nanocarriers. The ester bonds likely resulted from interactions between carboxylic acids and surfactants (39). SEM analysis performed in this study revealed that the synthesized nanoparticles were spherical and uniform, with size variations depending on the formulation parameters. These results are consistent with the earlier findings by Samrot et al (23), who also reported successful latex-based nanocarrier formation using *Calotropis gigantea* and *Euphorbia antiquorum*. AFM analysis from the present work further confirmed the SEM results, showing an increase in nanoparticle size after drug loading. The drug-loaded nanocarriers measured around 800 nm, which is larger than the ideal sub-200 nm range for systemic applications. However, this particle size is acceptable for localized or topical delivery, where slower diffusion and better surface adherence are beneficial. Further optimization of formulation parameters could help achieve smaller sizes for broader applicability. The three-dimensional surface topology obtained by AFM showed a clear difference between unloaded and drug-loaded formulations, indicating successful encapsulation. The observations agree with previous reports by Samrot et al. (23), which described similar morphological trends in E. antiquorum-based nanocarriers prepared with SPAN-20 surfactant. The zeta potential values in the current study were slightly negative, indicating moderate colloidal stability. Negatively charged nanoparticles are generally more stable due to electrostatic repulsion that prevents aggregation (40). The zeta potential values measured in the current study were slightly negative (-17 mV and -16 mV for unloaded and drug loaded nanocarriers, respectively) indicating moderate colloidal stability. The minimal change in surface charge suggests that curcumin was encapsulated within the core rather than adsorbed on the surface. Although surface modification was limited, the negative charge was sufficient to prevent aggregation, as negatively charged nanoparticles generally exhibit enhanced stability due to electrostatic repulsion (40).

Antibacterial Activity of the Nanocarrier

The antibacterial evaluation of the nanocarriers further confirmed their selective bioactivity. The curcumin-loaded nanocarriers exhibited activity against *S. aureus*, while no inhibition was observed against *E. coli*. These results are consistent with earlier findings by Klančnik et al (41), who demonstrated the antibacterial potential of several plant extracts against various bacterial strains. The limited efficacy against Gram-negative bacteria may be due to the outer lipopolysaccharide barrier, which restricts nanoparticle and hydrophobic compound penetration.

Drug Release Efficiency

The drug-release studies demonstrated that ethanol facilitated a higher and more sustained release of curcumin compared to water. This enhanced release can be attributed to the solubility of the non-polar nanocarrier matrix, allowing easier diffusion of the encapsulated drug. Similar observations were made by Hosseini et al. (42), who developed a tragacanth gum-based nanohydrogel for indomethacin delivery and reported that both pH and the network structure

of the nanocarriers significantly influenced the release behavior. In the present study, solvent polarity and the physicochemical composition of the *Plumeria alba* latex matrix appear to play major roles in regulating curcumin diffusion and release efficiency.

CONCLUSION

The chloroform extract of *Plumeria alba* latex exhibited notable antibacterial activity, particularly against *Staphylococcus aureus*. Comprehensive characterization of the extract through UV–Vis, FTIR, and GC–MS analyses confirmed the presence of various bioactive compounds. The extract was successfully utilized as a base material for the synthesis of nanocarriers. The unloaded nanocarriers measured approximately 200 nm, while the curcumin-loaded nanocarriers were around 800 nm in size, indicating successful drug encapsulation and stability. Furthermore, the curcumin-loaded nanocarriers demonstrated antibacterial activity against selected bacterial strains, suggesting their potential application in localized or targeted drug delivery systems. Future studies focusing on cytotoxicity and *in vivo* evaluation are warranted to validate their therapeutic safety and efficacy.

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