Green Synthesis of Plant Extract-Doped Nanolipid Carriers: a Sustainable Approach Towards Enhanced Bioactivity

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# Introduction

The ever-growing demand for innovative and sustainable solutions in various industries has driven the exploration of eco-friendly alternatives to conventional manufacturing processes. In this context, the green synthesis of nanoparticles using plant-derived materials has emerged as a promising approach, offering a range of advantages over traditional synthesis methods [(Deepika et al., 2022; Harsha & Subramanian, 2022; Solanki et al., 2022)](https://paperpile.com/c/8iwuE3/un6JA+t8Q9Z+qOMvL). This study delves into the green synthesis of plant extract-doped nanolipid carriers, highlighting the potential of this sustainable approach to enhance the bioactivity of these nanoformulations [(Ajay, Rakshagan, et al., 2022; Ajay, Sasikala, et al., 2022; Chidambaram et al., 2022)](https://paperpile.com/c/8iwuE3/KZd2n+j1UJf+T31qA).

The past decade has witnessed a significant rise in nanotechnology research, owing to the unique properties of nanomaterials that make them suitable for a wide range of [(Dikshit et al., 2021)](https://paperpile.com/c/8iwuE3/PtGFe)applications, including food safety, transportation, sustainable energy, environmental science, catalysis, and medicine ([Dikshit et al., 2021](https://doi.org/10.3390/catal11080902)). Notably, the green synthesis of nanoparticles, which utilizes eco-friendly, cost-effective, and biologically safe processes, has gained considerable attention([Dikshit et al., 2021](https://doi.org/10.3390/catal11080902))([(Peralta-Videa et al., 2016)](https://paperpile.com/c/8iwuE3/5No4O)). Numerous studies have explored the use of plants and microorganisms as reducing and stabilizing agents in the synthesis of metallic nanoparticles, showcasing the advantages of this approach over traditional methods([Peralta-Videa et al., 2016](https://link.springer.com/article/10.1007/s41204-016-0004-5))([(“A Comprehensive Review on Green Nanomaterials Using Biological Systems: Recent Perception and Their Future Applications,” 2018)](https://paperpile.com/c/8iwuE3/zkC9U)).

In the context of nanolipid carriers, the incorporation of plant extracts can potentially enhance their bioactivity and therapeutic efficacy. Plant-based phytochemicals can act as both reducing and capping/stabilizing agents in the synthesis of nanoparticles, leading to the formation of stable and bioactive nanoformulations([(“Applications of Phytogenic ZnO Nanoparticles: A Review on Recent Advancements,” 2021)](https://paperpile.com/c/8iwuE3/3fOet))([Saratale et al., 2018](https://doi.org/10.1016/j.colsurfb.2018.05.045)).

Green chemistry, as defined by IUPAC, focuses on creating chemical products and processes that minimize the use or creation of harmful substances for humans, animals, plants, and the environment. Put simply, green chemistry deals with chemical pollution and involves creating chemicals and production methods that limit or remove the need for dangerous substances.([Hatice Mutlu](https://onlinelibrary.wiley.com/authored-by/Mutlu/Hatice), [Leonie Barner](https://onlinelibrary.wiley.com/authored-by/Barner/Leonie),[(Mutlu & Barner, 2022)](https://paperpile.com/c/8iwuE3/85808)).Green chemistry involves creating chemical products and processes that minimize or eliminate the use and generation of hazardous substances. It spans the entire life cycle of a chemical product, from design and manufacture to use and disposal. Main objective of this method is to;Prevent pollution at the molecular level,Apply in all areas of chemistry as a comprehensive philosophy,Use innovative scientific solutions for environmental issues,Focusing on source reduction by preventing pollution generation,Reducing negative impacts on human health and the environment,Mitigating hazards associated with existing products and processes,Designing chemicals and processes to reduce inherent risks.([Source2](https://www.epa.gov/greenchemistry/basics-green-chemistry)).Green synthesis, is a biological method, which is an eco friendly alternative to chemical and physical method to synthesize nanoparticle.Albeit, this is avoids expensive, harmful and toxic chemicals [(Ajay, Suma, et al., 2022; Katyal et al., 2021; Maiti, 2021)](https://paperpile.com/c/8iwuE3/UIt1F+ohrcA+AAB7s).

Nanotechnology is one of the most effective technologies to develop drugs in nanoscale form and overcome the limitations of most drugs available currently.([(Malik et al., 2023)](https://paperpile.com/c/8iwuE3/3TA1))This is considered a revolution in drug development that allows the creation of various types of nanocarriers incorporating different drugs with different properties in order to improve the formulations in terms of design, structure and performance [[(Pereira et al., 2023)](https://paperpile.com/c/8iwuE3/G1ZGi)]. Nanolipid carriers are widely used as nanoformulations because they overcome the problem of dissolution of active ingredients and can incorporate all kinds of drugs [[(Elsewedy, Shehata, Almostafa, et al., 2022)](https://paperpile.com/c/8iwuE3/kv0Ka)]. In addition, the rationale for using nanolipid structures for topical administration is their ability to cross the skin barrier [[(Hua, 2015)](https://paperpile.com/c/8iwuE3/wBxrW))Many nanolipid agents have been tested for efficacy, such as anticancer agents, anti-inflammatory agents, antioxidants, antibacterial agents, and other agents [[(Ferreira et al., 2021)](https://paperpile.com/c/8iwuE3/3N9Lh),[(Elsewedy, Shehata, & Soliman, 2022)](https://paperpile.com/c/8iwuE3/G8vdj)]. Moreover, recent studies have shown that antibacterial drugs offer better performance using drug delivery systems [[(Carreño et al., 2020)](https://paperpile.com/c/8iwuE3/sSqkQ) ]. Nanostructured lipid carriers (NLCs) are one of the nanolipid structures that have shown significant progress in drug delivery strategies [[(Elmowafy & Al-Sanea, 2021)](https://paperpile.com/c/8iwuE3/U2zYk) ]. The lipid fraction of NLC contains liquid lipids (oils) and solid lipids (fats), which opens the way to incorporate hydrophobic drugs into the solid lipid fraction [ 7 ]. As a result, loading capacity was achieved in addition to better drug entrapment compared to other nanolipid structures [[(Elsewedy, Shehata, Almostafa, et al., 2022)](https://paperpile.com/c/8iwuE3/kv0Ka) ]. However, it is better to use higher viscosity formulations for effective topical application to extend the contact time on the affected area [(Merchant et al., 2025; Shenoy et al., 2022, 2023)](https://paperpile.com/c/8iwuE3/IqqA8+DlWI4+GMtWG). Therefore, in most cases the resulting nanolipid formulations were incorporated into the prepared hydrogels..

Lipid nanocarriers have been created as a substitute for polymeric nanoparticles, liposomes and emulsion([(“Nanostructured Lipid Carriers (NLC) System: A Novel Drug Targeting Carrier,” 2019)](https://paperpile.com/c/8iwuE3/kyUgn)). In addition, nanostructured lipid nanocarriers are second-generation lipid carriers developed to overcome the problems associated with solid lipid nanoparticles and used in various therapeutic approaches. NLCs have been widely considered for lipophilic drug delivery, but their suitability for hydrophilic drugs is now well known. The biocompatibility of lipids is responsible for their development as effective drug carriers. It has been found to be superior to other lipid formulations.Due to their non-toxic, non-immunogenic and biocompatible properties, NLCs have become the most studied lipid nanocarrier system.(([(“Nanostructured Lipid Carriers (NLC) System: A Novel Drug Targeting Carrier,” 2019)](https://paperpile.com/c/8iwuE3/kyUgn)).

Drug delivery systems involve injecting drugs into affected area, usually the skin. This method of drug administration has many advantages as an alternative to the oral route, which is the most used route of administration.([(Sastry et al., 2000)](https://paperpile.com/c/8iwuE3/bxTF6)).Oral drug delivery systems have a bright future for oral administration because they can improve the solubility and oral availability of weak drugs efficiency and stability([(“Biopharmaceutical Challenges Associated with Drugs with Low Aqueous solubility—The Potential Impact of Lipid-Based Formulations,” 2008)](https://paperpile.com/c/8iwuE3/ShIxH)) .17 NLCs are irregular and unstable lipid matrices that provide sufficient pores for molecular loading in the matrix.([(Shidhaye et al., 2008)](https://paperpile.com/c/8iwuE3/3qOcB)) NLC can be made using ultrasonic solvent emulsification technology. It has many advantages, such as better oral bioavailability, less systemic side effects, non-enzymatic degradation of the drug, lack of organic solvents and administration materials. Therefore, NLC has wide application in oral, intravenous, pulmonary, and transdermal delivery.18 The matrix of NLC is lipophilic in nature and is effective for oral delivery of lipophilic drugs through the intestinal lymphatic transport system.([S Shindhye et all 2008](https://pubmed.ncbi.nlm.nih.gov/18855604/))

Cloves (Syzygium aromaticum) have been used as a traditional Chinese medicinal herb for thousands of years. Syzygium aromaticum (L.) has dried flower buds that serve as the mantles(.Merr. et Perry) - A tree of the myrtle family (Myrtaceae). It is a source of antimicrobial substances against oral bacteria associated with caries and periodontal disease (Cai and Wu, 1996).Cloves possess antiseptic, antibacterial, antifungal, and antiviral properties.Traditional Chinese and Indian medicine have traditionally used Syzygiumaromaticum L, the dried shoots of clove, as a spice.The bioactive substances found in cloves include eugenol, -caryophyllene, and various other active compounds such as humulene, chlorinated hydrochloric acid (CHLA), chavicol, the analogue methyl salicylate, its precursor cyclohexone U2 the flavonoids eugenin, rhamnetin, kaempferol and eugenitin; triterpenoids such as oleanolic acid, stigmasterol and campesterol; and some sesquiterpenes.The ethylacetic acid extract of cloves demonstrated antitumor properties both in vitro and in vivo.OA is one of the antitumor-targeting areas of new drug Clove extract, which has been shown to be useful in treating cancer..([(Liu et al., 2014)](https://paperpile.com/c/8iwuE3/D5nuf)).. The aroma extract of clove buds and its two major aroma chemicals, eugenol and eugenyl acetate, showed obvious antioxidative activity in two different assays.([(“Antioxidant Property of Aroma Extract Isolated from Clove Buds [Syzygium Aromaticum (L.) Merr. et Perry],” 2001)](https://paperpile.com/c/8iwuE3/MKUMG)).Using [(Liu et al., 2014)](https://paperpile.com/c/8iwuE3/D5nuf)solvents with high polarity is more efficient in extracting bioactive chemicals from clove compared to using low-polarity solvents. Ethanol demonstrated superior qualities as a solvent for extracting phenolic compounds and flavonoids from clove bud, as opposed to water. Therefore, it is more suitable for applications in the food or pharmaceutical industry.([(“Phenolic Extracts of Clove (Syzygium Aromaticum) with Novel Antioxidant and Antibacterial Activities,” 2016)](https://paperpile.com/c/8iwuE3/tqFaa)).

# Materials and method

## Sample collection

The clove was collected from Tamil Nadu, India. The sample was cleaned in water to remove the debris. The sample was transported to the laboratory in an icebox, properly rinsed with tap water to eliminate any leftover salt, and then blotted on paper to absorb moisture.

## Preparation of clove extract

The clove was thoroughly washed, dried, and powdered. The powdered material was subjected to extraction using 80% ethanol with the help of mortar and pestle to obtain the extract rich in bioactive compounds.

## Preparation of NLC

NLC was prepared with the extracted enzyme by microemulsion method. Two solutions were prepared in the tris buffer. one solution containing liquid lipid and solid lipid. another solution with tween80 and SDS was kept in magnetic stirrer at 70 degree Celsius for 2 hours after that solution were allowed cool down sample was added to second solution simultaneously two solution mixed together and kept at -20 degree Celsius for overnight after that lyophilized the sample and used for the further analysis

## Test towards enhanced Bioactivity

After synthesizing clove extract doped NLC,tests were prepared to assess the enhanced bioactivity of the doped material. The following tests were assessed to quantify the potential bioactivity of the doped NLC.

### Anti-inflammatory Activity:Protein Denaturation assay

The Prepared Phosphate buffer of 4.780 μl and 0.2 μl of BSA were added along with the lyophilized sample (10 mg/mL) of varying concentrations ( 50μl, 100 μl, 150μl , 200μl ) and vortexed before being allowed to incubate in a water bath for 20 minutes, and the OD was taken at 660 nm. The inhibition percentage was calculated.

Anti-inflammatory activity (%) = [(Control - Sample) / Control] × 100

### Antioxidant Activity :DPPH Assay

The radical scavenging activity of a sample was measured by the DPPH (2.2-diphenyl-1-picrylhydrazyl) assay method. The lyophilized sample (10 mg/mL) of varying concentrations (50µl, 100µl, 150µl, 200µl) is added to makeup 3 mL with DPPH and incubated for 30 mins in the dark room. After 30 minutes of incubation, the absorbance of the DPPH solution was determined, and the optical density was measured at 510 nm.

The percentage of scavenging activity inhibition was calculated.

DPPH scavenging effect (%) = [(𝐴0 − 𝐴1) × 100] / 𝐴0 (1)

where, A0 is the absorbance of control and A1 is the absorbance of the sample.

### Antifungal activity :Agar well diffusion method

SDB was prepared and inoculated with bacteria strains ( Candida, Rhizopus ) respectively. Incubated at 37 degree Celsius for 2-3 hrs hours. SDA was prepared aseptically and poured into sterile petri plates. Then the bacterial lawn culture was performed in the plates. Four wells with a diameter of 10 mm and a depth of 4 mm was made using sterile gel puncture. For negative control dimethyl sulfoxide (DMSO) was added into the well and positive control antibiotic disc was placed in the media. The plates were then incubated at room temperature. After the incubation diameter of the zone was measured (Chehelgerdi et al., 2023).

# Results

## Chareterization of Clove extract doped NLC

### FTIR Spectrum

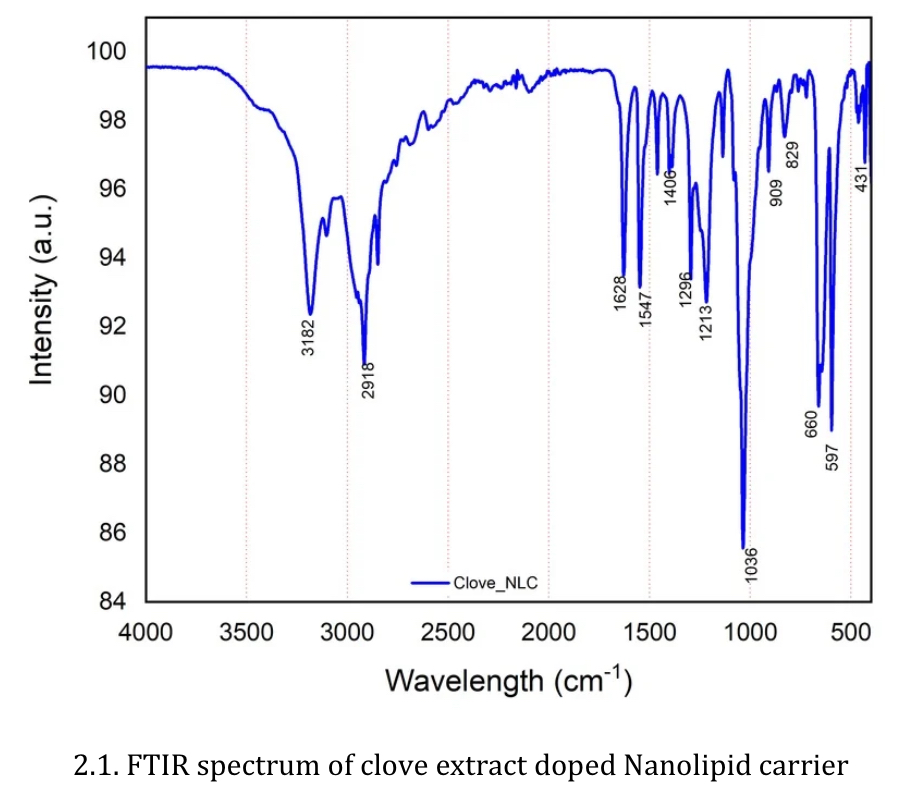
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Figure 1: FTR spectrum of clove extract doped nanolipid carrier

The FTIR spectrum of clove extract doped nanolipid carrier (NLC\_Clove) shows various peaks corresponding to different functional groups. The peak around 3192 cm⁻¹ is indicative of O-H stretching, suggesting the presence of hydroxyl groups, which are common in phenolic compounds found in clove. The peaks at 2918 and 1741 cm⁻¹ correspond to C-H stretching and C=O stretching, respectively, indicating alkanes and carbonyl groups. Other significant peaks at 1460, 1213, 990, and 820 cm⁻¹ correspond to C-H bending, C-O stretching, and other functional groups. These peaks confirm the presence of clove extract within the nanolipid carrier, indicating successful doping and the presence of active functional groups.

## XRD Spectrum

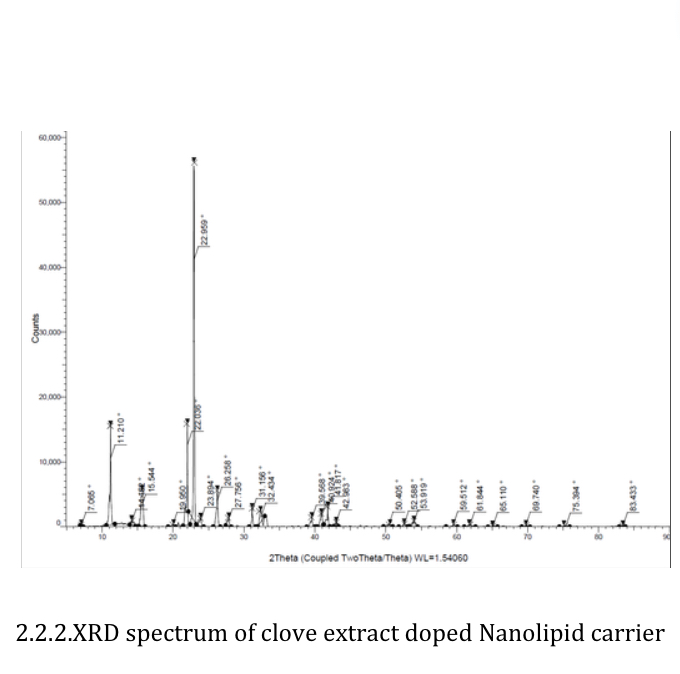
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Figure 2: XRD spectrum of clove extract doped nanolipid carrier

The XRD spectrum of clove extract doped nanolipid carrier (NLC\_Clove) displays sharp peaks at specific 2-theta values, indicating the crystalline nature of the sample. The presence of these distinct peaks confirms that the clove extract has been successfully incorporated into the nanolipid carrier while maintaining a crystalline structure. This crystalline form is crucial for the stability and controlled release of the active compounds. The sharpness and intensity of the peaks suggest high purity and a well-defined crystalline phase, which are essential characteristics for the functional performance of the nanolipid carrier in delivering the clove extract effectively.

## Anti-oxidant Assay

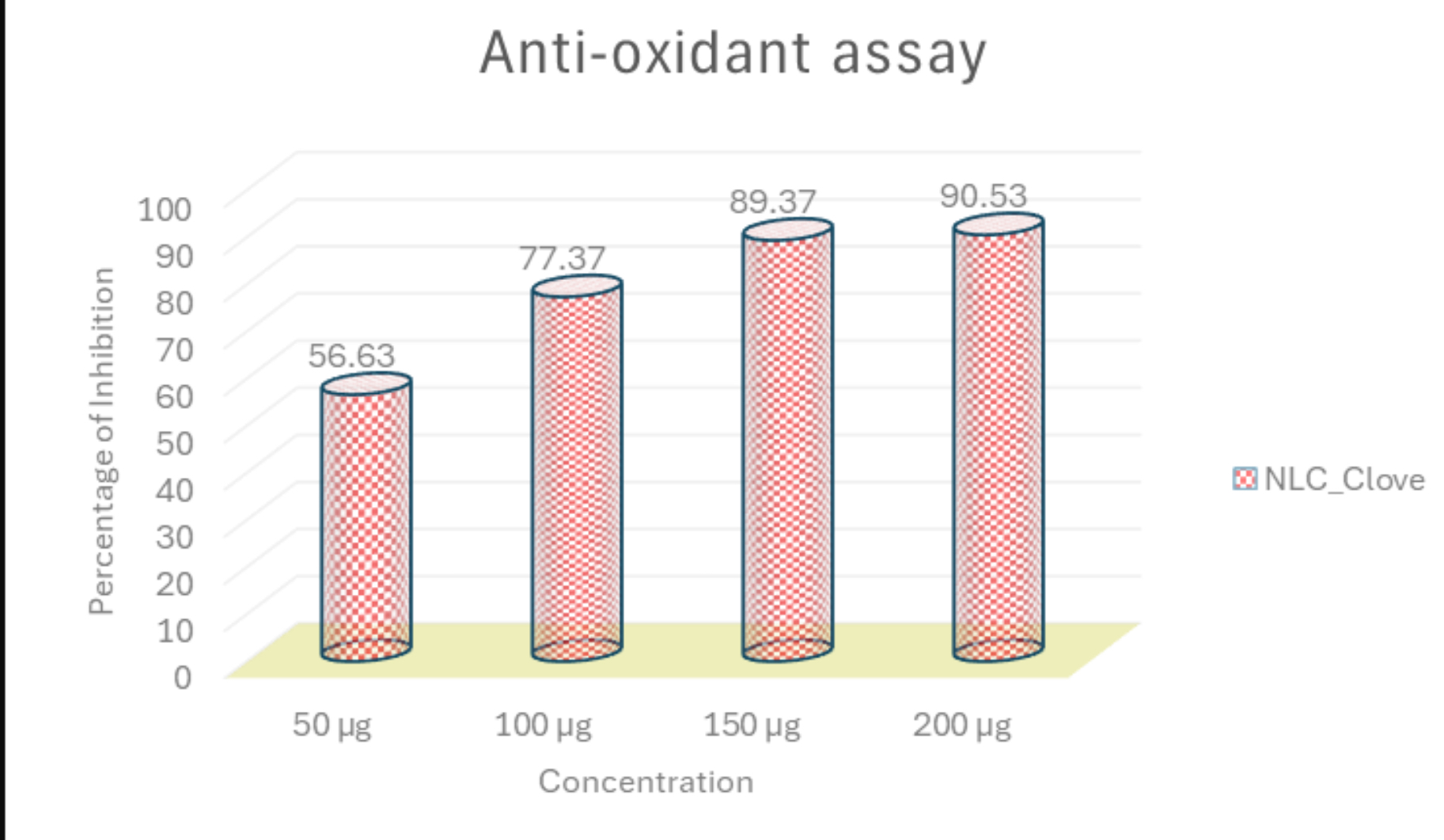
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Figure 3: Anti-oxidant assay

The anti-oxidant assay results are represented in a bar chart illustrating the percentage of inhibition of free radicals at varying concentrations of the clove extract doped nanolipid carrier (NLC\_Clove). Specifically, at 50 µg concentration, the percentage of inhibition is 56.63%, which indicates a moderate antioxidant activity. As the concentration increases to 100 µg, the inhibition percentage significantly rises to 77.37%. This trend continues with 150 µg showing an inhibition of 89.37% and reaching the highest inhibition at 200 µg with 90.53%. This dose-dependent increase in antioxidant activity suggests that NLC\_Clove is effective in scavenging free radicals, and its efficacy improves with higher concentrations.

## Antifungal activity

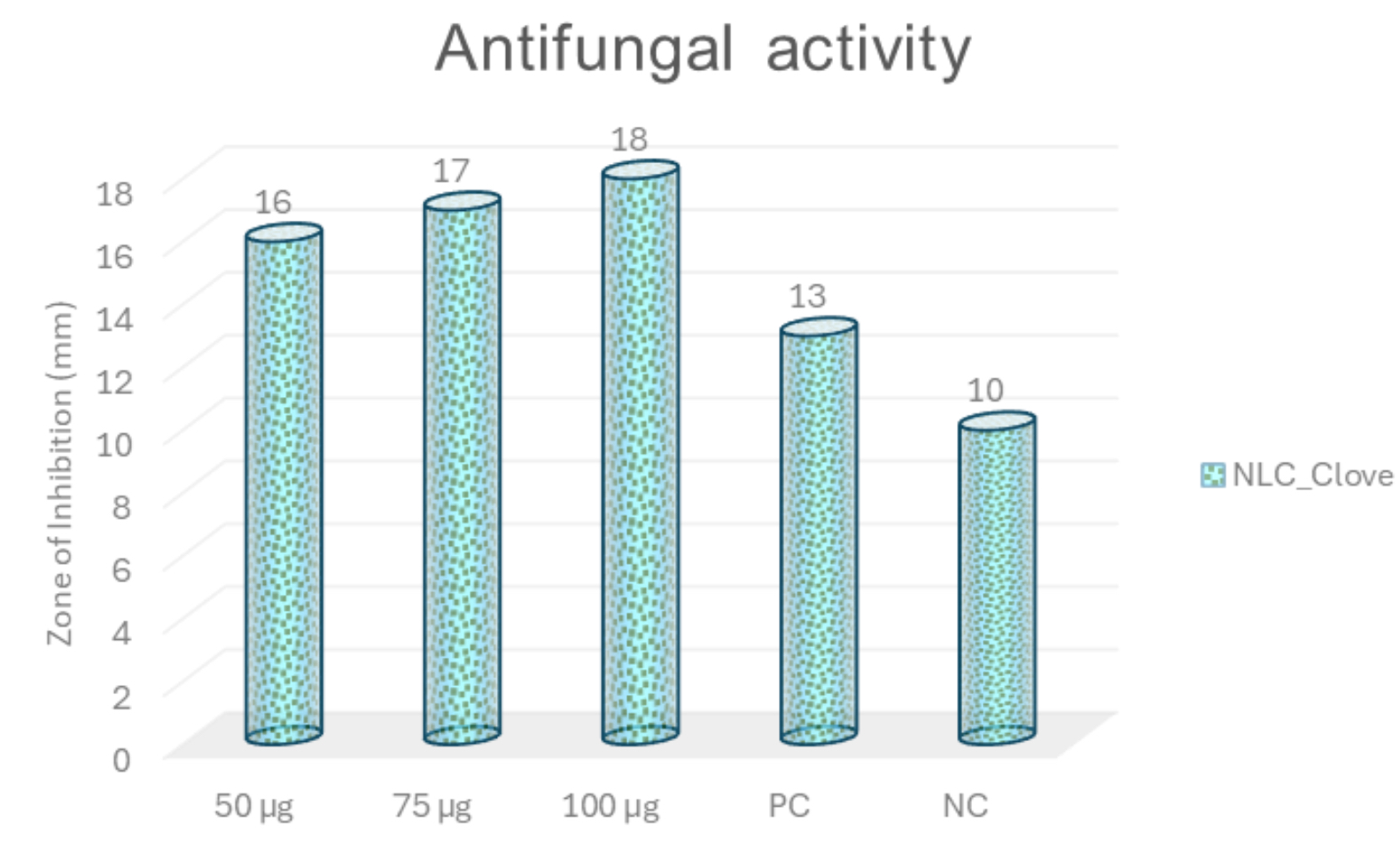
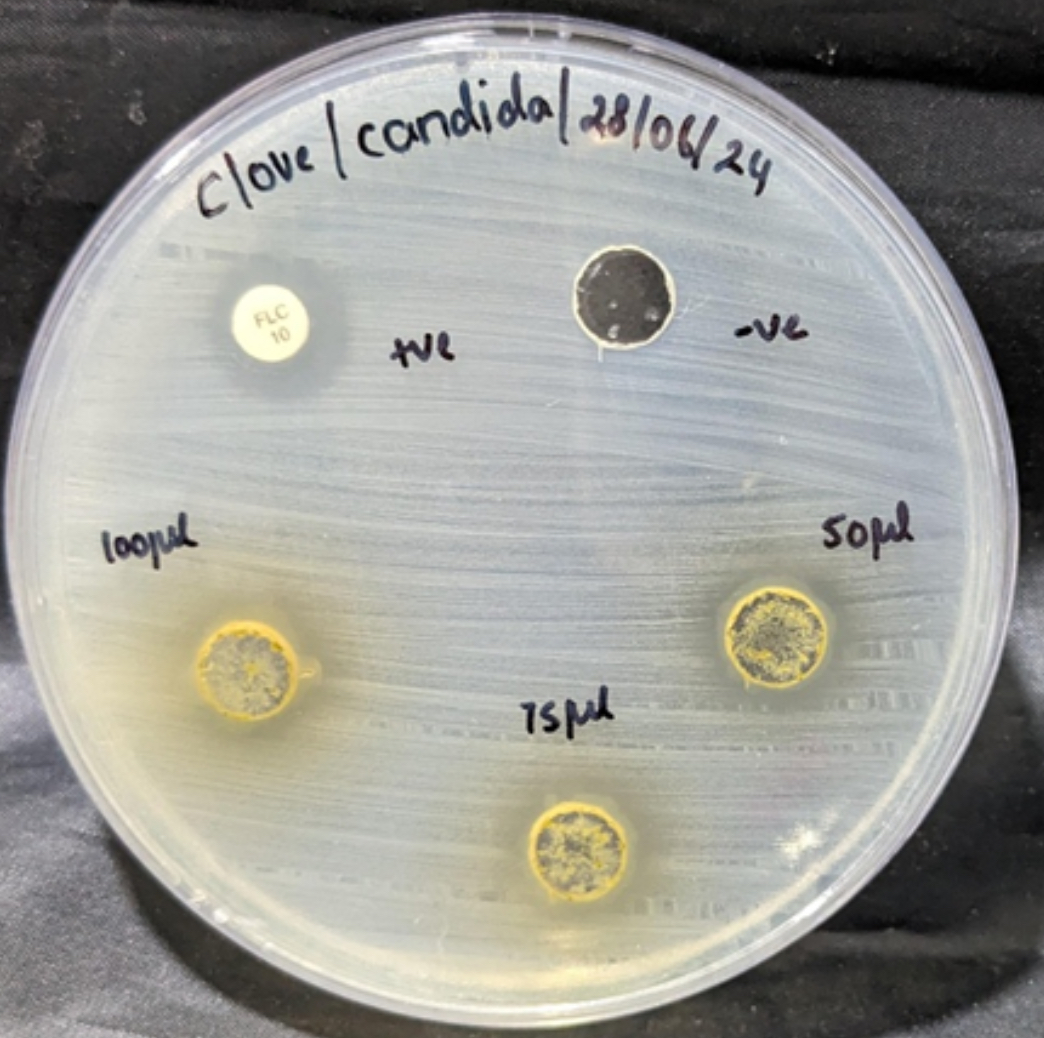
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Figure 4: Antifungal activity

The antifungal activity chart provides insight into the efficacy of NLC\_Clove against fungal pathogens, measured by the zone of inhibition in millimeters. At 50 µg, the zone of inhibition is 16 mm, which increases to 17 mm at 75 µg and further to 18 mm at 100 µg. These measurements indicate a strong antifungal activity that intensifies with higher concentrations of NLC\_Clove. The positive control (PC) shows a 13 mm inhibition zone, while the negative control (NC) has a 10 mm zone, indicating that NLC\_Clove outperforms the positive control and is significantly more effective than the negative control. This suggests that NLC\_Clove has a potent antifungal property, especially at higher doses (Saadh et al., 2024).

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**Figure 5:** Agar well diffusion method

The petri dish image shows the practical application of NLC\_Clove against Candida species, with different volumes (100 µL, 50 µL, and 15 µL) of NLC\_Clove applied. The clear zones around these spots indicate the extent of fungal inhibition. The larger the volume, the more pronounced the zone of inhibition, demonstrating a direct correlation between the amount of NLC\_Clove and its antifungal efficacy. The positive control (+ve) and negative control (-ve) are also present for comparison, with the positive control showing a smaller inhibition zone and the negative control showing none. This visual evidence supports the data from the antifungal activity chart, reinforcing the effectiveness of NLC\_Clove.

# Discussion

Nanotechnology has revolutionized the medical and pharmaceutical fields, providing innovative solutions to long-standing challenges. Among these advances, the development of nanolipid carriers (NLCs) has received much attention due to their ability to improve the delivery and efficacy of bioactive compounds.NLCs enhance dermal delivery of natural active ingredients by improving solubility, permeability, and stability, making them a promising system for bioactive compound efficacy([(*Website*, n.d.-a)](https://paperpile.com/c/8iwuE3/e9tGs)[Christina Avant](https://typeset.io/authors/christina-avanti-1ua37zpwjv),[(Fitriani et al., 2024)](https://paperpile.com/c/8iwuE3/nlwTo)) In particular, the incorporation of plant extracts into NLCs represents a promising way to improve the stability, bioavailability and overall therapeutic potential of these natural compounds. Plant extracts in NLCs (Nanostructured Lipid Carriers) offer efficient antimicrobial properties due to their chemical diversity and ability to protect bioactive compounds during food processing.

However, challenges like variability in bioactive content and lack of standardized toxicological data need to be addressed for widespread use.([(“Plant Extracts for the Control of Bacterial Growth: Efficacy, Stability and Safety Issues for Food Application,” 2012)](https://paperpile.com/c/8iwuE3/X2ftJ))

The results of X-ray diffraction (XRD), Fourier transform infrared spectroscopy (FTIR), comprehensive analysis of antifungals and DPPH show the successful formation and enhanced bioavailability of plant-derived nanolipid-doped carriers.XRD and FTIR analysis are important methods for characterizing the structural and chemical properties of materials. XRD analysis provides information on the crystal structure of the compound, while FTIR spectroscopy identifies functional groups and molecular interactions.

In this study, the XRD pattern shows different diffraction peaks indicating the crystalline nature of NLC. The importance of crystallinity in ensuring precise structural determination and stability, an advantage also relevant to the design and use of nanostructured lipid carriers (NLCs) in drug delivery systems.([(Van Aert et al., 2011)](https://paperpile.com/c/8iwuE3/GlI6u))The incorporation of the plant extract into the NLC was detected by the shift of these peaks, suggesting doping and positive interaction between the plant extract and the lipid matrix. The developed NLCs enhance the solubility and intestinal permeability of lipophilic SLM, showing excellent stability and preventing burst release and gastric degradation. These NLCs improve SLM permeation through Caco-2 cell monolayers via energy-dependent, clathrin- and caveolae-mediated transport, making them a promising oral delivery system.([(Piazzini et al., 2018)](https://paperpile.com/c/8iwuE3/r0xmC))These interactions were also confirmed by FTIR spectra. Compound groups corresponding to specific functional groups were found in the plant extract, indicating their presence in the NLC. In addition, changes in the FTIR spectrum, such as band shift or intensity change, show the strong interaction between plant extracts and molecules to form stable composite materials. The bioactivity of doped NLC was evaluated by antifungal and antioxidant tests. Antifungal activity was evaluated using Candida albicans, a common fungal pathogen. Cloves essential oil contains Eugenol and β-Caryophyllene as the main compounds. These compounds are related to antibacterial and antifungalactivity. The ethanolic extract has an activity to inhibit the growth of gram-positive and negative bacteria. The

essential oil inhibits the growth of bacteria and fungi.([(Hiwandika et al., 2021)](https://paperpile.com/c/8iwuE3/9ZbgK))The results showed that the antifungal activity of NLC and plant extract was significantly higher than that of pure plant extract and pure NLC. This enhanced antifungal effect may be due to several factors. First, the inclusion of plant extracts in NLC protects the bioactive compounds from degradation, thus maintaining their potency. Second, NLC promotes sustained release and control of plant extracts, resulting in prolonged exposure of fungal cells to antifungal agents. Finally, the small size and lipidic properties of NLCs enhance their penetration into fungal cells, thereby enhancing the release and efficacy of bioactive compounds. In addition to the antifungal activity, the antioxidant capacity of the doped NLC was evaluated using the DPPH assay [(Balaji Ganesh S & Sugumar, 2021; Jabin et al., 2021)](https://paperpile.com/c/8iwuE3/DsXYX+L2luw).

The DPPH test measures the ability of antioxidants to scavenge free radicals, an important step in preventing oxidative stress and related diseases [(Maheshwaran et al., 2024; Shenoy et al., 2025)](https://paperpile.com/c/8iwuE3/JuZvk+hMPUv). The results showed that doped NLC and plant extracts showed significantly higher antioxidant activity compared to pure plant extracts and pure NLCs. This improvement in antioxidant activity is due to the improved stability and bioavailability of the plant extract when incorporated into NLC. The lipid matrix of the NLC protects the antioxidant compounds from oxidation and degradation, thus maintaining their activity [(Govindaraj & Dinesh, 2021; Rajeshkumar et al., 2021; Sushanthi & Department of Oral and Maxillofacial Surgery, 2021)](https://paperpile.com/c/8iwuE3/Vk2HV+sZp6W+wiXli). In addition, the nanoscale size of NLC promotes better absorption and cellular uptake of antioxidants, thus improving their potency. The improved bioactivity of doped NLC compared to pure plant extract and pure NLC shows the benefits of the incorporation process. There are many methods that help in this improvement.Natural products like essential oils and flavonoids have significant therapeutic potential, but their hydrophobicity and volatility limit their applications. Encapsulation in Solid Lipid Nanoparticles (SLNs) and Nanostructured Lipid Carriers (NLCs) enhances their bioavailability and stability, offering promising solutions for controlled release and protection of bioactive substances.([(“Solid Lipid Nanoparticles and Nanostructured Lipid Carriers of Natural Products as Promising Systems for Their Bioactivity Enhancement: The Case of Essential Oils and Flavonoids,” 2021)](https://paperpile.com/c/8iwuE3/5JD2e))

First, the incorporation of bioactive compounds into NLCs improves their stability by protecting them from environmental factors such as light, heat, and oxygen that can cause degradation. This protection allows the bioactive compounds to be effective for a long time. Second, the absorption process improves the bioavailability of bioactive compounds. The nanoscale size of NLCs improves the absorption and penetration of biologically active compounds into biological membranes, resulting in better delivery to target sites. This is especially important for plant extracts containing compounds with low solubility and bioavailability. The lipid matrix of NLC plays an important role in improving the solubility of hydrophobic compounds, thus improving their bioavailability [(Graf et al., 2023; Ramamurthy & Jaiganesh, 2021; Tiwari & Jain, 2023)](https://paperpile.com/c/8iwuE3/D4Lwe+RHABm+tk5dN).

Third, the release of bioactive compounds can be controlled and stabilized by encapsulation in NLCs. This sustained release ensures long-term therapeutic results and reduces the frequency of administration. It also reduces the risk of toxicity and side effects associated with high doses of bioactive compounds.

The results of this study demonstrate the potential of NLC added to plant extracts as effective antifungal and antioxidant agents. nanostructured lipid carriers to enhance water affinity and demonstrated that encapsulated clove oil effectively inhibits cholinesterase enzymes in vitro, suggesting potential use in food and cosmetic formulations.([(“Encapsulation of Clove Oil in Nanostructured Lipid Carriers from Natural Waxes: Preparation, Characterization and in Vitro Evaluation of the Cholinesterase Enzymes,” 2019)](https://paperpile.com/c/8iwuE3/c6Msg))The improved bioavailability of these doped NLCs shows potential applications in various fields, including the pharmaceutical, cosmetic, and food industries. In the pharmaceutical field, these doped NLCs can be developed as novel antifungal and antioxidant agents for the treatment of stress-related diseases and disorders. In cosmetics, it can be used in skin care products to prevent oxidative damage and improve skin health. In the food industry, it can be used as a natural medicine to improve the shelf life and nutritional value of food.

Future research should focus on optimizing the formulation and manufacturing process of NLC doped with plant extracts to increase strength and stability. RCIE-NLCs effectively compensated for estrogen deficiency in a menopause mouse model induced by VCD, showing potential as an alternative to hormone replacement therapy (HRT). This was evidenced by increased estrogen levels and decreased FSH and LH levels compared to control groups.([(*Website*, n.d.-b)](https://paperpile.com/c/8iwuE3/muFoS))In addition, in vivo studies are needed to verify the therapeutic efficacy and safety of these doped NLCs in animal and human models. Understanding the pharmacology and biodistribution of these doped NLCs is also important to advance the development and commercialization of NLCs.

# Conclusion

The successful formation and bioavailability enhancement of nanolipid carriers doped with plant extracts, demonstrated by XRD, FTIR, antifungal and DPPH analysis, represents a significant advance in the field of nanotechnology. The combination and interaction of NLC with plant extract creates a stable composite material with good antifungal and antioxidant properties. The impregnation process improves the stability, bioavailability and potency of the bioactive compounds, demonstrating the potential of these doped NLCs as effective therapeutic agents. The promising results of this study pave the way for the research and development of plant-loaded NLCs for various applications, ultimately contributing to improved health and well-being.

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