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Development and Characterization of Herbal Extract-Loaded Chitosan Nanoparticles for Alopecia

Vidhi A. Deshmukh[1], Aishwarya P. Sitafale[1], Amruta N. Mandekar[1], Supriya Y. Humbad[1], Vaishnavi S. Tale[1], V. G. Bora[1], K. R. Biyani[2]

[1]Department of Pharmaceutics, Anuradha College of Pharmacy, Chikhli, Buldhana, (M.S.) India
[2]Principal, Anuradha College of Pharmacy, Chikhli, Buldhana, (M.S.) India

Abstract: *Alopecia, characterized by hair loss from areas where it normally grows, presents a widespread dermatological challenge with deep psychosocial impacts. Conventional topical therapies often suffer from poor skin penetration, local irritation, and volatile retention at the target hair follicle site. To circumvent these biopharmaceutical limitations, this review explores the development, characterization, and technological framework of herbal extract-loaded chitosan nanoparticles designed for targeted follicular delivery. Polymeric nano-carriers utilize biodegradable and biocompatible polyelectrolytes, predominantly chitosan interacting with poly-g-glutamic acid (PGA), to form stable matrix systems via complex coacervation. Bioactive phytochemicals from seven targeted medicinal sources—Rosemary, Tulsi, Amla, Curry Leaves, Rose, Hibiscus, and Green Tea—are integrated due to their documented anti-androgenic, antioxidant, cell-signaling, and microvascular-stimulating properties. The formulation assembly can be characterized for quality control matrices including optimal particle size distribution, polydispersity index (PDI), positive surface zeta potential, entrapment kinetics, and accelerated stability guidelines under controlled relative humidity. Conclusively, the synthesis of polymeric-phyto nanocarriers establishes a highly scalable, sustainable, and biomimetic interface capable of optimizing follicular localization for efficient hair regeneration matrices.*

Keywords: Alopecia, Hair Loss, Chitosan Nanoparticles, Poly-g-Glutamic Acid (PGA), Herbal Extracts, Phyto-nanoparticles, Topical Drug Delivery, Hair Follicle Targeting, Quercetin.

I. INTRODUCTION

Alopecia refers to partial or complete loss of hair from areas where hair normally grows. Hair loss may occur because of genetic, hormonal, inflammatory, autoimmune, nutritional, environmental, or other complex factors. Among the different clinical presentations, androgenetic alopecia (AGA) is recognized as one of the most common chronic patterns of progressive hair loss, affecting millions of individuals globally. In addition to AGA, other pathological forms such as Alopecia Areata, an autoimmune condition characterized by patchy hair loss, and Telogen Effluvium, which is often triggered by severe physiological or emotional stress, present significant therapeutic challenges. The psychological impact of these conditions often leads to diminished self-esteem and compromised quality of life, highlighting the critical need for highly reliable and sustainable long-term treatment strategies [1].

Physiologically, hair growth is a highly regulated cyclic process consisting mainly of anagen (growth), catagen (regression), and telogen (resting) phases. The precise duration and transition between these distinct phases are strictly controlled by complex interactions among follicular epithelial cells, dermal papilla cells, stem cells, hormones, growth factors, and several intricate cell-signaling pathways. Disruption in any of these biological cascades can prematurely push hair follicles into the regression phase, leading to accelerated thinning and eventual loss. Published scientific

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reviews indicate that phytochemicals may significantly influence hair growth through potent antioxidant, anti-inflammatory, anti-androgenic, and cell-signaling mechanisms. Plant-derived bioactive compounds such as flavonoids, terpenoids, and phenolic compounds have therefore attracted substantial research interest in advanced hair-loss therapeutic development [1,2]. However, conventional topical treatments frequently show severe practical limitations related to poor skin penetration, the necessity for frequent application, local irritation, and highly variable deposition at the intended hair follicle site. To overcome these biopharmaceutical hurdles, the utilization of engineered nanoparticles has emerged as a revolutionary paradigm in modern dermatological research. The unique structural properties of nanoparticles, such as their sub-micron size, high surface-area-to-volume ratio, and customizable surface chemistry, enable them to efficiently bypass the stratum corneum barrier. Consequently, the hair follicle itself can act as a crucial, highly receptive penetration pathway for appropriately designed nanoparticles [3]. By encapsulating unstable phytochemicals or specialized synthetic drugs within target-specific nanoparticles, researchers can successfully achieve sustained, controlled release kinetics directly inside the follicular microenvironment. Nanocarriers can be engineered to maximize solubility, prevent degradation, enhance follicular deposition, and bypass the tough stratum corneum barrier [3,4].

1.1 Hair Growth Cycle

The physiological cycle transitions sequentially through the following phases [2,7,9]:

• Anagen (Growth Phase): Active cell division occurs; matrix cells proliferate and the hair shaft is produced. Characteristically lasts 2-6 years.

• Catagen (Regression Phase): A short phase involving controlled follicular involution and cell apoptosis. Lasts 2-3 weeks.

• Telogen (Resting Phase): No active growth occurs, leading to eventual shedding and initiation of a new cycle. Lasts 2-4 months.

A comprehensive therapeutic strategy for hair regrowth aims to maintain or promote anagen, support dermal papilla cell activity, reduce oxidative stress/inflammation, and optimize the local follicular microenvironment.



Fig. 1: Hair Growth Cycle

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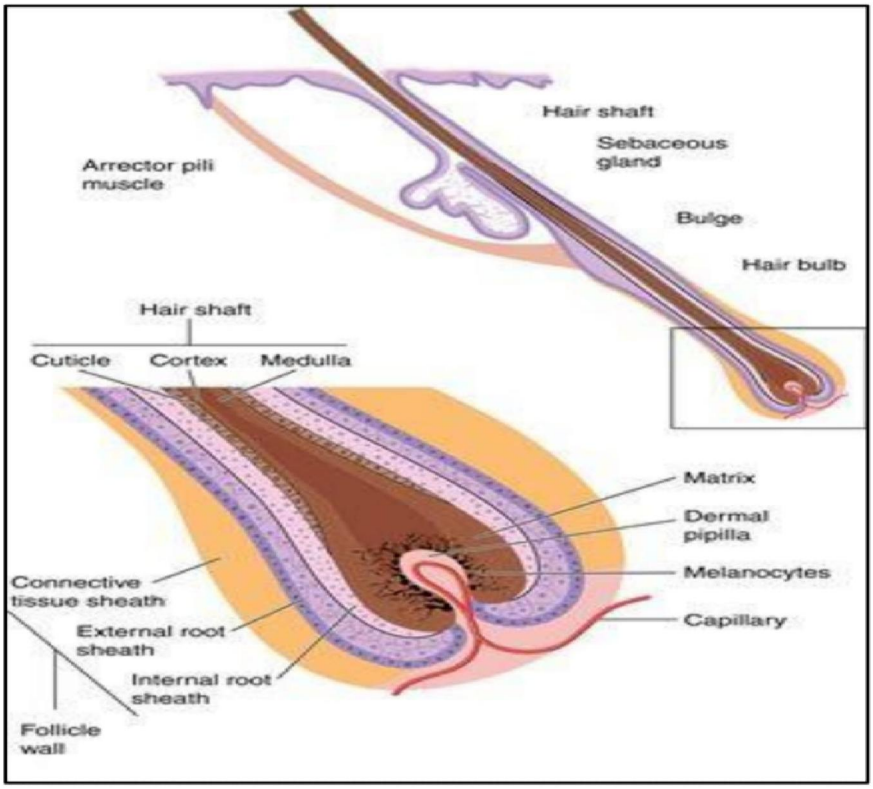
1.2 Anatomy of Hair

Hair is composed of dead keratinized cells held together by keratin proteins. Each hair has two main structural parts:

• Hair Shaft: The visible portion of the hair that extends above the surface of the skin.

• Hair Root: The portion extending below the skin surface into the dermis and sometimes the subcutaneous layer.

Both consists of three discrete cellular layers: the innermost Medulla (absent in fine hair), the thickest structural body called the Cortex (containing pigments and keratin fibers), and the protective Cuticle composed of overlapping keratinized cells. The hair root is surrounded by the hair follicle, expanding at the base into the hair bulb around the vascularized dermal hair papilla.



1.3 Major Types of Alopecia

Type of Alopecia	Pathological & Structural Features
Androgenetic Alopecia (AGA)	Progressive follicular miniaturization associated with androgen sensitivity and high DHT lev
Alopecia Areata	Autoimmune-mediated, usually non-scarring patchy hair loss driven by cellular immune dys
Telogen Effluvium	Excessive shedding associated with an abrupt shift of follicles into telogen phase due to sy
Traction Alopecia	Hair loss related to repeated mechanical traction or continuous pulling forces on root shafts

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Scarring Alopecia	Follicular destruction accompanied by permanent dermal fibrosis and irreversible scarring

1.4 Role of Chitosan and Poly-g-Glutamic Acid in Hybrid Nanoparticles

Chitosan and poly-g-glutamic acid (PGA) are biopolymers that have attracted widespread attention in biomedical drug-delivery research because of their strict biodegradability and biocompatibility. In this project, they serve as the structural nanoparticle matrix [5].

Chitosan (Cationic Polymer): A natural polysaccharide obtained by the deacetylation of chitin. Under mildly acidic conditions, chitosan carries a positive charge due to protonation of its amino functional groups. This enables electrostatic complexation with anionic polymers and promotes bioadhesion onto negatively charged scalp structures.

Poly-g-Glutamic Acid (Anionic Polymer): A water-soluble, biodegradable biopolymer containing free carboxyl functional groups. When combined sequentially under controlled agitation with chitosan, the electrostatic integration yields a dense polyelectrolyte complex coacervation capable of high entrapment efficiency and sustained controlled release kinetics [6,8].

1.5 Hair Follicle and Hybrid Nanocarriers as a Target

The hair follicle is a deep, highly receptive skin appendage extending directly into the dermis. Utilizing hybrid nanocarriers synthesized from lipid-polymer composites overcomes poor aqueous solubility and environmental degradation of phytoconstituents (such as quercetin) [13,14]. The sub-micron diameter allows preferential deposition within the follicular infundibulum, establishing a localized long-acting reservoir that minimizes systemic side effects and maximizes regional therapeutic bioavailability [15,16].

II. DRUG / ACTIVE PROFILE (HERBAL PROFILES)

1. Rosemary

- **Synonyms**: Rosmarinus, Compass Plant, Polar Plant.
- **Biological Source**: Dried leaves of Rosmarinus officinalis Linn. (Family: Lamiaceae). **Chemical Constituents**: Volatile oils (1,8-cineole, camphor, alpha-pinene), rosmarinic acid, carnosic acid, and ursolic acid.
- **Uses & Nanoparticle Applications**: Rosemary works effectively by blocking the 5-alpha-reductase enzyme, reducing the production of Dihydrotestosterone (DHT). It enhances localized microcirculation across the scalp. When encapsulated into a hybrid phyto-nanoparticle matrix, its lipophilic volatile oils achieve excellent deep follicular penetration.

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Fig 3: Rosemerry

2. Tulsi (Holy Basil)

- **Synonyms**: Surasa, Holy Basil, Sacred Basil, Tulasi.
- **Biological Source**: Fresh or dried leaves of Ocimum sanctum Linn. (Family: Lamiaceae).
- **Chemical Constituents**: Eugenol (up to 70% in volatile oil), carvacrol, caryophyllene, ursolic acid, and rosmarinic acid.
- **Uses & Nanoparticle Applications**: Functions as a potent adaptogen that lowers cortisol levels to reverse stress-induced Telogen Effluvium. Its robust antimicrobial properties clear out Malassezia species. At the nanoscale, it acts as a powerful antioxidant scavenger that mitigates ROS stress at the hair bulb.



Fig. 4: Tulsi (Holy Basil)

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3. Amla (Indian Gooseberry)

- **Synonyms**: Emblic Myrobalan, Amritphala, Dhatriphala.
- **Biological Source**: Fresh or dried fruits of Emblica officinalis Gaertn. (Family: Euphorbiaceae).
- **Chemical Constituents**: Highly concentrated Vitamin C (Ascorbic acid), hydrolyzable tannins (Emblicanin A & B, Punigluconin), gallic acid, and ellagic acid.
- **Uses & Nanoparticle** Applications: Directly stimulates the proliferation of Dermal Papilla Cells inside the hair follicle matrix. Integrating Amla into a hybrid nanoparticle platform shields its highly sensitive Ascorbic acid content from environmental oxidative degradation, maximizing Keratin protein synthesis.



Fig. 5: Amla (Indian Gooseberry)

4. Curry Leaves

- **Synonyms**: Kadhi Patta, Sweet Neem, Surabhinimba.
- **Biological Source**: Fresh leaves of Murraya koenigii (Linn.) Spreng. (Family: Rutaceae).
- **Chemical Constituents**: Carbazole alkaloids (mahanimbine, girinimbine), beta-carotene, iron, calcium, and essential volatile oils.
- **Uses & Nanoparticle Applications**: Supplies a rich blend of amino acids and bioavailable Iron that structuralizes the hair roots, reducing structural fragility. The unique carbazole alkaloids possess anti-inflammatory properties that calm chronic scalp inflammation and perifollicular fibrosis.

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Fig. 6: Curry Leaves

5. Rose

- **Synonyms**: Shatapatri, Gulab
- **Biological Source**: Rose consists of the fresh or dried petals of Rosa damascena Mill., belonging to the family Rosaceae. Rose flowers are used to obtain rose water, essential oil, and other medicinal preparations.
- **Chemical Constituents**: Geraniol, Citronellol, Phenylethyl alcohol, Flavonoids, Anthocyanins, Tannins, Quercetin, kaempferol and Vitamin C.
- **Uses and Nanoparticle Applications:** Rose is used as a flavouring agent, perfuming agent, and in cosmetic preparations. It possesses antioxidant, anti-inflammatory, and antimicrobial properties. Rose extract is used in the green synthesis of silver and gold nanoparticles, which are investigated for antimicrobial activity, drug delivery, antioxidant formulations, and wound-dressing applications.

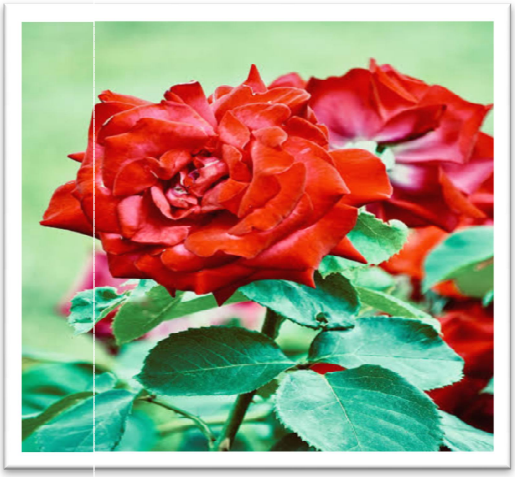


Fig. 7: Rose

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6. Hibiscus

- **Synonyms**: China Rose, Shoe-flower, Jaswand.
- **Biological Source**: Fresh or dried flowers and leaves of Hibiscus rosa-sinensis Linn. (Family: Malvaceae).
- **Chemical Constituents**: Anthocyanins, flavonoids (quercetin, kaempferol), plant mucilage (pectin), and organic acids.
- **Uses & Nanoparticle Applications**: Triggers upregulation of Vascular Endothelial Growth Factor (VEGF) in the scalp, promoting capillary generation around shrunk hair follicles. Formulating Hibiscus into nano-sized delivery systems helps its bulky flavonoid compounds cross the tough Stratum Corneum barrier effectively.



Fig. 8: Hibiscus

7. Green Tea

- **Synonyms**: Thea, Tea leaves
- **Biological Source**: Green tea consists of the processed, unfermented leaves and leaf buds of Camellia sinensis (L.) Kuntze.
- **Chemical Constituents**: Epigallocatechin gallate (EGCG), Epicatechin, Epigallocatechin, Epicatechin gallate, Caffeine, Theanine, tannins, Flavonoids
- **Uses and Nanoparticle Applications**: Green tea is used as a beverage and possesses antioxidant and anti-inflammatory properties. It is investigated for antimicrobial and cardioprotective effects. Green tea extract is used in the green synthesis of silver and gold nanoparticles, which are studied for antimicrobial formulations, drug delivery, antioxidant applications, and experimental cancer research.



Fig. 9: Green Tea

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III. MATERIALS AND METHODS

Concept: The formulation incorporates selected herbal extracts into a hybrid carrier system combining biodegradable polyelectrolyte polymers, Chitosan (cationic polymer) and Poly-glutamic acid (anionic polymer), providing structural release controls, enhanced stability, and improved skin interface compatibility for topical application in alopecia.

3.1 Materials

Chitosan (Low/Medium Molecular Weight, High Deacetylation grade), Polyglutamic Acid (PGA), Model active phytochemical standard Quercetin, Glacial Acetic Acid (analytical grade), Distilled and Purified Water, and authenticated plant parts for extraction of the seven medicinal herbs (Rosemary, Tulsi, Amla, Curry Leaves, Rose, Hibiscus, Green Tea).

3.2 Methods

1. Collection and Authentication of Herbal Materials

The seven selected herbal materials will be collected from reliable authentic botanical sources. Their classification will be verified by a qualified botanist, and the raw materials will be meticulously washed and processed to remove dust, soil, and foreign matter.

2. Preparation of Herbal Extracts

The plant materials will be thoroughly air shade-dried and converted into fine powders using a mechanical grinder. Separate hydro-alcoholic or alcoholic maceration/soxhlet extraction techniques will be executed depending on the lipophilic nature of active phytoconstituents. The final solutions will be filtered, concentrated under vacuum using a rotary evaporator, and stored in airtight dark glass containers at 4°C.

3. Preparation of Chitosan Polymer Solution

A precisely weighed mass of chitosan will be dissolved in a 1% v/v dilute aqueous acetic acid solution. Continuous magnetic stirring will be carried out overnight at room temperature to ensure complete dissolution and protonation of amino groups. The final solution will be filtered to remove un-dissolved fibers and allowed to stand to eliminate entrapped air bubbles.

4. Preparation of Poly-g-Glutamic Acid (PGA) Solution

A measured quantity of poly-g-glutamic acid (PGA) will be slowly dispersed and dissolved in purified water. The pH of the solution will be monitored and adjusted using dilute sodium hydroxide if necessary to ensure full ionization of the carboxyl groups, creating an optimal anionic charge state.

5. Preparation of Herbal Extract-Loaded Chitosan Nanoparticles

The concentrated herbal extracts (or standard quercetin) will be solubilized and mixed into the polymeric solution phase based on drug solubility profiles. The anionic PGA solution will then be added dropwise into the cationic chitosan solution under high-speed, continuous magnetic stirring (or probe sonication). Spontaneous complex polyelectrolyte coacervation/ionic gelation will occur, precipitating sub-micron hybrid nanoparticles. Critical formulation parameters such as chitosan-to-PGA ratio, extract loading concentrations, pH controls, and stirring rates will be systematically optimized.

IV. EVALUATION PARAMETERS

To evaluate the baseline physical, chemical, and preliminary stability parameters of the compiled Chitosan-PGA herbal hybrid nanoparticles, the following tests are executed:

1. Particle Size Distribution and Polydispersity Index (PDI)

The average hydrodynamic diameter and size distribution uniformity (PDI) of the synthesized nanoparticles will be evaluated at 25°C utilizing Dynamic Light Scattering (DLS) or Photon Correlation Spectroscopy instruments. A low PDI indicates a highly monodisperse and stable formulation.

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2. Zeta Potential Analysis

The surface charge characteristics of the hybrid nanocarriers will be determined via laser Doppler anemometry. A highly positive zeta potential (preferable due to protonated chitosan groups) confirms excellent electrostatic repulsion between individual particles, preventing agglomeration, and ensures robust electrostatic adhesion onto the negatively charged scalp surface.

3. Morphological Characterization

The structural appearance, shape, and surface roughness of the nanoparticles will be visually characterized utilizing Transmission Electron Microscopy (TEM) or Scanning Electron Microscopy (SEM). Samples are typically diluted and stained with phosphotungstic acid prior to imaging.

4. Entrapment Efficiency (EE) and Loading Capacity

The percentage of herbal active (or marker compound like quercetin) successfully trapped inside the nanomatrix will be quantified. The un-entrapped free drug will be separated by high-speed centrifugation. The supernatant will be analyzed via UV-Visible Spectroscopy or High-Performance Liquid Chromatography (HPLC). Entrapment Efficiency (% EE) is computed using the standard formula:

EE (%) = [(Total Amount of Drug Added - Amount of Free Unbound Drug) / Total Amount of Drug Added] × 100

5. In-Vitro Drug Release Kinetics

The release profile will be tracked using a Franz diffusion cell setup or dialysis bag method in simulated skin fluid (pH 5.5) maintained at 37°C. Aliquots will be withdrawn at pre-determined intervals and replaced with fresh buffer, followed by drug quantification to model mathematical release kinetics.

6. Preliminary Stability Studies

The formulations will be placed inside a controlled humidity chamber and subjected to accelerated stability parameters as per ICH guidelines (e.g., 40°C ± 2°C and 75% ± 5% RH) for a period of 3 months. Samples will be analyzed periodically for changes in particle size, zeta potential, visual appearance, and active content.

V. CONCLUSION

In conclusion, the compilation and review of Chitosan-Poly-g-Glutamic Acid (PGA) herbal hybrid nanoparticles establish a highly advanced, biocompatible, and structurally proficient drug delivery vehicle for the potential management of alopecia. By binding the therapeutic synergy of seven targeted medicinal plants (Rosemary, Tulsi, Amla, Curry Leaves, Rose, Hibiscus, Green Tea), the formulation integrates multiple biological modes of action including 5-alpha-reductase enzyme inhibition, intense antioxidant scavenging, and hair follicle matrix revitalization. The spontaneous polyelectrolyte complexation between cationic chitosan and anionic PGA successfully generates sub-micron delivery systems capable of maximizing chemical entrapment, protecting sensitive phytoconstituents from premature oxidative stress, and establishing a sustained release profile. Utilizing these bio-polymeric nanoparticles effectively bypasses the skin's tough stratum corneum barrier, selectively routing active phytoconstituents down the hair follicle infundibulum to optimize localized deposition and therapeutic performance while curtailing systemic side effects.

VI. FUTURE SCOPE

The future scope of this research involves validating the specific combinations of these seven herbs through strict ex-vivo cutaneous permeation testing and follicular mapping on model animal skins to visualize the exact depth of particle penetration. Furthermore, detailed in-vitro cell culture studies utilizing human dermal papilla cells will help decode the exact molecular signaling pathways (such as Wnt/β-catenin activation) triggered by the encapsulated actives. Transitioning this optimized nanoparticle colloidal suspension into user-friendly topical vehicles like thickened hydrogels, non-greasy scalp serums, or bioactive foams will enhance patient compliance. Conclusively, executing systematic clinical trials could establish these natural, polymer-stabilized nanocarriers as safe, economically sustainable, and commercially viable therapeutic alternatives to synthetic hair-loss treatments.

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REFERENCES

[1] Phytochemicals and novel delivery systems in alopecia management: An integrative review. Phytomedicine Plus. 2025; article 100949. doi: 10.1016/j.phyplu.2025.100949.

[2] Choi JY, Boo MY, Boo YC. Can Plant Extracts Help Prevent Hair Loss or Promote Hair Growth? A Review Comparing Their Therapeutic Efficacies, Phytochemical Components, and Modulatory Targets. Molecules. 2024;29(10):2288. doi: 10.3390/molecules29102288.

[3] Patzelt A, Lademann J. Recent advances in follicular drug delivery of nanoparticles. Expert Opinion on Drug Delivery. 2020;17(1):49-60. doi: 10.1080/17425247.2020.1700226.

[4] Bioactive Compound-Loaded Nanocarriers for Hair Growth Promotion: Current Status and Future Perspectives. Pharmaceutics. 2023. PMID: 37960095.

[5] Lin YH, Chung CK, Chen CT, Liang HF, Chen SC, Sung HW. Preparation of nanoparticles composed of chitosan/poly-g-glutamic acid and evaluation of their permeability through Caco-2 cells. Biomacromolecules. 2005;6(2):1104-1112. doi: 10.1021/bm049312a.

[6] Ren D, Chen P, Zheng P, Xu Z, Lu S. Preparation of Poly-g-Glutamic Acid/Chitosan Nanoparticles and pH Responsive Release Properties. Journal of Functional Polymers. 2020;33(1):54-62. doi: 10.14133/j.cnki.1008-9357.20181128001.

[7] Ahmed A, Alali AM, Abdullah E, Alharbi MN, Alayoubi HM. Herbal Remedies for Hair Loss: A Review of Efficacy and Safety. Skin Appendage Disorders. 2025;11(4):360-371. doi: 10.1159/000542876.

[8] Kim HS, Kwon HK, Lee DH, Le TN, Park HJ, Kim MI. Poly(g-Glutamic Acid)/Chitosan Hydrogel Nanoparticles for Effective Preservation and Delivery of Fermented Herbal Extract for Enlarging Hair Bulb and Enhancing Hair Growth. International Journal of Nanomedicine. 2019;14:8409-8419. doi: 10.2147/IJN.S227514.

[9] Balogun-Agbaje OA, Odeniyi OA, Odeniyi MA. Drug delivery applications of poly-g-glutamic acid. Future Journal of Pharmaceutical Sciences. 2021;7:125.

[10] Liu Z, He Y, Ma X. Preparation, Characterization and Drug Delivery Research of g-Polyglutamic Acid Nanoparticles: A Review. Current Drug Delivery. 2024;21(6):795-806. doi: 10.2174/1567201820666230102140450.