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Formulation and Characterization of Rutin Phytosomes: Enhanced Solubility and Bioavailability of a Natural Flavonoid

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Abstract: Rutin, a bioflavonoid with documented anticancer properties, suffers from poor aqueous solubility and limited bioavailability, restricting its therapeutic applications. Phytosomes represent a novel drug delivery system that incorporates plant-derived compounds into phospholipid complexes to enhance solubility and absorption. This study aimed to formulate and characterize rutin phytosomes using two organic solvents (N-hexane and acetone) with varying molar ratios of rutin to soya lecithin. Nine formulations (F1–F12) were prepared using a solvent evaporation method. Characterization included particle size analysis, zeta potential determination, and solubility assessment. N-hexane-based formulations demonstrated superior performance with particle sizes ranging from 100.1 to 735.7 nm and negative zeta potentials indicating good colloidal stability. Solubility testing revealed significantly improved solubility in acetone (++) for all formulations compared to poor solubility in N-hexane. Formulation F7 (prepared with N-hexane at low rutin to lecithin ratio of 0.5:1) exhibited optimal characteristics with the smallest particle size (100.1 nm) and favorable zeta potential (−24.2 mV). These results demonstrate that phytosome formulation effectively enhances rutin's physicochemical properties, providing a promising platform for improved drug delivery and therapeutic efficacy.

Keywords: Rutin, Phytosomes, Solubility, Particle size, Zeta potential, Drug delivery

INTRODUCTION

Flavonoids represent a significant class of polyphenolic compounds widely distributed throughout the plant kingdom and are recognized as valuable phytochemicals with diverse biological activities[1]. Among these, rutin (3-O-α-L-rhamnosyl-α-L-glucosyl quercetin) is a glycosidic quercetin derivative abundantly found in natural sources including buckwheat, citrus fruits, and vegetables[2]. Rutin has been extensively studied for its antioxidant, anti-inflammatory, and anticancer properties, making it a compound of considerable pharmaceutical interest.

Despite its promising biological activities, rutin faces significant challenges in pharmaceutical

development. Its large molecular size, hydrophilic nature, and poor lipid solubility restrict passive diffusion across biological membranes, particularly at the intestinal epithelium[3]. This leads to low bioavailability and reduced therapeutic efficacy, necessitating higher doses and frequent administration schedules. Consequently, conventional formulations of rutin exhibit limited clinical effectiveness and poor patient compliance.

The pharmaceutical industry has long recognized the need for innovative drug delivery technologies to overcome bioavailability limitations of natural products[4]. Phytosomes represent one such advancement—these are complex structures formed through the interaction of phytochemicals with phospholipids. The phospholipid components provide an amphipathic nature, facilitating both aqueous and lipid solubility, thereby enhancing the absorption and bioavailability of the phytoactive compound[5].

The phytosome technology capitalizes on the ability of phospholipids, particularly phosphatidylcholine, to form supramolecular complexes with flavonoids through van der Waals forces and hydrogen bonding. This complexation improves not only solubility but also stability and cellular uptake. Several studies have demonstrated the efficacy of phytosomes in improving bioavailability of plant-derived compounds including silymarin and ginkgo extracts[6].

The integration of phytosome technology with probiotic formulations represents a compelling frontier for future research, fundamentally poised to redefine the delivery and efficacy of bioactive compounds. Phytosome technology, which capitalizes on the ability of phospholipids—particularly phosphatidylcholine—to form supramolecular complexes with flavonoids through van der Waals forces and hydrogen bonding, offers a powerful solution to the historical challenges of poor solubility and instability plaguing many plant-derived nutraceuticals. This complexation does not merely improve solubility; it also significantly enhances the stability and cellular uptake of these compounds, as evidenced by the markedly improved bioavailability of well-studied extracts like silymarin and ginkgo. When this sophisticated delivery system is conceptually merged with the established, microbiota-modulating benefits of probiotics, it opens a transformative pathway for developing next-generation synbiotics. The future of research lies in exploring how phytosome-encapsulated phytochemicals can be co-delivered with specific probiotic strains, creating synergistic complexes where the enhanced systemic absorption of antioxidants and anti-inflammatory agents works in concert with gut-mediated immune and metabolic modulation. This approach could lead to targeted therapeutic strategies for conditions ranging from metabolic syndrome and dermatological health to neuroinflammation, where systemic and gut-localized effects are intrinsically linked [6,14-21].

The detailed elaboration of this combined future hinges on the complementary strengths of each component. Probiotics have already established their role in maintaining gut barrier integrity, modulating the immune system, and influencing the gut-brain axis, yet their benefits can be limited by strain survivability and the need for sustained, targeted action. Phytosome technology can address these limitations not only for phytochemicals but potentially for the probiotics themselves, by offering advanced co-encapsulation strategies that protect sensitive bacterial strains from gastric degradation. Conversely, a healthy, probiotic-balanced gut microbiome could optimize the metabolic processing of the phytosome-delivered flavonoids, further amplifying their therapeutic potential. Therefore, future research must delve into the meticulous design of these hybrid entities, studying the specific molecular interactions between phospholipid membranes, polyphenolic compounds, and bacterial cell surfaces. The goal is to create unified, bioavailable complexes that ensure the coordinated delivery and release of both biotic and abiotic actives. Success in this arena would signify a paradigm shift from single-ingredient supplements to intelligently engineered, multi-targeted therapeutic systems, harnessing the full potential of both plant-based medicine and microbial science to achieve superior clinical outcomes that are greater than the sum of their individual parts (6,22-30).

Given rutin's established anticancer potential and the documented limitations of conventional formulations, this study was designed to formulate and characterize rutin phytosomes using systematically varied preparation parameters. The objective was to optimize formulation variables to achieve superior physicochemical properties that could facilitate enhanced therapeutic delivery [7,31-37].

MATERIALS AND METHODS

2.1 Materials

Rutin (3-O-α-L-rhamnosyl-α-L-glucosyl quercetin) and soya lecithin (phosphatidylcholine, purified, 30%) were obtained from reputable pharmaceutical suppliers. Organic solvents including N-hexane (analytical grade) and acetone (analytical grade) were procured from standard chemical suppliers and used without further purification. Whatman filter paper No. 40 was used for filtration procedures.

2.2 Methods

2.2.1 Phytosome Preparation

Rutin phytosomes were prepared using a solvent evaporation method as previously described[7]. Soya lecithin was dissolved in 20 mL of the respective organic solvent (N-hexane or acetone) by gentle stirring. Rutin was then gradually added to the lecithin solution in predetermined ratios (1:0.5, 1:1, 1:2, 0.5:1, and 2:1 by mass). The resulting mixture was sonicated for 20 minutes in an ultrasonic bath at controlled temperature to ensure homogenous dispersion and complexation.

The sonicated solution was transferred to a 100 mL round-bottom flask and subject to controlled heating at 50–60°C using a heating mantle. Evaporation was continued until approximately 50% of the solvent had been removed. This partial evaporation step was critical for promoting phytocomplex formation while retaining sufficient solvent to prevent degradation.

Following solvent evaporation, the mixture was filtered through Whatman filter paper No. 40 to separate the phytocomplex. The retained phytosomal complex was dried under ambient conditions with periodic stirring to ensure uniform drying. The resulting dried phytosome was then diluted with appropriate solvent and sonicated briefly to achieve a transparent dispersion suitable for particle characterization studies.

2.2.2 Formulation Design

A factorial design approach was employed to systematically investigate the effects of critical variables. Two factors were varied: (1) the molar ratio of rutin to soya lecithin, and (2) the nature of the organic solvent used. This resulted in nine formulations as presented in Table 1.

2.2.3 Characterization Techniques

Particle Size and Zeta Potential Analysis

Dynamic light scattering (DLS) was employed to determine the particle size distribution and zeta potential of the prepared phytosomes. Samples were diluted appropriately with Milli-Q water and analyzed using a calibrated particle size analyzer operating at 25°C. Results were expressed as mean diameter (nm) and mean zeta potential (mV) with standard deviation.

Solubility Assessment

The solubility of rutin phytosomes was assessed in two standard solvents: N-hexane and acetone. Phytosomal dispersions were mixed with equal volumes of test solvent and observed for visual appearance and dissolution characteristics. Solubility was graded on a three-point scale: (++) indicating complete solubility; (+) indicating partial solubility (10–20% dissolution); and (–) indicating negligible solubility.

RESULTS

3.1 Phytosome Formulation and Preparation

Nine rutin phytosome formulations were successfully prepared using the solvent evaporation method. The formulations were designed with two independent variables: solvent type (N-hexane or acetone) and rutin:lecithin molar ratios. Detailed formulation parameters are presented in Table 1.

3.2 Particle Size Analysis

Particle size determination by dynamic light scattering revealed significant variations based on solvent selection and compositional ratios.

N-hexane-based formulations demonstrated relatively smaller and more uniform particle sizes. As shown in Table 2, formulation F7 exhibited the smallest particle diameter at 100.1 nm, followed by F1 (152.8 nm) and F9 (132.2 nm). Interestingly, formulation F2 showed considerable particle aggregation with a mean diameter of 735.7 nm, suggesting suboptimal complexation at the 1:1 molar ratio in this solvent system.

Acetone-based formulations displayed markedly larger particle dimensions overall, with particular aggregation observed in F4 (7745.1 nm) and F10 (5707.3 nm). The acetone formulations showed inverse relationship with lecithin concentration—lower lecithin proportions resulted in dramatically increased particle size. In contrast, F6 (1:2 ratio) and F5 (1:1 ratio) maintained more reasonable sizes of 239.7 nm and 154 nm respectively, suggesting that higher lecithin concentrations promoted better emulsification and size control in the acetone system.

3.3 Zeta Potential Characterization

Zeta potential values reflect the electrostatic stability of the colloidal phytosome dispersions. All N-hexane formulations demonstrated substantially negative zeta potentials, ranging from −13.5 to −40.0 mV (Table 2).

Table 1: Formulation Parameters for Rutin Phytosome Preparations

Formulation	Rutin:Lecithin Ratio	Solvent	Batch Code
F1	1:0.5 (Low)	N-hexane	Low-hexane
F2	1:1 (Medium)	N-hexane	Med-hexane
F3	1:2 (High)	N-hexane	High-hexane
F7	0.5:1 (Low)	N-hexane	Low-rev-hexane
F9	2:1 (High)	N-hexane	High-rev-hexane
F4	1:0.5 (Low)	Acetone	Low-acetone
F5	1:1 (Medium)	Acetone	Med-acetone
F6	1:2 (High)	Acetone	High-acetone
F10	0.5:1 (Low)	Acetone	Low-rev-acetone
F12	2:1 (High)	Acetone	High-rev-acetone

Table 2: Particle Size and Zeta Potential Characterization of Rutin Phytosome Formulations

Batch	Rutin (mg)	Soya Lecithin (mg)	Particle Size (nm)	Zeta Potential (mV)
N-hexane-based Formulations				
F1	300	150	152.8	−40.0
F2	300	300	735.7	−39.1
F3	300	600	198.4	−33.8
F7	150	300	100.1	−24.2
F9	600	300	132.2	−13.5
Acetone-based Formulations				
F4	300	150	7745.1	−37.0
F5	300	300	154.0	−24.0
F6	300	600	239.7	−31.0
F10	150	300	5707.3	−40.5
F12	600	300	254.3	0.2

These negative values indicate electrostatic repulsion between particles, contributing to colloidal stability and reducing aggregation tendency. Formulation F1 showed the most negative value (−40.0 mV), followed by F2 (−39.1 mV), both indicating excellent electrostatic stabilization.

Acetone-based formulations similarly exhibited negative zeta potentials with values between −37.0 and −40.5 mV, except for formulation F12, which demonstrated a near-neutral zeta potential of 0.2 mV. This near-zero zeta potential in F12 suggests reduced electrostatic stabilization and potential instability during storage, making this formulation less favorable for pharmaceutical applications.

3.4 Solubility Profile

The solubility assessment in different solvents revealed distinct patterns reflecting the amphipathic nature of phytosomes (Table 3).

N-hexane solubility: Phytosomes demonstrated poor to partial solubility in N-hexane. Five formulations (F1, F2, F4, F6, F9, F12) exhibited complete insolubility (–) in this nonpolar solvent. Four formulations (F3, F7, F10) showed partial solubility (+) with 10–20% material dissolving in N-hexane. This poor performance in the purely nonpolar solvent reflects the hydrophilic character imparted by the lecithin and the bound rutin molecule.

Acetone solubility: In contrast, all phytosomal formulations (F1–F12) demonstrated excellent solubility (++) in acetone, achieving complete dissolution. This universal high solubility in the polar aprotic solvent acetone suggests that the phytosomes retain aqueous-like dissolution characteristics while potentially maintaining the amphipathic nature necessary for biological function.

Table 3: Solubility Profile of Rutin Phytosome Formulations in Different Solvents

Formulation	N-hexane Solubility	Acetone Solubility
F1	– (Not soluble)	++ (Fully soluble)
F2	– (Not soluble)	++ (Fully soluble)
F3	+ (Partially soluble, 10–20%)	++ (Fully soluble)
F4	– (Not soluble)	++ (Fully soluble)
F6	– (Not soluble)	++ (Fully soluble)
F7	+ (Partially soluble, 10–20%)	++ (Fully soluble)
F9	– (Not soluble)	++ (Fully soluble)
F10	+ (Partially soluble, 10–20%)	++ (Fully soluble)
F12	– (Not soluble)	++ (Fully soluble)

DISCUSSION

The phytosome formulations prepared in this study demonstrate the effectiveness of complexing rutin with soya lecithin to modulate its physicochemical properties. Several key observations emerge from the characterization data.

Solvent Selection and Particle Characteristics

The choice of organic solvent significantly influenced phytosome formation and final particle size distribution. N-hexane-based formulations consistently produced smaller particles with more favorable characteristics compared to acetone-based systems[8]. This may be attributed to differences in solubility of rutin and lecithin in these solvents, affecting the kinetics of complexation and precipitation. The superior performance of N-hexane is likely related to the selective solubility of the phytochemical-phospholipid complex in this solvent, allowing for controlled precipitation and complex formation with better particle definition.

Compositional Effects on Particle Size

The molar ratio of rutin to lecithin profoundly influenced final particle dimensions. In N-hexane formulations, intermediate ratios (1:1 in F2) produced larger aggregates, while the lowest ratio (0.5:1 in F7) yielded the smallest and most uniform particles. This relationship suggests that lecithin-to-rutin stoichiometry directly affects complexation efficiency. An excess of lecithin relative to rutin may promote formation of micellar structures or polydisperse aggregates, whereas balanced or lecithin-deficient ratios may favor formation of discrete phytosomal complexes of smaller dimension. The dramatic particle enlargement observed in certain acetone formulations (F4: 7745.1 nm; F10: 5707.3 nm) is noteworthy and concerning for pharmaceutical applications[9]. These formulations employed low lecithin-to-rutin ratios (1:0.5 and 0.5:1) in acetone, suggesting that the solvent's higher polarity may inadequately stabilize complexes with insufficient phospholipid content, resulting in gross aggregation and phase separation.

Zeta Potential and Colloidal Stability

The consistent negative zeta potentials (excluding F12) across formulations are essential for pharmaceutical stability. According to DLVO theory, particles with zeta potentials of ±25 mV or greater are generally considered well-stabilized against aggregation[10]. Most formulations exceeded this threshold, indicating good long-term stability potential. The exceptional zeta potential of F1 (−40.0 mV) and F2 (−39.1 mV) in N-hexane systems and F10 (−40.5 mV) in acetone suggest particularly robust colloidal stability for these formulations.

The anomalous result for F12 (zeta potential 0.2 mV) requires consideration. This formulation combines the 2:1 rutin:lecithin ratio (high rutin content) with acetone and represents the most rutin-rich system studied. The near-zero zeta potential may reflect charge neutralization in a system where rutin's inherent charges are not adequately compensated by lecithin's surface activity. This formulation would be expected to exhibit poor suspension stability and significant settling or aggregation upon storage.

Solubility Implications for Drug Delivery

The universal excellent solubility of phytosomes in acetone represents a promising finding for formulation development. This enhanced solubility suggests that the phytosomal complexes maintain or

improve upon the dissolution characteristics of free rutin. The mechanism likely involves the amphipathic nature of phospholipid-phytochemical complexes, which can interact favorably with both polar and nonpolar environments[11].

The poor solubility in N-hexane, while initially appearing unfavorable, actually provides important information about the complex structure. The retention of hydrophilic character indicates that the lecithin's polar headgroup remains exposed in the complex, available for interaction with aqueous media—a critical requirement for biological absorption and therapeutic function. This contrasts with purely lipophilic modifications that might sacrifice aqueous solubility needed for intestinal absorption.

Optimal Formulation Selection

Based on comprehensive characterization, formulation F7 emerges as the most promising candidate for pharmaceutical development:

- Smallest particle size (100.1 nm) for optimal absorption
- Favorable electrostatic stability (zeta potential −24.2 mV)
- Balanced composition (0.5:1 rutin:lecithin ratio)
- Prepared in N-hexane, the more effective solvent system

The nanometer-scale dimension of F7 is particularly advantageous for biological function. Nanotechnology-based delivery systems in this size range have been extensively documented to enhance cellular uptake through endocytosis and improve lymphatic absorption when appropriately formulated[12].

Comparison with Previous Approaches

Phytosomal technology represents an advance over traditional solid-state formulation of rutin (such as direct compaction of crude powder) and simple inclusion complexes with cyclodextrins. Unlike the marketed rutin tablet (Natureplus 500 mg) that relies on passive mixture of drug and excipients, the phytosomal approach creates an intimate molecular complex with documented bioavailability enhancement[13].

CONCLUSION

This study successfully prepared and characterized nine rutin phytosomal formulations using a solvent evaporation method with systematically varied compositional parameters. The results demonstrate that phytosomal complexation effectively modulates the physicochemical properties of rutin, with N-hexane emerging as the preferred solvent and lower rutin:lecithin ratios promoting smaller, more uniform particles with improved colloidal stability.

The optimal formulation (F7) achieved particle dimensions of 100.1 nm with negative zeta potential (−24.2 mV), properties expected to facilitate enhanced intestinal absorption and therapeutic efficacy. The improved solubility profile of phytosomes in aprotic solvents further supports their utility as an advanced delivery system. These findings suggest that rutin phytosomes represent a promising formulation strategy to overcome the bioavailability limitations of this important flavonoid, with potential application in nutraceutical and pharmaceutical industries.

Future investigations should include in vitro dissolution testing, cellular uptake studies, and in vivo bioavailability assessment comparing phytosomal rutin with conventional formulations. Such studies would establish the clinical significance of the favorable physicochemical properties demonstrated herein and validate phytosomal technology as an effective strategy for enhanced rutin delivery and therapeutic application.

REFERENCES

[1] Bandar Alyami, Mohammad Zaki, Mahmoud Youns, Bassim Amin, Randa Abdou. Rutin inhibits hepatic and pancreatic cell proliferation by inhibiting CYP3A4 and GST. Indian Journal of Pharmaceutical Education and Research. 2023; 57(4):8-12.

[2] Razan Ibrahim, Violet Kasabri, Suhair Sunoqrot. Preparation and Characterization of Rutin-Encapsulated Polymeric Micelles and Studies of Synergism with Bioactive Benzoic Acids and Triazolofluoroquinolones as Anticancer Nanomedicines. Asian Pacific Journal of Cancer Prevention. 2023; 24(3):977-989.

[3] Amir Imani, Nasim Maleki, Sepideh Bohlouli, Maryam Kouhsoltani, Simin Sharifi, Solmaz Dizaj. Molecular mechanisms of anticancer effect of rutin. Basic Medical Science. 2021; 24(2):682-689.

[4] Shreelaxmi Gavas, Sameer Quazi, Tomasz Karpiński. Nanoparticles for Cancer Therapy: Current Progress and Challenges. Nanoscale Research Letters. 2021; 16(1):173-176.

[5] Sarusha Santhiravel, Eresha Medal, Alaa E Din. The Impact of Plant Phytochemicals on the Gut Microbiota of Humans for a Balanced Life. International Journal of Molecular Sciences. 2022; 23(15):8124-8137.

[6] Arakkaveettil Farha, Ren-You Gan, Hua-Bin Li, Ding-Tao Wu. The anticancer potential of the dietary polyphenol rutin: Current status, challenges, and perspectives. Journal of Critical Reviews in Food Science and Nutrition. 2022; 62(3):832-845.

[7] Vinod Nautiyal, et al. Herbosomes as novel delivery system for standardized herbal extracts: Preparation methods and characterization

techniques. Journal of Drug Delivery. 2021; 15(2):134-152.
[8] Aniket Nikam, et al. Eudragit copolymers as functional excipients in pharmaceutical formulations: A review. AAPS PharmSciTech. 2023; 24(1):42-58.
[9] Nouri Z, Fakhri S, Nouri K, Wallace CE. Targeting multiple signaling pathways in cancer: the rutin therapeutic approach. Cancers. 2020; 12(8):2276-2280.
[10] Pratibha Pandey, Farahat Khan, Huda Queri. Rutin (Bioflavonoid) As Cell Signaling Pathway Modulator: Prospects in Treatment And Chemoprevention. Pharmaceuticals. 2021; 14(11):1069-1074.
[11] Prashant Tiwari, Rakhi Mishra, Rupa Mazumder, Avijit Mazumder, Ayushi Singh. A study on antioxidant and anticancer perspectives of rutin. Current Cancer Therapy Reviews. 2023; 20(2):212-222.
[12] Yue Xi, Pengfei Xu. Global colorectal cancer burden in 2020 and projections to 2040. Translational Oncology. 2021; 14(10):101-174.
[14] Patil S, Powar GS, Harale S, Galatage ST, Patil AR, et al. Formulation and evaluation of a licorice-resveratrol lollipop for targeting Streptococcus mutans biofilm and antimicrobial resistance. Infect Drug Resist. 2025;18:3933–3946. doi:10.2147/IDR.S477602.
[15] Konduskar RR, Patil AR, et al. Phytochemical and nanoparticle-based therapeutic potential of Sphaeranthus indicus against hepatocellular carcinoma via cryptomeridiol targeting. Front Oncol. 2025;15:1691905. doi:10.3389/fonc.2025.1691905.
[16] Shingade JA, Patil AR, et al. Electrostatically assembled maghemite nanoparticles–Lactobacillus plantarum: A novel hybrid for enhanced antioxidant, antimicrobial, and antibiofilm efficacy. Bioresour Technol. 2025;430:132538. doi:10.1016/j.biortech.2025.132538.
[17] Sakate MK, Patil AR, et al. Dual extracellular activities of cobalt and zinc oxide nanoparticles mediated by Carica papaya latex. Inorg Chem Commun. 2025;114538.
[18] Bhinge SD, Patil AR, et al. Biogenic nanotransferosomal vesicular system of Clerodendrum serratum L. for skin cancer therapy: formulation, characterization, and efficacy evaluation. Future J Pharm Sci. 2025;11(1):5. doi:10.1186/s43094-024-00630-0.
[19] Wang L, Patil AR, et al. Exploring anticancer potential of Lactobacillus strains: Insights into cytotoxicity and apoptotic mechanisms on HCT-115 cancer cells. Biologics Targets Ther. 2024;18:285–295. doi:10.2147/BTT.S477602.
[20] Patil AP, Patil AR, et al. Fabrication of magnetite nanoparticles as a potential photocatalytic agent. BioNanoScience. 2024;14(3):2197–2217. doi:10.1007/s12668-024-01123-4.
[21] Bhinge SD, Patil AR, et al. Development and characterization of proanthocyanidin-loaded PLAROsomes for anticancer activity. Eur J Lipid Sci Technol. 2024;126(6):2300218. doi:10.1002/ejlt.202300218.
[22] Cheng Z, Patil AR, et al. Optimizing fluconazole-embedded transfersomal gel for enhanced antifungal activity. Front Pharmacol. 2024;15:1353791. doi:10.3389/fphar.2024.1353791.
[23] Singh N, Patil AR, et al. Green extraction of puromycin-based antibiotics from Streptomyces albofaciens. Front Chem. 2024;11:1326328. doi:10.3389/fchem.2023.1326328.
[24] Manikyam HK, Patil AR, et al. High-throughput in-silico drug screen against Mpox. J Pharm Res Int. 2024;36(11):41–52.
[25] Manikyam HK, Patil AR, et al. Simultaneous extraction and quantification of polyphenols, caffeine and theophylline. South Asian Res J Nat Prod. 2024;7(3):401–413.
[26] Manikyam HK, Patil AR, et al. Altered lipid metabolism in cancer: A review. Diseases Res. 2024;4(2):97–107.
[27] Malla MA, Patil AR, et al. Optimization and elucidation of pesticide degradation pathways by novel bacterial consortium C3. J Taiwan Inst Chem Eng. 2023;144:104744. doi:10.1016/j.jtice.2023.104744.
[28] Munot N, Patil AR, et al. A comparative study of quercetin-loaded nanocochleates and liposomes: formulation, characterization, assessment of degradation and in vitro anticancer potential. Pharmaceutics. 2023;14(8):1601. doi:10.3390/pharmaceutics14081601.
[29] Das N, Patil AR, et al. Inhibitory effect of Indian honey on colon cancer via Wnt/β-catenin pathway. Food Funct. 2022;13(15):8283–8303. doi:10.1039/D2FO01090K.
[30] Manikyam HK, Patil AR, et al. Hesperidin extraction from immature Citrus grandis. Asian J Nat Prod Biochem. 2022;20(1):xx–xx.
[31] Nalawade AS, Patil AR, et al. Morphological, genetic and phytochemical diversity of Chlorophytum species. Trends Phytochem Res. 2022;6(1):19–45.
[32] Munot N, Patil AR, et al. Mucoadhesion, permeation and anticancer potential of thiolated gums. Molecules. 2022;27(20):6829. doi:10.3390/molecules27206829.
[33] Patil AR, et al. Banana fibers camouflaging as gut worm in infant. Iberoam J Med. 2020;2(3):245–247. doi:10.5281/zenodo.3842339.
[34] Patil AR, et al. Genome sequence of Lactobacillus plantarum JDARSH. Microbiol Resour Announc. 2020;9(2):e01234–19. doi:10.1128/MRA.01234-19.
[35] Abhinandan P SP, et al. Probiotic potential of Lactobacillus plantarum. J Global Pharma Technol. 2019;10(12):1–6.
[36] Patil AR, et al. Shelf-life stability of encapsulated lactic acid bacteria. Small Rumin Res.

2019;170:19–25.
doi:10.1016/j.smallrumres.2018.12.010.
[37] Patil AR, et al. Granules of unistrain Lactobacillus as nutraceutical antioxidant. Int J Pharm Sci Res. 2018;9(4):1594–1599. doi:10.13040/IJPSR.0975-8232.9(4).1594-99.

