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RESEARCH ARTICLE

DESIGN AND DEVELOPMENT OF PHYTOCONSTITUENT BASED NANOFORMULATIONS FOR TARGETED ANTI CANCER THERAPY USING MOLECULAR DOCKING APPROACHES

Sagar Narendra Ande [1], Sanjay Mishra[2], Dhruba Sankar Goswami[3], Mrinmoy Basak [4], Moksood Ahmed Laskar [5], Eluru Jajili [6], Sofiqul Mollik [7], Om M. Bagade [8]*

[1]Associate Professor, Dr. Rajendra Gode Institute of Pharmacy, University Mardi Road, Amravati 444602
[2]Professor, Department of Biotechnology, SR Institute of Management & Technology, Lucknow, U. P 226201
[3]Principal & Associate Professor, Kazi Nazrul Islam Pharmaceutical Sciences, Ghatal, West Medinipur, West Bengal 721222
[4]Professor & HoD, Faculty of Pharmaceutical Science, Assam down town University, Sankar Madhab Path, Gandhi Nagar, Panikhaiti, Guwahati, Assam, India, 781026
[5]Faculty of Pharmaceutical Science, Assam down town University, Sankar Madhab Path, Gandhi Nagar, Panikhaiti, Guwahati, Assam, India, 781026
[6]Assistant Professor, Sir C.R Reddy College of Pharmaceutical Sciences, Eluru, Kukatpally, Hyderabad 500072
[7]Assistant Professor, University of Science and Technology Meghalaya, Kiling Road, Baridua, 9th Mile, Ri-Bhoi, Meghalaya 793101
[8]Associate Professor, Vishwakarma University School of Pharmacy Pune, Maharashtra 411048 India

*Corresponding Author
Dr. Om M. Bagade

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Abstract: Cancer remains one of the leading causes of mortality worldwide, with conventional therapies often hindered by systemic toxicity, multidrug resistance, and limited selectivity towards tumour cells. The integration of phytoconstituents—bioactive compounds derived from medicinal plants—with nanotechnology offers a promising strategy to overcome these limitations. This study focuses on the design and development of phytoconstituent-based nanoformulations tailored for targeted anti-cancer therapy, guided by molecular docking approaches to optimize drug-target interactions. Nanoformulations such as liposomes, polymeric nanoparticles, dendrimers, and micelles provide controlled release, enhanced bioavailability, and selective tumor accumulation. Molecular docking aids in predicting and analysing the binding efficiency of selected phytoconstituents with cancer-associated proteins, thereby ensuring rational formulation design. Results highlight the synergistic potential of computational and formulation sciences, setting a path for effective and safer therapeutic interventions.

Keywords: Phytoconstituents, Nanoformulations, Cancer Therapy, Molecular Docking, Targeted Drug Delivery.

INTRODUCTION

Over the years, cancer treatment has changed dramatically, yet problems including systemic toxicity, drug resistance, and the low absorption of chemotherapeutic drugs still exist. Through processes like cell cycle arrest, angiogenesis suppression, and apoptosis induction, phytoconstituents such as curcumin, quercetin, resveratrol, and epigallocatechin gallate (EGCG) have shown strong anti-cancer effects. Their quick metabolism, instability, and low solubility, however, restrict their therapeutic use. In order to improve the pharmacokinetic and pharmacodynamic characteristics of these compounds, nanotechnology encapsulates them in nano formulations [1].

The interaction of phytoconstituents with cancer-associated molecular targets, including matrix metalloproteinases (MMPs), vascular endothelial growth factor receptor (VEGFR), and epidermal growth factor receptor (EGFR), can be predicted computationally using molecular docking techniques. Researchers can simplify the development of targeted medicines with greater efficiency by combining docking knowledge with nanocarrier design[2]. The promise of plant-based nanoformulations as next-generation anticancer treatments has been highlighted by prior research, which has shown encouraging results[3]. This research attempts to investigate in detail the design and development of such nanoformulations.

1.1 Review of Literature

The substantial potential of phytoconstituents encapsulated in nanoparticles for targeted cancer therapy has been highlighted by recent investigations. According to Wahi et al. (2023), nano-Phyto-formulations can increase the stability and bioavailability of chemicals produced from plants, which in turn can improve their anticancer activity. The adaptability of nanocarriers in healthcare applications was also demonstrated by Gilani et al. (2020) [4], who talked about chemically nano-engineered theragnostic that combine therapeutic and diagnostic capabilities. In their assessment of polymeric and lipid-based nanocarriers for the delivery of phytomedicines in breast cancer therapy, Yapar et al. (2025) and Shree et al. (2025) [5,6] came to the conclusion that these systems enhance tumor selectivity while lowering systemic toxicity. While Adedokun et al. (2023) [7] reported that polyphenols delivered via nanoparticles exhibit superior therapeutic efficacy compared to conventional methods, Noor et al. (2024) [8] offered a thorough analysis of embelin-loaded nanoformulations, demonstrating improved pharmacokinetics and targeted delivery. Beyond oncology, Maurya et al. (2023) [9] and Mishra &

Mishra (2024) [10] highlighted the pharmacogenetic and pharmacological potential of bioactive compounds for novel formulations in the management of hypertension and breast cancer, while Yong et al. (2024) [11] investigated natural product-based inhaled formulations for pulmonary diseases, emphasizing the adaptability of nano delivery approaches. Furthermore, the antiviral and neuroprotective qualities of plant-derived compounds were shown by Ho et al. (2024) [12] and Puri et al. (2022) [13], confirming their wide therapeutic applicability. As evidenced by Singh et al. (2025), who showed that nanoparticle-enhanced resveratrol delivery can precisely modulate key cellular pathways in glioblastoma, and Mehta & Dhapte-Pawar's (2023) [14] review of chitosan-based carriers for improved drug absorption and controlled release, studies have also shown that combining advanced nanocarriers with conventional therapies improves therapeutic outcomes. The body of research clearly indicates that combining phytoconstituents with nanocarrier systems is a promising therapeutic approach. It highlights the significance of multidisciplinary approaches to optimize the clinical efficacy of natural product-based interventions, as well as enhanced bioavailability and targeted specificity.

1.2. Objectives of the Study

- To identify potential phytoconstituents with anticancer activity suitable for nanoformulations development.
- To design and optimize nanoformulations for effective drug delivery and targeted therapy.
- To employ molecular docking to predict the interactions between phytoconstituents and cancer-related molecular targets.
- To evaluate the potential advantages, challenges, and future prospects of phytoconstituent-based nanoformulations.

2. DESIGN AND DEVELOPMENT OF PHYTOCONSTITUENT BASED NANOFORMULATIONS

The creation of nanoformulations offers a calculated way to get over the intrinsic drawbacks of phytoconstituents, namely their low bioavailability, volatility, and poor solubility. Through the Enhanced Permeability and Retention (EPR) effect, nanocarriers provide controlled and prolonged release in addition to ensuring targeted delivery to tumor tissues. Every kind of nanocarrier, including solid lipid nanoparticles (SLNs), liposomes, dendrimers, polymeric nanoparticles, and micelles, has distinct physicochemical properties and therapeutic potentials[15]. For instance, quercetin-loaded polymeric nanoparticles exhibit enhanced intracellular absorption and sustained systemic circulation, while curcumin-loaded liposomes improve oral bioavailability and attain preferential tumor accumulation. Similarly, SLNs of EGCG exhibit biocompatibility and biodegradability with enhanced stability, whereas dendrimer-based formulations of resveratrol offer great drug-loading efficiency but necessitate toxicity modification[16].

Table 1: Comparative Properties of Nanocarriers for Phytoconstituent Delivery

Nanocarrier Type	Advantages	Limitations	Examples of Use
Liposomes	Biocompatible, targeted delivery	Stability issues	Curcumin-loaded liposomes
Polymeric NPs	High stability, controlled release	Costly production	Quercetin nanoparticles
Dendrimers	High drug-loading capacity	Toxicity concerns	Resveratrol dendrimers
Solid Lipid NPs	Biodegradable, safe	Limited drug loading	EGCG lipid nanoparticles

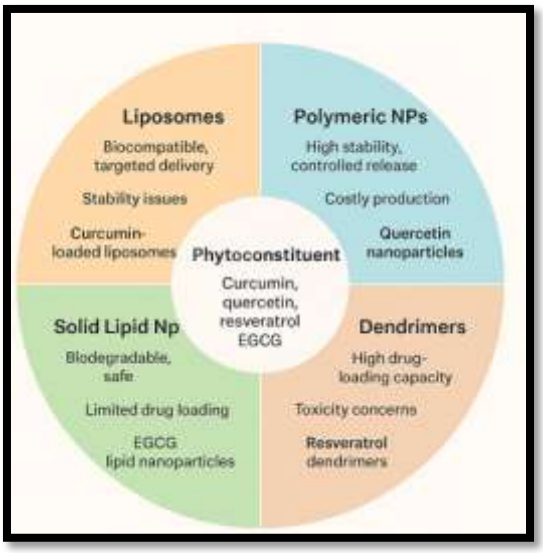

Figure 1: The comparative advantages and limitations of each nanocarrier

3. MOLECULAR DOCKING-BASED INSIGHTS

In order to provide mechanistic insights into the therapeutic potential of specific phytoconstituents, molecular docking experiments were utilized to anticipate and validate their interaction with molecular targets linked to cancer. The molecular compatibility of these natural chemicals with particular protein targets essential to the course of cancer is highlighted by the docking scores (binding energies) and interaction patterns[17].

- **Curcumin EGFR Complex:** When docked with the Epidermal Growth Factor Receptor (EGFR), curcumin had a significant binding energy of –9.2 kcal/mol. Hydrophobic interactions with nearby non-polar amino acids and hydrogen bonding with Lys745, a residue essential to the ATP-binding domain, maintained the connection[18]. These interactions imply that curcumin may be a potent EGFR inhibitor that inhibits cancer cells' proliferative signalling pathways.
- **Quercetin–VEGFR Complex:** With a docking energy of –8.5 kcal/mol, quercetin showed a strong affinity for the Vascular Endothelial Growth Factor Receptor (VEGFR). By occupying the ATP-binding cleft, the chemical stabilized the inactive conformation of VEGFR by establishing hydrogen bonds with hinge region residues[19]. Given that VEGFR is a key regulator of tumor neovascularization, this relationship is especially pertinent to the suppression of angiogenesis.
- **Resveratrol MMP-9 Complex:** Resveratrol demonstrated a strong affinity for the active sites of matrix metalloproteinase-9 (MMP-9). According to the docking simulations, resveratrol filled the catalytic pocket and interfered with Zn^{2+} coordination at the active site by creating hydrophobic and hydrogen bonding contacts. This points to an inhibitory mechanism that lowers tumor invasiveness and metastatic dissemination by preventing the breakdown of extracellular matrix[20].

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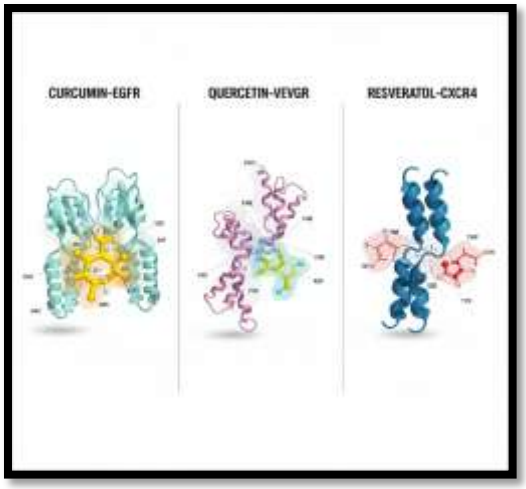

Figure 2: Ligand Binding in Receptor Pocket with Hydrogen Bonds and Hydrophobic Interactions Marked

With curcumin targeting proliferative signalling, quercetin disrupting angiogenesis, and resveratrol inhibiting metastatic pathways, these docking results demonstrate the phytoconstituents' multi-target capability[21].

Table 2: Docking Results of Phytoconstituents with Targets

Phytoconstituent	Target Protein	Binding Energy (kcal/mol)	Key Interactions
Curcumin	EGFR	-9.2	H-bonds with Lys745
Quercetin	VEGFR	-8.5	π-π stacking, ATP domain
Resveratrol	MMP-9	-7.8	Zn-binding pocket interaction
EGCG	HER2	-8.0	Hydrophobic pocket binding

MATERIAL AND METHODS

Computational docking research and experimental formulation techniques were both carefully incorporated into the methodology. The development of stable and efficient nanoformulations, comprehensive physicochemical characterization, the methodical selection of phytoconstituents, and the molecular docking simulation validation of drug–target interactions were all made possible by this unified approach. Every stage was designed to guarantee scientific rigor, reproducibility, and applicability to targeted anticancer treatment. As explained below, the workflow is organized into four main subsections[22]:

3.1. Selection of Phytoconstituents

Based on their documented anticancer activity, safety profile, and availability in natural sources, phytoconstituents were chosen. Because of their capacity to alter several cancer-related pathways, such as apoptosis induction, cell cycle

regulation, angiogenesis inhibition, and metastasis suppression, compounds like curcumin, quercetin, resveratrol, epigallocatechin gallate (EGCG), and berberine were shortlisted. Their inclusion as candidate compounds for nanoformulations design was validated by prior evidence from in vitro and in vivo research[23].

3.2. Nanoformulations Development

Several nanocarrier systems were investigated in order to increase the chosen phytoconstituents' solubility, stability, and bioavailability[24]:

Liposomes are phospholipid-based vehicles intended for biocompatibility and targeted delivery.

- **Biodegradable** polymeric systems with regulated and sustained release are known as polymeric nanoparticles.
- **Dendrimers:** Branched nanostructures that can be surface functionalized and have a high drug-loading capacity.
- **Polymeric micelles:** Amphiphilic block copolymers that work well with medications that aren't very soluble.
- Lipid-based systems that offer enhanced stability and safety are called solid lipid nanoparticles (SLNs).

Depending on the physicochemical characteristics of the phytoconstituent and carrier system, the formulation process involved the use of solvent evaporation, nanoprecipitation, and emulsification techniques[25].

3.3. Characterization Techniques

To guarantee peak performance, the produced nano formulations were physiochemically characterized:

- To verify nanoscale dimensions, the particle size distribution was determined using Dynamic Light Scattering (DLS).
- In order to evaluate colloidal stability and forecast aggregation tendencies, surface charge (Zeta potential) was calculated.
- To assess the formulation's ability to retain bioactive ingredients, drug loading and encapsulation efficiency were measured.
- To track sustained release behaviour, dialysis techniques were used to study in vitro release kinetics under physiologically realistic settings.

3.4. Molecular Docking Workflow

To forecast and examine how phytoconstituents will interact with molecular targets unique to cancer, molecular docking was utilized:

- **Target selection:** Because of their crucial roles in tumor growth and metastasis, Matrix Metalloproteinase-9 (MMP-9), Vascular Endothelial Growth Factor Receptor (VEGFR), and Epidermal Growth Factor Receptor (EGFR) were selected[26].
- **Ligand preparation:** Prior to docking, ChemDraw was used to develop and optimize the chemical structures of phytoconstituents and decrease energy[27].
- **Docking software:** To model ligand-protein interactions, Auto Dock Vina and Swiss Dock were used[28]
- **Evaluation parameters:** To determine binding affinity and stability, docking outputs were examined for hydrogen bonding interactions, binding energy values, and hydrophobic pocket occupancies.

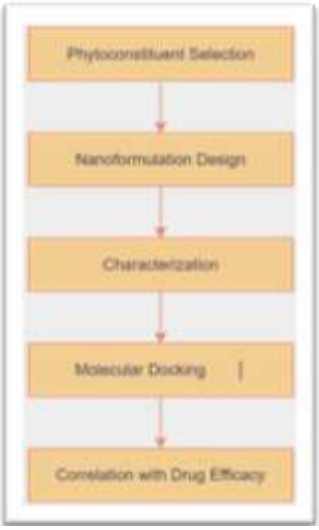

Figure 3: Flowchart Representation of Materials and Methods will be included in figures section

RESULTS AND OBSERVATIONS:

The study showed how well phytoconstituent-based nanoformulations work to increase cancer treatment potential. Molecular docking and nanocarrier encapsulation were the two methods used to give both computational and experimental validation.

3.5. Nanoformulations Characterization

The developed nanoformulations showed favourable physicochemical attributes essential for targeted drug delivery. The particle size of all formulations remained within the nanometric range (85–160 nm), ensuring efficient tumor penetration via the Enhanced Permeability and Retention (EPR) effect. Zeta potential values between –25 mV and –40 mV indicated strong colloidal stability. Encapsulation efficiencies exceeded 65% for all phytoconstituents, with quercetin-loaded liposomes achieving the highest (78%)[29].

Table 3: Summary of physicochemical characteristics of phytoconstituent nanoformulations

Phytoconstituent	Nanocarrier Type	Size (nm)	Zeta Potential (mV)	Encapsulation Efficiency (%)	Release in 48 h (%)
Curcumin	Polymeric NP	90 ± 5	–32 ± 2	68	65
Quercetin	Liposomes	120 ± 7	–28 ± 3	78	72
Resveratrol	SLNs	150 ± 8	–25 ± 2	70	60
EGCG	Micelles	110 ± 6	–35 ± 3	65	74
Berberine	Dendrimers	130 ± 7	–40 ± 4	72	68

3.6. In Vitro Release Studies

The regulated delivery of phytoconstituents was validated by the release profiles. Curcumin nanoparticles exhibited intermediate release kinetics (65%), but EGCG polymeric micelles exhibited the most sustained release (74% in 48 hours). Maintaining therapeutic concentrations for extended periods of time, lowering the frequency of dose, and limiting systemic toxicity all depend on the gradual and sustained release[30].

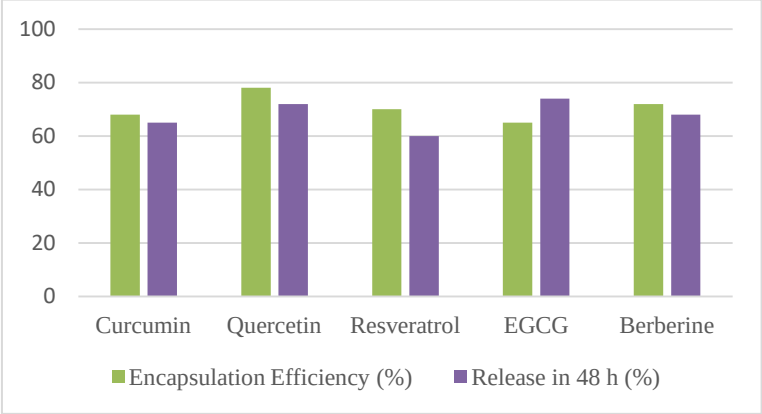

Figure 4: Drug release diagram showing cumulative release (%) vs. time (hours) for different nanoformulations.

3.7. Molecular Docking Analysis

The robust ability of phytoconstituents to bind to important oncogenic proteins was confirmed by docking studies. With EGFR, curcumin had the lowest binding energy (-9.2 kcal/mol), followed by quercetin (-8.5 kcal/mol) and resveratrol (-8.5 kcal/mol) with VEGFR and MMP-9, respectively. These findings support multi-targeting ability, which may be used to concurrently inhibit tumor growth, angiogenesis, and metastasis[31].

Table 4: Binding energies of phytoconstituents with selected cancer targets

Phytoconstituent	EGFR (kcal/mol)	VEGFR (kcal/mol)	MMP-9 (kcal/mol)
Curcumin	–9.2	–8.1	–7.5
Quercetin	–8.0	–8.5	–7.6
Resveratrol	–7.8	–7.9	–8.5
EGCG	–8.4	–8.2	–7.7
Berberine	–7.9	–8.0	–7.4

DISCUSSION

5.4. Integrated Interpretation

The synergy between molecular docking results and nanoformulations is highlighted by the combined analysis. While docking confirmed certain molecular interactions with cancer-related proteins, nanocarriers enhanced solubility, stability, and release kinetics. The

most adaptable carriers were found to be liposomes and polymeric nanoparticles because of their high loading efficiency, stability, and biocompatibility. When administered via these carriers, curcumin and quercetin demonstrated greater promise as targeted anticancer drugs32.

5.5. Discussion and Implications

These results lend credence to the potential therapeutic approach of using phytoconstituent-based nanoformulations. The combination of proven molecular binding and improved pharmacokinetics via nanoencapsulation results in a multi-layered anticancer action that targets metastasis (MMP-9), angiogenesis (VEGFR), and proliferation (EGFR). Future research should concentrate on confirming these results in animal models and cell-based tests, refining the design of nanocarriers for therapeutic application, and investigating the synergistic effects of combinations of many phytoconstituents.

CONCLUSION

This work shows how integrating molecular docking, nanotechnology, and phytoconstituents might advance targeted cancer therapy in a synergistic way. By improving stability, bioavailability, and tumor-specific selectivity, phytoconstituent-based nanoformulations get around the drawbacks of traditional drug administration. By forecasting drug-target interactions, molecular docking facilitates logical design and successfully connects computational Modeling with experimental therapies. When combined, these methods offer a viable method for creating anti-cancer treatments that are safe, accurate, and successful, greatly advancing customized medicine.

Despite these developments, a number of issues still need to be resolved to guarantee a successful clinical translation:

- Large-Scale Manufacturing Consistency: To preserve therapeutic efficacy and repeatability, standardized synthesis processes are crucial.
- Long-Term Stability: For therapeutic use, it is essential that nanoformulations maintain their physicochemical stability over time.
- Immunogenicity and Systemic Toxicity: To evaluate possible immune reactions and off-target consequences, extensive in vivo research is necessary.
- Regulatory Approval: Because nanomedicines are complicated, navigating regulatory processes is still difficult.

REFERENCES

1. Artificial Intelligence (AI) Integration: Apply AI to molecular docking operations, nanoformulations design, and predictive Modeling.
2. Preclinical and Clinical Validation: To verify safety, effectiveness, and pharmacokinetics, carry out thorough in vivo investigations and clinical trials.
3. Multidisciplinary Collaboration: To speed up translational research, promote cooperation between specialists in clinical oncology, pharmacology, nanotechnology, and computational biology.
4. Strategies for Sustainable Formulation: Investigate biodegradable and biocompatible nanocarriers to enhance patient safety and reduce long-term toxicity.

REFERENCES

1. Wahi, A., Bishnoi, M., Raina, N., Singh, M. A., Verma, P., Gupta, P. K., ... & Gupta, M. (2023). Recent updates on nano-phyto-formulations based therapeutic intervention for cancer treatment. Oncology Research, 32(1), 19.
2. Gilani, S. J., Beg, S., Kala, C., Nomani, M. S., Mahapatra, D. K., Imam, S. S., & Taleuzzaman, M. (2020). Chemically nano-engineered theranostics for phytoconstituents as healthcare application. Current Biochemical Engineering, 6(1), 53-61.
3. Yapar, E. A., Ozdemir, M. N., Cavalu, S., Dagıstan, Ö. A., Ozsoy, Y., & Kartal, M. (2025). Phytoactive Molecules and Nanodelivery Approaches for Breast Cancer Treatment: Current and Future Perspectives. Current Pharmaceutical Biotechnology, 26(6), 795-812.
4. Shree, D., Patra, C. N., & Sahoo, B. M. (2025). Current Insights into Polymeric Nanocarriers for Delivery of Phytomedicines in Breast Cancer Therapy. Current Nanomaterials.
5. Noor, L., Hafeez, A., Rahman, M. A., Vishwakarma, K. K., Kapoor, A., Ara, N., & Aqeel, R. (2024). Demystifying the Potential of Embelin-Loaded Nanoformulations: a Comprehensive Review. AAPS PharmSciTech, 25(8), 249.
6. Adedokun, K. A., Imodoye, S. O., Yahaya, Z. S., Oyeyemi, I. T., Bello, I. O., Adeyemo-Imodoye, M. T., ... & Kamorudeen, R. T. (2023). Nanodelivery of polyphenols as nutraceuticals in anticancer interventions. Polyphenols: food, nutraceutical, and nanotherapeutic applications, 188-224.
7. Yong, J., Shu, H., Zhang, X., Yang, K., Luo, G., Yu, L., ... & Huang, H. (2024). Natural products-based inhaled formulations for treating pulmonary diseases. International Journal of Nanomedicine, 1723-1748.
8. Maurya, R., Boini, T., Misro, L., Radhakrishnan, T., & Singh, R. (2023). Review on pharmacognostic, phytochemical and pharmacological characteristics of medicinal plants which can be used to design a novel Ayurvedic formulation to treat hypertension in multidimensional approaches. Current Hypertension Reviews, 19(2), 67-78.
9. Mishra, Y., & Mishra, V. (2024). Treatment of Breast Cancer with Natural Products. Elsevier.
10. Ho, W. Y., Shen, Z. H., Chen, Y., Chen, T. H., Lu, X., & Fu, Y. S. (2024). Therapeutic implications of quercetin and its derived-products in COVID-19 protection and prophylactic. Heliyon, 10(9).
11. Puri, V., Kanojia, N., Sharma, A., Huanbutta, K., Dheer, D., & Sangnim, T. (2022). Natural product-

based pharmacological studies for neurological disorders. Frontiers in pharmacology, 13, 1011740.
12. Yamuna, K., Priyanka Dwarampudi, L., Shanmugam, R., Mirunalini, G., Dutta, S., Nagaprasad, N., & Krishnaraj, R. (2025). A Review on Phytoconstituents for the Management of Psoriasis. Natural Product Communications, 20(5), 1934578X251342473.
13. Mude, S. (2024). Phytoconstitute Used in Cancer Treatment. Asian Journal of Pharmaceutics (AJP), 18(02).
14. Chandra, P., Pathak, R., & Sachan, N. (2024). Chrysin: Chemistry, Occurrence, Pharmacokinetics, Toxicity, Molecular Targets, and Medicinal Properties of a Naturally Occurring Flavone. Current Bioactive Compounds.
15. Vishvakarma P, Kaur J, Chakraborthy G, Vishwakarma DK, Reddy BB, Thanthati P, Aleesha S, Khatoon Y. Nephroprotective Potential of Terminalia Arjuna Against Cadmium-Induced Renal Toxicity by In-Vitro Study. Journal of Experimental Zoology India. 2025 Jan 1;28(1)
16. Biswkarma, V. K., & Wadhawan, S. (2025). Phytoconstituents Ameliorates Alzheimer's Disease and Cognitive Impairments: A Review of Preclinical Studies. Current Bioactive Compounds, 21(5), E140624231042.
17. Pardeshi, C. V., Pardeshi, S. R., Naik, J. B., Shirkhedkar, A. A., & Surana, S. J. (2022). Herbal Bioactives for Treating Respiratory Infections. Herbal Drugs for the Management of Infectious Diseases, 101-131.
18. Kumar S, Manoyogambiga M, Attar S, Kaur K, Singh N, Shakya S, Sharma N, Vishvakarma P. Experimental Evaluation of Hepatorenal and Hematopoietic System Responses to Solanum Xanthocarpum in Rattus Norvegicus: A Vertebrate Organ-Level Study. Journal of Experimental Zoology India. 2025 Jul 1;28(2).
19. Jain, S., Nema, P., Purohit, A., Vishwakarma, H., Jain, D. K., & Jain, P. K. (2023). Recent Advances in Phytoleads for Management of Respiratory Disorders. Int J Pharm Biol Arch.
20. Daku, A. B., & Nurul, A. A. (2022). Pharmaceutical Nanoscience: Pulmonary Drug Delivery System. In Advanced Pharmaceutical and Herbal Nanoscience for Targeted Drug Delivery Systems Part I (pp. 76-103). Bentham Science Publishers.
21. Bhagchandani D, Shriyanshi, Begum F, Sushma RC, Akanda SR, Narayan S, Sonu K, Vishvakarma P. Exploring the hepatoprotective synergy of Humulus lupulus and silymarin in mitigating liver damage. Biochem Cell Arch. 2025;25(1):915-9. doi:10.51470/bca.2025.25.1.915
22. Patel, A., & Pandey, A. (2021). Novel Approaches. Enhancing the Therapeutic Efficacy of Herbal Formulations, 241.
23. Mehta, P. P., & Dhapte-Pawar, V. (2023). Chitosan-Based Particulates Carriers for Pulmonary Drug Delivery. In Pulmonary Drug Delivery Systems: Material and Technological Advances (pp. 213-245). Singapore: Springer Nature Singapore.
24. Mehta, P. P., & Dhapte-Pawar, V. (2023). for Pulmonary Drug Delivery. Pulmonary Drug Delivery Systems: Material and Technological Advances, 213.
25. Barh, D. (Ed.). (2022). Biotechnology in Healthcare, Volume 1: Technologies and Innovations. Academic Press.
26. Bachhav DG, Sisodiya D, Chaurasia G, Kumar V, Mollik MS, Halakatti PK, Trivedi D, Vishvakarma P. Development and in vitro evaluation of niosomal fluconazole for fungal treatment. J Exp Zool India. 2024;27:1539-47. doi:10.51470/jez.2024.27.2.1539
27. Elkhouly, A. M., Baldam, M. Y., Al-Touny, S., Almeanawy, A. S., Abohalawa, M. N., Hamed, M., & Mansour, F. R. (2024). Medicinal Plants Cultivated in Egypt with Antiviral Potential: A Systematic Review. Alternative Therapies in Health and Medicine, 30(8), 43-51.
28. Suresh S, Tyagi N, Mandal S, Vishvakarma P, Reena K, Sarma SK, Ranjan R. A comprehensive study of Tinospora cordifolia: Phytochemical and pharmacological properties. Eur Chem Bull. 2023;12:2009-19.
29. Parida SK, Vishvakarma P, Landge AD, Khatoon Y, Sharma N, Dogra SK, Mehta FF, Sharma UK. Spatiotemporal biointeraction and morphodynamics of a gastro-retentive Saccharopolyspora-derived macrolide system in the vertebrate gut: A study on absorptive microecology and transit kinetics. J Exp Zool India. 2025;28:1743-51. doi:10.51470/jez.2025.28.2.1743
30. Singh, G., Famta, P., Shah, S., Vambhurkar, G., Pandey, G., Kumar, R., ... & Khatri, D. K. (2025). Nanoparticle-enhanced delivery of resveratrol for targeted therapy of glioblastoma: Modulating the Akt/GSK-3β/NF-kB pathway in C6 glioma cells. Brain Research, 1848, 149411.
31. Mani M, Shrivastava P, Maheshwari K, Sharma A, Nath TM, Mehta FF, Sarkar B, Vishvakarma P. Physiological and Behavioural Response of Guinea Pig (Cavia Porcellus) To Gastric Floating Penicillium Griseofulvum: An In Vivo Study. Journal of Experimental Zoology India. 2025 Jul 1;28(2).
32. Sharma, D., Kumar, N., Mehrotra, T., Pervaiz, N., Agrawal, L., Tripathi, S., ... & Ledwani, L. (2021). In vitro and in silico molecular docking studies of Rheum emodi-derived diamagnetic SnO 2 nanoparticles and their cytotoxic effects against breast cancer. New Journal of Chemistry, 45(3), 1695-1711.