Development and Evaluation of Herbal Hair Gel from Walnut

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Abstract - The rising consumer preference for natural, eco-friendly, and sustainable personal care products has spurred significant interest in herbal formulations that minimize the use of synthetic chemicals. This study focuses on the development and comprehensive evaluation of a herbal hair gel formulated using extracts from Juglans regia (walnut) shells, a byproduct of the walnut processing industry often discarded as waste. The research leverages the rich phytochemical composition of walnut shells, including bioactive compounds such as juglone (5-hydroxy-1,4-naphthoquinone), phenolic acids, flavonoids, tannins, and essential fatty acids like alpha-linolenic acid, to create a multifunctional hair gel that combines styling efficacy with therapeutic benefits for hair and scalp health. The study aligns with the principles of green chemistry and circular bioeconomy by valorizing agricultural waste into a high-value cosmetic product, addressing both environmental sustainability and consumer demand for clean-label hair care solutions

The formulation process began with the collection of Juglans regia shells from local fruit markets in Uttar Pradesh, India, ensuring the use of high-quality, pesticide-free raw material. The shells were cleaned, shade-dried, and oven-dried at 40°C to preserve thermolabile constituents, followed by pulverization and sieving through a 40-mesh sieve to achieve uniform particle size. A hydroethanolic solvent (70% ethanol: 30% water) was used for maceration over 72 hours to extract bioactive compounds, including phenolics, flavonoids, and juglone, known for their antimicrobial, antioxidant, and hairstrengthening properties. The extract was concentrated using a rotary evaporator at 45°C under reduced pressure, yielding a semi-solid residue stored at 4°C for subsequent formulation. Preliminary phytochemical screening confirmed the presence of phenolics, tannins, flavonoids, glycosides, and alkaloids, validating the therapeutic potential of the extract for hair care applications.

The herbal hair gel was formulated using carbomer 940 as the gelling agent (1% w/w) due to its clarity, stability, and compatibility with herbal extracts. The optimized formulation included 2.5% w/w Juglans regia extract, 5% glycerin as a humectant, 0.5% vitamin E as an antioxidant, and minimal preservatives (0.2% methylparaben and 0.05% propylparaben) to ensure microbial safety without compromising the natural profile of the product. Triethanolamine was used to adjust the pH to a scalp-compatible range of 6.0–6.5, and distilled water served as the primary solvent to achieve a final weight of 100 g. The gel preparation involved hydrating the carbomer in water, incorporating the extract-preservative-glycerin blend, and adjusting the pH to form a clear, homogenous, and viscous gel. Optional additions, such as lavender essential oil (0.1% w/w), enhanced the sensory appeal and provided mild soothing effects.

The formulated gel underwent rigorous evaluation to ensure its functionality, safety, and consumer acceptability. Organoleptic properties were assessed, revealing a light brown, smooth, and non-sticky gel with a mild herbal odor, maintaining consistency over 30 days. Physicochemical parameters included pH (5.4–6.1), viscosity (58,000 cps initially, stable at 56,800–58,100 cps), spreadability (6.2–6.8 cm), extrudability (9.1–9.5 g/10s), and washability, all of which met desirable standards for topical cosmetic products. The pH was within the ideal range for scalp compatibility (4.5–6.5), ensuring minimal irritation, while the viscosity supported easy application and effective hair setting without dripping. Spreadability and extrudability tests confirmed uniform coverage and ease of use, and the gel was easily washable, enhancing its practicality.

Antioxidant activity was evaluated using the DPPH free radical scavenging assay, demonstrating significant free radical inhibition with an IC50 of 21.5 µg/mL for the extract and 42.8 µg/mL for the gel, indicating robust protection against oxidative stress, a key factor in hair loss and scalp inflammation. The antimicrobial efficacy was tested using the agar well diffusion method against Staphylococcus aureus (Gram-positive), Escherichia coli (Gram-negative), and Candida albicans (yeast), organisms commonly associated with scalp infections and dandruff. The gel exhibited zones of inhibition of 17 mm, 15 mm, and 13 mm, respectively, compared to standard drugs (ampicillin: 20–22 mm; fluconazole: 19 mm), confirming broad-spectrum antimicrobial potential suitable for combating scalp infections and supporting dandruff control.

Microbial load testing, conducted per Indian Pharmacopoeia standards (IS 14648:1999), showed bacterial counts of 150–175 CFU/mL and fungal counts of 60–70 CFU/mL over 30 days, well within acceptable limits for topical cosmetics. Stability studies were performed under three conditions—room temperature (25 ± 2°C), refrigerated (4 ± 1°C), and accelerated (40 ± 2°C, 75% RH)—for 30 days. Parameters such as pH, viscosity, color, and phase separation showed no significant changes, with only a slight color fade at high temperatures, indicating robust formulation stability. Statistical analysis using one-way ANOVA ($p < 0.05$) confirmed the reliability and reproducibility of the results, with all measurements conducted in triplicate and expressed as mean ± standard deviation.

This study's significance lies in its innovative use of walnut shells, an agricultural byproduct, to create a sustainable, multifunctional hair gel that addresses the limitations of synthetic hair care products, such as scalp irritation, dryness, and environmental impact. Unlike conventional gels containing synthetic polymers, alcohols, and harsh preservatives, the Juglans regia-based gel offers styling benefits alongside nourishment, hydration, and protection against microbial and oxidative damage. The natural brown tint from walnut extract provides a mild hair-darkening effect, appealing to consumers seeking chemical-free alternatives to synthetic dyes.

Chapter I: Introduction

Hair plays a crucial role not only in aesthetics but also in psychological and cultural identity. The condition of one's hair is often viewed as a reflection of overall health, grooming, and personality. Consequently, hair care has become a significant domain in both the pharmaceutical and cosmetic industries. With rising consumer awareness about harmful effects of synthetic chemicals in hair care products, there has been a growing interest in herbal and plant-based formulations. Herbal cosmetics and treatments are gaining immense popularity due to their minimal side effects, eco-friendly nature, and holistic therapeutic benefits. Among the various plant sources being investigated for their dermatological benefits, Juglans regia—commonly known as walnut—has shown promising potential in hair care applications. (1)

Juglans regia, a species belonging to the family Juglandaceae, is native to Central Asia and the Balkans but is now cultivated in many temperate countries. Traditionally, various parts of the walnut tree, including its kernels, shells, bark, and leaves, have been used in traditional medicine to treat ailments ranging from inflammation and infections to skin and scalp disorders. The walnut fruit is rich in polyunsaturated fatty acids, antioxidants, vitamins (especially Vitamin E and B-complex), minerals like zinc and selenium, and bioactive phytochemicals such as juglone, ellagic acid, and flavonoids. These components make Juglans regia particularly suitable for dermatological and trichological formulations, especially in the development of hair care products. (2)

Hair gels are among the most widely used hair styling products, particularly valued for their ability to set hair in desired shapes, control frizz, add shine, and offer a lasting hold. Commercial hair gels often contain synthetic polymers, alcohols, artificial fragrances, and preservatives that, with prolonged use, may cause adverse effects such as scalp irritation, dryness, flakiness, hair thinning, or even hair fall. In this context, formulating a natural, plant-based hair gel using Juglans regia extract serves as a safer and more sustainable alternative. Herbal gels not only provide styling benefits but also nourish the scalp and hair, making them ideal multifunctional products for holistic hair care. (3)

The active components of Juglans regia offer a diverse range of benefits for hair and scalp health. The presence of juglone (5-hydroxy-1,4-naphthoquinone), a naturally occurring compound in walnut husk, is known for its antimicrobial and antifungal properties, helping combat scalp infections and dandruff. Ellagic acid, another important constituent, possesses strong antioxidant and anti-inflammatory activities, protecting hair follicles from oxidative stress, which is a major contributor to hair loss and scalp inflammation. Walnut oil, extracted from the kernel, is rich in alpha-linolenic acid and other omega-3 fatty acids that improve scalp hydration, strengthen hair roots, and enhance hair elasticity and shine. The high content of biotin and zinc in walnut is also crucial for keratin production, which is the primary protein that constitutes hair. (4) Moreover, the traditional use of walnut as a natural dye is well-documented. The hulls of Juglans regia have been historically used to color fabrics and hair, providing a natural brown tint. This attribute offers an added advantage for hair gel formulation, especially for users who prefer a mild hair-darkening effect without resorting to harsh chemical dyes. The coloring effect of walnut extract, combined with its conditioning and antidandruff properties, creates a unique profile that positions it as an ideal ingredient for herbal hair gels. (5)

The formulation of hair gel from Juglans regia involves a carefully balanced process. The preparation must ensure that the active ingredients are efficiently extracted and remain stable within the gel base. For this purpose, aqueous or hydroalcoholic extraction methods are typically used to obtain a concentrated walnut extract. A suitable gelling agent, such as carbomer 940, is employed to create the desired gel consistency. Carbomer-based gels offer excellent clarity, viscosity control, and compatibility with a wide range of additives. Other ingredients such as humectants (e.g., glycerin), pH adjusters (e.g., triethanolamine), preservatives (e.g., methylparaben), and optional fragrances may be included to enhance the aesthetic appeal, shelf-life, and consumer acceptability of the final formulation. (6)

After formulation, it is essential to evaluate the gel for various parameters to ensure its functionality, safety, and consumer appeal. These include physical appearance, color, odor, pH, spreadability, viscosity, stability under different environmental conditions, and microbial load. Moreover, functional tests such as washability, drying time, and styling hold help determine the product's practical performance. In vitro studies may also be conducted to assess the antioxidant activity or antifungal properties of the gel, further validating the therapeutic claims of the formulation. (7)

The development of such an herbal formulation aligns with the principles of green chemistry and sustainable development. It promotes the utilization of agricultural byproducts (such as walnut shells and husks) that are otherwise discarded as waste, thereby contributing to waste valorization. Additionally, the reduced use of synthetic chemicals and preservatives minimizes the environmental burden and health risks associated with traditional hair care products. (8)

This project report aims to present a complete study on the formulation and evaluation of a herbal hair gel using Juglans regia extract. It encapsulates a detailed methodology for extraction, formulation steps, and evaluation parameters. The report also highlights the importance of herbal alternatives in modern cosmetology and provides insights into the potential of walnut-based formulations in hair care. The findings of this project could serve as a foundation for the commercial development of safe, effective, and eco-friendly hair styling products tailored for modern consumers seeking natural solutions. (9)

In conclusion, the exploration of Juglans regia in hair gel preparation opens new avenues in the field of herbal cosmetology. With its rich phytochemical composition, traditional relevance, and proven efficacy, walnut-based hair gels represent a promising addition to the repertoire of plant-derived cosmetic innovations. This project not only underscores the importance of natural product research but also contributes to a growing body of evidence supporting the use of herbal ingredients in functional, safe, and consumerfriendly hair care products.In recent years, the global market for herbal personal care products has witnessed exponential growth, largely driven by increased consumer preference for clean-label, organic, and eco-conscious formulations. Synthetic hair styling products, while effective in providing hold and shine, often come with a list of undesirable side effects including hair dryness, scalp irritation, and allergic reactions. These issues stem from the use of synthetic polymers, alcohols, parabens, artificial colorants, and synthetic fragrances. Such ingredients may not only weaken the hair shaft over time but also lead to product buildup, which clogs hair follicles and interferes with normal scalp function. The emerging preference for herbal hair care formulations is not only a trend but a movement toward safer, sustainable, and holistic grooming practices.(10)

In this context, Juglans regia stands out as a potent candidate for natural hair gel formulations. The various parts of the walnut plant have been used in Ayurvedic and Unani systems of medicine for centuries. Its leaves are known for their anti-inflammatory and antimicrobial effects, while the shells and kernels are appreciated for their antioxidant richness. The kernel oil, in particular, is a rich source of tocopherols (vitamin E), phytosterols, and polyunsaturated fatty acids—all essential components for nourishing hair and improving scalp health. These properties help in enhancing follicular strength, reducing oxidative stress in scalp tissues, and improving the lipid content of the scalp, which is vital for maintaining hair moisture and luster.(11)

Additionally, Juglans regia has gained popularity in recent cosmetic research for its potential to promote hair growth and prevent premature hair greying. Several studies suggest that its phenolic constituents and micronutrients contribute to melanogenesis and keratinocyte proliferation—both crucial for hair pigmentation and regeneration. Unlike synthetic colorants, the natural pigments derived from walnut hulls provide a subtle tint that enhances the natural color of hair without damaging its protein structure. This makes walnut-based hair gels not only styling aids but also natural conditioning and tinting agents. (12)

Formulating a hair gel using Juglans regia offers numerous technical and functional advantages. From a formulation science perspective, carbomer-based gels provide an ideal medium for incorporating aqueous herbal extracts. They allow for excellent dispersion of actives and offer stability across a broad pH range. The use of neutralizing agents such as triethanolamine helps adjust the pH to make the formulation skin- and scalp-friendly, reducing the risk of irritation. Additionally, natural humectants like glycerin not only improve the spreadability and feel of the gel but also contribute to hair hydration by preventing moisture loss from hair strands. The final product is thus a multifunctional formulation offering hold, hydration, nourishment, and protection.

From a sustainability point of view, the use of walnut shells and by-products in such formulations adds an eco-friendly dimension. These parts are often discarded after commercial processing of walnuts for culinary or oil extraction purposes. Utilizing these biowastes in cosmetic formulations reduces landfill load and aligns with the principles of zero-waste product development and circular bioeconomy. Moreover, plant-based products have a lower environmental footprint in terms of carbon emissions and water usage compared to petrochemical-based cosmetic ingredients.

The process of developing this hair gel also provides a practical application of pharmaceutical and cosmetic formulation principles for pharmacy students. It involves an understanding of extraction techniques, phytochemical screening, formulation science, quality control parameters, and product evaluation. Additionally, it encourages innovation and problem-solving, especially when modifying traditional formulations to suit modern aesthetic and functional standards. This kind of interdisciplinary project not only strengthens the academic foundation but also nurtures entrepreneurial thinking, as there is increasing demand for herbal personal care products in niche markets, such as vegan and cruelty-free beauty.

The project also contributes to the growing body of literature advocating for the scientific validation of traditional herbal knowledge. While Juglans regia has a well-documented ethnobotanical history, there remains a need for standardized, evidence-based formulations that translate traditional use into clinically and commercially viable products. This includes not only evaluating the physicochemical and sensory attributes of the formulation but also assessing its safety, stability, and efficacy through rigorous testing. Furthermore, a well-designed study could pave the way for future enhancements such as combining walnut extract with other herbal actives like Aloe vera, Amla, or Neem to provide synergistic benefits.

Finally, this project highlights the importance of regulatory and quality considerations in herbal product development. In India, the growing herbal cosmetics sector is governed by regulatory frameworks such as the Drugs and Cosmetics Act and guidelines from the AYUSH ministry. These provide standards for permissible ingredients, labeling, shelflife determination, and safety evaluation. Developing a formulation like walnut-based hair gel thus familiarizes students with the real-world constraints and quality benchmarks that must be met in professional practice. (13)

In summary, the formulation of a hair gel using Juglans regia presents a unique opportunity to combine ancient herbal wisdom with modern pharmaceutical techniques. The plant's rich phytochemical profile makes it highly suitable for promoting hair health while addressing consumer demands for clean, natural, and sustainable personal care products.

Chapter II REVIEW LITERATURE

2.1 Maja Colnik et.al Pistachio and walnut shells accumulate in large quantities as waste during food processing and represent a promising lignocellulosic biomass for the extraction of valuable components. Subcritical water technology was used as an environmentally friendly technique to study the extraction of active ingredients and other valuable degradation products from walnut and pistachio waste. Subcritical water extraction (SWE) was carried out under different process conditions (temperature (150– 300 ◦C) and short reaction times (15–60 min)) and compared with conventional extraction using different organic solvents (acetone, 50% acetone and ethanol). The extracts obtained from pistachio and walnut shell waste are rich in various bioactive and valuable components. The highest contents of total phenols (127.08 mg GA/g extract at 300 ◦C for 15 min, from walnut shells), total flavonoids (10.18 mg QU/g extract at 200 ◦C for 60 min, from pistachio shells), total carbohydrates (602.14 mg TCH/g extract at 200 ◦C for 60 min, from walnut shells) and antioxidant activity (91% at 300 ◦C, for 60 min, from pistachio shells) were determined when the extracts were obtained via subcritical water. High contents of total phenols (up to 86.17 mg GA/g extract) were also determined in the conventional extracts obtained with ethanol. Using the HPLC method, sugars and their valuable derivatives were determined in the extracts, with glucose, fructose, furfurals (5-hydroxymethylfurfural (5-HMF) and furfural) and levulinic acid being the most abundant in the extracts obtained by subcritical water. The results show that subcritical water technology enables better exploitation of biowaste materials than conventional extraction methods with organic solvents, as it provides a higher yields of bioactive components such as phenolic compounds and thus extracts with high antioxidant activity, while at the same time producing degradation products that are valuable secondary raw materials.

2.2 Ali Jahanban-Esfahlan et,al. The fruit is made up of an outer green shell cover or husk, the middle shell which must be cracked to release the kernel, a thin layer known as skin or the seed coat, and finally, the kernel or meat. The nutritional importance of walnut fruit is ascribed to its kernel. The shell and husk are burned as fuel or discarded away as waste products. In the past two decades, the evaluation of the phenolic content and antioxidant activity of different parts of walnut has received great interest. In this contribution, the recent reports on the extraction and quantification of phenolic content from each part of the walnut tree and fruit using different solvents were highlighted and comparatively reviewed. The current review paper also tries to describe the antioxidant content of phenolic extracts obtained from different parts of the walnut tree and fruit.

2.3 A.A.Mesbah1 et al. Most types of bacteria are classified, either as Grampositive or Gramnegative strains. The Gram-positive bug is summarized in the resistance of Staphylococcus aureus to methicillin, which is the bacteria that are resistant to many drugs in the event that many types are Gram-negative and difficult to treat because they have anti-drug external membranes. Bacterial infection that infects new born children breast-feeding women and people suffering from chronic diseases such as diabetes, cancer, vascular disease and lung disease. Injecting drug users, those with injuries, intravenous catheters, surgical incisions, and those whose immune systems are impaired due to disease or as a result of immunosuppressive drugs are all at increased risk of developing a Staphylococcus aureus infection. Therefore, the aim of the current study was to examine the antimicrobial activity of walnut shell water extracts in dyeing cotton fabrics and its applications in nursing. The results of the study concluded that copper sulfate (at 30 % concentration) recorded the highest washing stability for all concentrations of the dye under study when used as a dye stabilizer solution. The same solution also recorded the highest stability and the highest bacterial resistance of the tested fabrics. The effectiveness of treated fabrics continued for a period of more 2020 than 4 years under normal storage conditions with a relatively low degree of resistance to bacteria. Overall, using water extract of walnut shell in dying fabrics will give a wide range of protection against pathogens.

2.4 Summaia Fordos1 et al. Walnut is among the four most consumed dry fruits around the globe. Apart from the edible walnut kernel, walnut fruit consists of a walnut shell (WS) and walnut husk/hull (WH), usually discarded in walnut processing and consumption. These walnut by-products are flled with benefcial compounds that fnd their use in diferent felds. This review summarizes recent developments and research on functional aspects of walnut waste (shell and husk/hull) in various felds. WS has many important bioactive compounds, including lignin, cellulose, oleic, and palmitic acids. The creation of WS and carbon-based materials, such as activated carbons and unmodifed/modifed WS, as adsorbents have been explored. Possible uses for WSderived by-products include all-natural but powerful adsorbents for eliminating hazardous substances, such as heavy metals, dangerous compounds, and synthetic industrial colors. Similarly, WH also has many benefcial compounds like juglone. WH has antioxidant properties and can be used as textile and protein strainers. These wastes are used in agriculture, laboratory, medical, and food industries, which can be employed as sustainable and environment-friendly alternatives.

2.5 Hania Albatrni et al. Agricultural-based adsorbents have received an upsurge of interest in the water treatment industry especially in the area of adsorption. They have been widely investigated as the next generation adsorbents due to their unique physio-chemical properties and high affinity towards a wide variety of constituents ranging from organic compounds to heavy metal ions. In addition, agricultural-based adsorbents are now a cheaper and sustainable option as opposed to non-renewable and expensive adsorbents originating from coal, polymers, and petroleum residues. Among different agriculture wastes available, walnut shells exhibit great potential as activated carbon precursor. They have outstanding chemical stability, high surface area and low ash content. In this review, walnut shellbased adsorbents have been assessed in terms of their activation methods and preparation. Furthermore, adsorbents' resulting characteristics and factors influencing the adsorption capacity have been summarized and thoroughly analyzed. It has been determined that the adsorption efficiency is heavily associated with the characteristics of the adsorbent including pore diameter, surface area, surface functional groups and the nature of the background solution including pH, temperature and ionic strength. This review identifies different activation methods reported in the literature including chemical and physical activation and chemical impregnation and functionalization. The literature survey also entails a comprehensive discussion involving types of mechanisms and factors controlling adsorption behaviors towards targeted contaminants. Moreover, a detailed analysis of adsorption isotherms and kinetics involved in the adsorption process is also included. Finally, this review mentions future research needs and challenges of adsorption by walnut shell-based adsorbents.

2.6 Jibrael Kingsford Odoom et al .Oil spills are of great concern because oily wastewater disrupts the aquatic ecosystem, causes animal mutations, contaminates surface water resources, and causes diseases such as human cancer. Current efforts are geared towards recovering spilled oil from marine environments and ensuring the effective separation of oil and water in the collected emulsion. After oil separation from the emulsion, a polishing step is required to treat the residual oil in the water before discharging the effluent into the aquatic environment. Adsorption using natural materials as adsorbents is seen as an attractive option due to its simplicity, cost-effectiveness, accessibility, and eco-friendliness. Recent adsorption studies have focused on modifying eco-friendly materials to enhance their adsorption potential. This study investigated a two-step modification of walnut shells (WS) to treat oily wastewater. Firstly, WS was modified with sodium hydroxide (NaOH) via the wet impregnation method to attain WS/NaOH. Then, tetrabutylammonium bromide (TBAB) was introduced as a co-adsorbent to enhance the oil removal potential of WS/NaOH. The surface morphologies and chemical composition of the WS and WS/NaOH were characterized by scanning electron microscopy and Fourier transform infrared spectroscopy, respectively. A one-factor-atatime experimental design was employed in this study. Findings from this research project indicated that raw WS and WS/NaOH are excellent adsorbents for the treatment of oily wastewater, with a removal efficiency of 81 % and 88 %, respectively. They generated adsorption capacitiesof 201 mg/g and 220 mg/g, respectively. However, with the introduction of TBAB as a co-adsorbent, an efficiency and capacity of 91 % and 226 mg/g, respectively, were achieved, proving the effectiveness of TBAB. Adsorption isotherm and kinetic studies were conducted to understand the adsorption mechanism of the proposed adsorbent. It was concluded that the Freundlich and Pseudo second-order model best represents the experimental results, as they show higher R^2 values of iii 0.9695 and 0.9998, respectively. This research project presents an eco-friendly and highly efficient adsorbent from modified WS to treat oily wastewater, offering a sustainable, scalable alternative to traditional methods by utilizing agricultural waste to remove oil pollutants in petrochemical wastewater treatment efficiently.

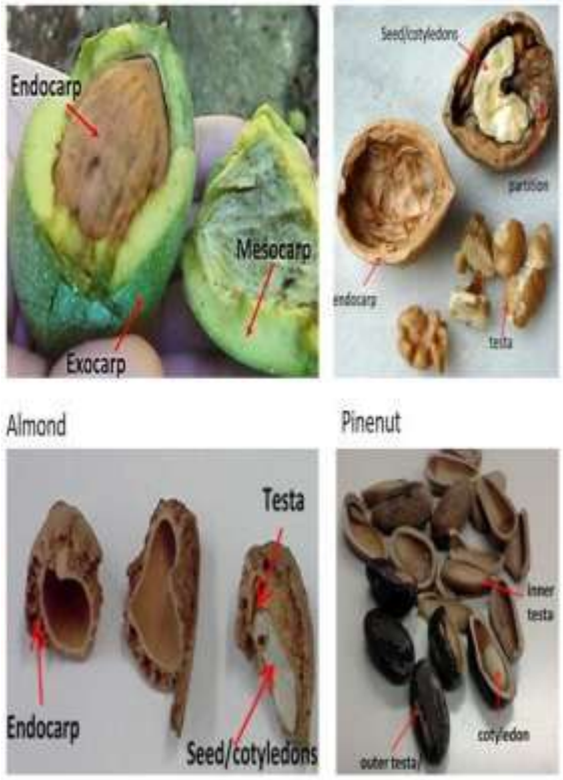
2.7 Carla S. G. P. et al. The shells of three important food nuts, walnut, almond, and pine nut, were studied in view of valorization as residues. The shells differed chemically: walnut shells had 10.6% extractives, 30.1% lignin, and 49.7% polysaccharides; almond shells 5.7% extractives, 28.9% lignin, and 56.1% polysaccharides; and pine nut shells 4.5% extractives, 40.5% lignin, and 48.7% polysaccharides. The polysaccharide composition also differed, e.g., glucose/xylose ratio of 1.12, 0.94, and 2.29 for walnut, almond, and pine nut shells, respectively. Walnut and almond shells have a SG lignin (S/G 1.6 and 1.0, respectively) and pine nut shell a G lignin. The lipophilic extracts contained mostly saturated and unsaturated alkanoic acids. The ethanol-water extracts contained total phenolics, flavonoids, and condensed tannins. The antioxidant activity was moderate (IC50 15.2, 7.9, and 8.2 μg/mL for walnut, almond, and pine nut). The three nut shells fractured easily with little formation of fines.

Chapter III: MATERIALS AND METHODS

This section describes in detail the materials used, the extraction of active constituents from Juglans regia, the formulation of herbal hair gel, and the evaluation of physicochemical and microbiological properties of the final product. The study combines natural product chemistry, herbal formulation, and cosmetic evaluation protocols drawn from validated references and literature.

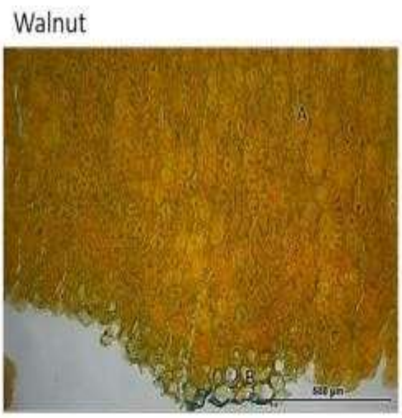
Juglans regia (common walnut) is a deciduous tree native to regions including the Mediterranean, Central Asia, and parts of India. The plant parts used in this study are the leaves and green husks, which are rich in bioactive compounds such as juglone (5hydroxy-1,4-naphthoquinone), tannins, flavonoids, phenolic acids, and essential fatty acids. These compounds contribute to the plant's antimicrobial, antioxidant, and hairstrengthening properties, making it a promising candidate for hair care formulations

3.1 **Source**: Fresh Juglans regia leaves and green husks are sourced from organic farms in Uttar Pradesh, India, to ensure high-quality, pesticide-free raw material. The plant material is collected during the early autumn season (September–October) when bioactive compound concentrations are optimal.



3.3 **Composition**: Juglans regia leaves contain approximately 2–3% juglone, 5–10% tannins, and trace amounts of essential oils, while the green husks are rich in phenolic compounds (up to 4% gallic acid equivalents) and omega-3 fatty acids. These components are known to combat dandruff-causing fungi (e.g., Malassezia spp.), reduce oxidative stress on the scalp, and promote follicular health

3.4 **Rationale for Selection**: The antimicrobial properties of juglone make it effective against scalp infections that contribute to hair loss, such as pityriasis simplex capitis (dandruff). Tannins and phenolic acids provide astringent and antioxidant effects, strengthening hair roots and reducing inflammation. The fatty acids nourish the scalp, improving hair texture and resilience.



3.5 Supporting Ingredients

To create a stable and effective hair gel, additional ingredients are incorporated to form the gel matrix, enhance texture, and ensure safety. These are kept minimal to maintain focus on Juglans regia:Xanthan

3.5.1 **Gum**: A natural polysaccharide derived from Xanthomonas campestris fermentation, used as the gelling agent. It forms a three-dimensional polymer matrix that entraps water and active ingredients, providing a smooth, spreadable consistency Concentration: 1–2% w/w.

3.5.2 **Distilled Water**: Acts as the primary solvent and hydrating agent, ensuring proper dispersion of Juglans regia extract and other components. It is sourced from a laboratorygrade purification system to eliminate impurities.

3.5.3 **Grapefruit Seed Extract**: A natural preservative with antimicrobial properties, used to extend shelf life without synthetic parabens. Concentration: 0.5% w/w.

3.5.4 **Essential Oils**: Lavender (Lavandula angustifolia) essential oil is added (0.1% w/w) for fragrance and mild soothing effects on the scalp, complementing the therapeutic action of Juglans regia.

3.6 . Equipment and Tools

3.6.1 **Maceration Apparatus**: Glass containers with airtight lids for extracting bioactive compounds from Juglans regia.

3.6.2 **Rotary Evaporator**: For concentrating the extract under reduced pressure.

3.6.3 Homogenizer: High-speed mixer (10,000 rpm) for uniform blending of gel components**.**

3.6.4 **Digital pH Meter**: Calibrated to measure the pH of the gel (range: 0–14, accuracy: ±0.01).

3.6.5 **Viscometer**: Brookfield viscometer for assessing gel viscosity (range: 100–100,000 cP).

3.6.6 **Incubator**: For stability studies at controlled temperatures (25°C and 40°C).Microbiological Testing Equipment: Petri dishes, agar plates, and incubators for antifungal activity testing.

3.6.7 **Collapsible Tubes**: Aluminum tubes (50 g capacity) for packaging the final gel product.

3.7 Materials Required

Category	Materials
Plant Material	Dried walnut (Juglans regia) shells
Solvents	Distilled water, ethanol (70%)
Reagents	Triethanolamine (TEA), glycerin, Vitamin E, preservatives (methylparaben, propylparaben)
Gel base	Carbomer 940
Equipment	Grinder, beakers, glass rods, pH meter, Brookfield viscometer, incubator
Microbial tools	Nutrient agar, PDA, petri dishes, inoculation loop

3.7.1 Materials

3.7.1.1 Plant Material

Juglans regia shells were sourced from local walnut processors or collected postdehusking of fresh walnuts. The outer shells, representing the pericarp of the walnut fruit, were selected due to their rich composition of polyphenols, lignin, flavonoids, and natural tannins.

3.7.1.2 Chemicals and Reagents

The following chemicals were used in the extraction and formulation processes:

Ethanol (95%) – Merck (analytical grade)
Distilled water – Laboratory grade
Carbomer 940 – Gelling agent, Himedia
Glycerin – Humectant, Central Drug House (CDH)
Triethanolamine (TEA) – Neutralizer and pH adjuster, SD Fine Chemicals
Methylparaben & Propylparaben – Preservatives, Loba Chemie
Perfume base (optional) – Cosmetic grade
Vitamin E (tocopherol) – Antioxidant
pH buffer solutions (pH 4.0 and 7.0) – For calibration
Reagents for phytochemical screening – $FeCl_3$, NaOH, H_2SO_4, etc.

All solvents and reagents used were of analytical grade, and distilled or deionized water was used throughout the process.

3.7.1.3 Preparation of Juglans regia Extract

3.7.1.3.1 Cleaning and Drying of Raw Material

Walnut shells were washed thoroughly with running tap water followed by distilled water to remove dust, dirt, and adhering impurities. The cleaned shells were then dried under shade for 5–7 days to avoid degradation of heat-sensitive constituents, followed by oven drying at 40°C for 6 hours to ensure complete dehydration (Queirós et al., 2019).

3.7.1.3.2 Pulverization and Sieving

Dried shells were crushed using a mechanical grinder and then sieved through a 40-mesh sieve to obtain a uniform particle size suitable for extraction and reproducibility in bioactive analysis (Albatrni et al., 2022).

3.7.1.3.3 Solvent Extraction Procedure

The powdered material (100 g) was macerated in 500 mL of hydroethanolic solvent (ethanol:water = 70:30 v/v) in a conical flask. The mixture was allowed to stand for 72 hours at room temperature, with intermittent shaking. This method helps extract both polar and moderately polar constituents like phenolics, tannins, and juglone (Queirós et al., 2019).

The extract was filtered using Whatman No. 1 filter paper, and the filtrate was subjected to solvent evaporation using a rotary evaporator at 45°C under reduced pressure. The semi-solid mass obtained was stored in an amber glass bottle at 4°C until further use in formulation.

3.7.1.3.4 Preliminary Phytochemical Screening

To confirm the presence of major phytoconstituents relevant for hair care, standard phytochemical tests were performed on the extract:

- Phenolics and Tannins – Ferric chloride test
- Flavonoids – Alkaline reagent test
- Saponins – Foam test
- Glycosides – Keller-Killiani test
- Alkaloids – Mayer's and Wagner's test

These qualitative tests are standard protocols reported in natural product studies for extract profiling (Harborne, 1998; Kokate, 2005).

3.7.1.4 Formulation of Herbal Hair Gel

A The gel was prepared using the following optimized formulation:

B Gel Base Preparation

Carbomer 940 was sprinkled into 60 mL of distilled water under continuous stirring at 500 rpm and allowed to hydrate for 1 hour.

Ingredients	Concentration (% w/w)
Juglans regia extract	2.5%
Carbomer 940	1.0%
Glycerin	5.0%
Vitamin E	0.5%
Methylparaben	0.2%
Propylparaben	0.05%
Triethanolamine (TEA)	q.s. to adjust pH
Distilled Water	q.s. to 100%

Separately, the walnut extract was mixed with glycerin and preservatives in a beaker and stirred to achieve uniformity.

The extract-preservative mixture was added slowly to the hydrated carbomer with continuous stirring.

pH was adjusted to 6.0–6.5 using dropwise addition of TEA. The mixture was stirred for an additional 30 minutes.

The final volume was made up with water and stirred until a clear, homogenous gel formed. The gel was stored in a sterile, airtight glass container.

3.7.1.5 Physicochemical Evaluation of Hair Gel

The formulated hair gel was subjected to the following tests:

3.7.1.5.1 Organoleptic Evaluation

- Color: Visual inspection
- Odor: Subjective assessment
- Appearance: Clear/opaque, homogeneity, presence of air bubbles

3.7.1.5.2 pH Determination

The pH was measured using a digital pH meter calibrated with standard buffer solutions at 25°C. The reading was taken by immersing the electrode directly into the gel. An ideal pH range for scalp products is 5.5–6.5.

3.7.1.5.3 Viscosity Measurement

Viscosity was determined using a Brookfield Viscometer with spindle no. 64 at 10 rpm at room temperature. Measurements were conducted in triplicate and average values reported in cps (centipoise).

3.7.1.5.4 Spreadability

A fixed amount of gel (1 g) was placed between two glass slides. A weight of 500 g was applied over the top slide for 5 minutes. The diameter of the gel spread was measured in centimeters.

- Spreadability (S) was calculated using the formula: • S = (M × L)/T
- Where:
- M = weight tied to upper slide (g),
- L = length moved (cm),
- T = time taken (s)

3.7.1.5.5 Extrudability Test

The gel was filled into collapsible aluminum tubes. The force required to extrude a constant volume of gel within a fixed time was recorded.

3.7.1.5.6 Washability

Small quantity of gel was applied to a glass slide, allowed to dry for 10 min, and then washed under running water. Ease of removal was assessed visually.

3.7.1.6 Microbial Load Testing

Microbial contamination was tested using the plate count method. Total bacterial count (TBC) and Total fungal count (TFC) were determined using nutrient agar and potato dextrose agar (PDA), respectively. Plates were incubated at 37°C for 24 hours (bacteria) and 28°C for 72 hours (fungi). Colony forming units (CFU) were counted and compared with acceptable cosmetic limits (as per IS 14648:1999 standards).

3.7.1.7 Stability Studies

Stability testing was carried out for 30 days at three different storage conditions:

Room temperature (25 ± 2°C)

Refrigerator (4 ± 1°C)

Accelerated condition (40 ± 2°C, RH 75%)

Parameters like pH, viscosity, color, and phase separation were monitored at 0, 15, and 30 days. Observations were recorded to determine formulation robustness.

3.7.1.8 Antioxidant Activity (DPPH Assay)

The antioxidant potential of the extract and the final formulation was assessed using the DPPH free radical scavenging method.

0.1 mM DPPH solution in methanol was prepared.

Various concentrations of extract (10–100 µg/mL) were added to 3 mL of DPPH solution.

The mixture was incubated for 30 minutes in the dark.

Absorbance was read at 517 nm using a UV-Vis spectrophotometer.

% inhibition was calculated as:

% Inhibition = [(A_control − A_sample)/A_control] × 100

IC_{50} values were determined using linear regression. Ascorbic acid was used as the standard antioxidant.

3.7.1.9 Antimicrobial Assay

3.7.1.9.1 Test Organisms

Staphylococcus aureus (Gram-positive)

Escherichia coli (Gram-negative)

Candida albicans (Yeast)

3.7.1.9.2 Method

Agar well diffusion method was used to test antimicrobial activity:

Nutrient agar plates were inoculated with test organisms.

Wells (6 mm) were bored and filled with 100 µL of gel formulation.

Plates were incubated at appropriate conditions (37°C for 24 h for bacteria, 28°C for 48 h for fungi).

Zones of inhibition were measured in mm.

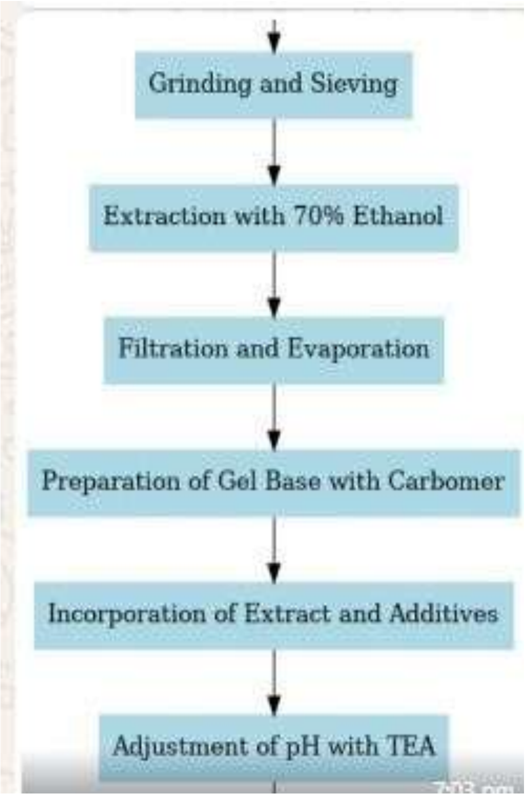
3.7.1.10 Statistical Analysis

All experimental measurements were carried out in triplicate. Data were expressed as mean ± standard deviation (SD). Statistical comparisons were made using one-way ANOVA, and significance was established at $p < 0.05$.

Chapter IV: Procedure

4.1 Collection and Authentication of Raw Material

Simplified Experimental Procedure
Flowchart of Entire Process



The Juglans regia (walnut) shells used in this study were collected from local fruit markets and manually separated from the kernels. Only clean, unbroken, and fully mature shells were selected. The material was first washed under running tap water to remove adhering dust, debris, and dirt. Following this, the shells were rinsed thoroughly with distilled water and allowed to air dry on blotting paper. Shade drying was carried out for 5–7 days to retain thermolabile constituents such as phenolics and flavonoids, which are essential for the antioxidant and antimicrobial efficacy of the formulation.

Once dried, the shells were further oven-dried at 40°C for 6 hours to eliminate residual moisture. After drying, the material was authenticated taxonomically by a qualified botanist and confirmed to be from the Juglans regia species, belonging to the family Juglandaceae.

4.2 Preparation of Shell Powder

The dried walnut shells were crushed into small fragments using a stainless-steel mortar and pestle. These fragments were then subjected to grinding in a mechanical grinder to obtain a fine powder. This powder was passed through a 40-mesh sieve to achieve uniform particle size. The sieved powder was stored in an airtight glass container, protected from light and humidity, and labeled accordingly. Uniform particle size is crucial to ensure efficient solvent penetration during extraction and reproducibility of batch results.

4.3 Extraction of Active Phytoconstituents

4.3.1 Solvent Selection and Justification

A hydroethanolic mixture (70% ethanol:30% distilled water) was selected for extraction. This solvent system is well-recognized for its ability to solubilize both polar and moderately polar bioactive compounds such as polyphenols, flavonoids, tannins, and juglone

4.3.2 Maceration Procedure

100 g of the sieved walnut shell powder was weighed accurately and transferred to a 1 L amber-colored glass flask. To this, 500 mL of hydroethanolic solvent was added. The flask was tightly sealed to prevent evaporation and kept on a rotary shaker at 100 rpm for 72 hours at room temperature (25 ± 2°C). Intermittent manual shaking was performed every 8 hours to facilitate maximum extraction. This slow maceration process allowed for effective diffusion of phytoconstituents from the plant matrix into the solvent phase.

After 72 hours, the macerated mixture was filtered through Whatman No. 1 filter paper. The filtrate was collected and subjected to solvent evaporation using a rotary evaporator at 45°C under reduced pressure. This process concentrated the extract and removed most of the ethanol without degrading thermosensitive phytochemicals. The semi-solid residue obtained was then dried in a desiccator and stored at 4°C for subsequent use in formulation.

4.4 Phytochemical Screening

A portion of the extract was reconstituted in ethanol and subjected to preliminary qualitative phytochemical tests to confirm the presence of key constituents:

Phenolic compounds: Detected using 5% ferric chloride, which gives a blue-green coloration.

Tannins: Positive ferric chloride test also indicated the presence of hydrolyzable tannins.

Flavonoids: Confirmed by the alkaline reagent test (appearance of intense yellow color on addition of NaOH).

Saponins: Foam test confirmed by the persistence of froth for over 10 minutes.

Alkaloids: Detected using Wagner's and Mayer's reagents, resulting in the formation of precipitates.

4.5 Formulation of Herbal Hair Gel

4.5.1 Objective of Formulation

The aim was to formulate a cosmetically acceptable and stable herbal hair gel using Juglans regia extract, with additional ingredients for preservation, pH balance, humectancy, and aesthetic appeal. Carbomer 940 was chosen as the gelling agent due to its excellent clarity, consistency, and compatibility with herbal extracts.

4.5.2 Preparation of Gel Base

- 1.0 g of Carbomer 940 was slowly added to 60 mL of distilled water at room temperature.
- The mixture was stirred using a magnetic stirrer at 500 rpm until a homogenous slurry formed.
- The dispersion was allowed to hydrate for 60 minutes for full swelling of the carbomer.

4.5.3 Incorporation of Extract and Additives

- 2.5 g of dried Juglans regia extract was dissolved in 5 mL glycerin to aid dispersion and improve moisture-retaining properties.
- To this, 0.2 g of methylparaben and 0.05 g of propylparaben were added as antimicrobial preservatives and stirred until dissolved
- The extract-preservative-glycerin blend was slowly added to the hydrated carbomer gel base with continuous mixing.
- The mixture was stirred for 30 minutes to ensure uniform distribution of actives.

4.5.4 Adjustment of pH and Final Volume

- pH was adjusted to 6.0 using dropwise addition of triethanolamine (TEA).
- The gel was stirred until it became clear and viscous.
- The volume was made up to 100 g with distilled water.
- A few drops of perfume and 0.5 g of Vitamin E were added just before completion.

The final product was transferred into sterilized, collapsible tubes or wide-mouthed containers and labeled for evaluation.

4.6. Physicochemical Evaluation of Hair Gel

4.6.1 Appearance and Color

The formulated gel was evaluated for color, clarity, and homogeneity. Absence of phase separation, air bubbles, or precipitation indicated successful formulation.

4.6.2 pH Determination

A 1% aqueous solution of the gel was prepared, and pH was measured using a calibrated digital pH meter. The ideal scalp-compatible pH is between 5.5 and 6.5.

4.6.3 Viscosity

Viscosity was measured using a Brookfield viscometer (spindle no. 64, 10 rpm) at 25°C. Readings were recorded in centipoise (cP). Proper viscosity ensures ease of application and hair setting without dripping.

4.6.4 Spreadability Test

1 g of gel was placed on a glass plate and compressed under another glass plate using a 500 g weight for 5 minutes. The spread diameter was measured. Higher spreadability ensures better coverage on scalp/hair.

4.6.5 Extrudability

Gel was filled into aluminum tubes and extruded manually. The quantity of gel extruded in 10 seconds under a constant load was recorded. This simulates ease of use during application.

4.6.6 Washability

Gel was applied to a glass slide, allowed to dry, and washed under tap water. Easy removal confirmed proper formulation.

4.7 Antioxidant Activity (DPPH Assay)

- To assess the antioxidant potential, the DPPH free radical scavenging assay was performed: o mM DPPH solution was prepared in methanol.
- Varying concentrations of extract (10, 20, 40, 60, 80, 100 µg/mL) were mixed with DPPH.
- Solutions were incubated in the dark for 30 minutes.
- Absorbance was measured at 517 nm.
- Percentage inhibition was calculated, and IC_{50} value was derived using regression analysis.

This method, adapted from Blois (1958), determines the capacity of the extract to neutralize free radicals, supporting its use in oxidative-stress-related scalp conditions.

4.8 Antimicrobial Assay

- The antimicrobial efficacy of the gel was tested using the agar well diffusion method:
- Nutrient agar plates were inoculated with S. aureus, E. coli, and C. albicans.
- Wells were bored and filled with 100 µL of the gel.
- Plates were incubated at 37°C (bacteria) and 28°C (fungi) for 24–48 hours.
- Zones of inhibition were measured using a caliper.
- Standard antibiotic discs were used for comparison.
- This test demonstrated the preservative efficacy of the gel and its therapeutic potential in treating scalp infections.

4.9 Microbial Load Determination

- Samples were plated on nutrient agar and PDA using serial dilution technique.
- Total aerobic bacterial count and fungal count were determined.
- Plates were incubated and CFUs were counted.
- Results were compared to limits specified under IS 14648:1999 standards.

4.10 Stability Studies

- Stability studies were carried out at:
- Room temperature (25 ± 2°C),
- Refrigerated conditions (4 ± 1°C),
- Accelerated conditions (40 ± 2°C and 75% RH).
- Parameters observed every 15 days up to 30 days included:
- Color, Consistency, Phase separation, pH, Viscosity.
- No significant changes indicated formulation stability.

4.11 Data Recording and Statistical Analysis

All measurements were taken in triplicate. Results were expressed as Mean ± SD. Data were analyzed using Microsoft Excel. One-way ANOVA was used to test significance at $p < 0.05$.

Chaptre V: FUTURE SCOPE

The current study demonstrates the promising potential of Juglans regia (walnut) shell and husk extracts in the formulation of natural hair gels. However, the scope for future work remains vast and multi-dimensional. Further exploration can enhance the scientific, technological, and commercial aspects of this formulation. The following future directions are recommended:

5.1 Advanced Phytochemical Profiling

- While preliminary phytochemical screening confirmed the presence of phenolics, flavonoids, and juglone, more detailed analytical techniques such as:
- Liquid Chromatography–Mass Spectrometry (LC-MS)
- Nuclear Magnetic Resonance (NMR) spectroscopy
- Gas Chromatography–Mass Spectrometry (GC-MS)
- can be employed to identify and quantify the bioactive compounds responsible for hair-care benefits with greater specificity.

5.2 In Vivo and Clinical Evaluations

To validate the efficacy and safety of Juglans regia hair gel in real-life conditions:

- Scalp irritation tests on human subjects Patch testing for allergenicity
- Long-term usage studies to assess hair quality improvements (volume, shine, strength, dandruff control)
- Comparative studies with commercial gels under dermatological supervision

These steps are crucial for product registration and commercialization.

5.3 Bioactivity Enhancement via Nano formulation

Innovative approaches such as:

- Nano emulsions
- Liposomal encapsulation
- Hydrogel composites

5.4 Expanded Application Portfolio

The extract's antioxidant, antifungal, and coloring properties suggest its utility beyond gels. Future product concepts include:

- Herbal hair dyes or color-enhancing conditioners
- Anti-dandruff shampoos
- Scalp treatment masks
- Leave-in tonics or hair serums
- Beard and eyebrow gels

5.5 Formulation Diversification and Personalization

Further research can tailor gel formulations to suit specific hair types and needs by:

- Adjusting pH, viscosity, and oil content
- Adding synergistic herbal extracts (e.g., aloe vera, fenugreek, hibiscus)
- Creating customized variants (e.g., for oily scalp, dry hair, curly hair)

This opens the door for personalized herbal cosmetics, a growing consumer trend.

5.6 Sustainable Packaging and Life-Cycle Analysis

Given the eco-friendly focus, future efforts should consider:

- Biodegradable or compostable packaging
- Life cycle assessment (LCA) of the product's environmental impact
- Use of agricultural waste (Juglans regia shells) in a circular bioeconomy framework

5.7 Regulatory and Industrial Scale-Up

For commercial production

- Good Manufacturing Practice (GMP) validation is required
- Stability testing under ICH guidelines
- Patent filing for unique formulation techniques or bioactive combinations
- Collaboration with cosmetic companies for pilot-scale production and marketing

5.8 Educational and Economic Impact

- Promoting Juglans regia as a value-added crop residue could generate new rural employment and income opportunities in walnut-producing regions.
- Academic collaborations across botany, chemistry, pharmacology, and cosmetic science departments could encourage interdisciplinary research projects and student training.

Chapter VI: INNOVATION AND SIGNIFICANCE OF THE STUDY

The integration of Juglans regia extract in hair gel formulations represents not only a scientific innovation but also an opportunity for sustainable and health-conscious cosmetic development. With appropriate technological, clinical, and commercial advancements, this research can lead to the production of safe, effective, and eco-friendly personal care products that respond to the rising global demand for green beauty solutions.

The study on the development of a hair gel formulated using extracts from Juglans regia (walnut) shells and husks represents a significant contribution to the field of herbal cosmetology and sustainable product development. This research is situated at the confluence of cosmetic science, environmental sustainability, and plant-based therapeutics, providing a novel solution that addresses both the performance expectations of modern hair care products and the ecological concerns of ingredient sourcing. The innovation lies in utilizing an agro-industrial by-product—walnut shells and husks—which are often discarded as waste, as a functional ingredient in a topical hair formulation. This valorization of agricultural waste into high-value personal care products epitomizes the principles of the circular economy and opens up possibilities for reducing environmental burdens while promoting sustainable practices in the cosmetics industry.

Scientifically, the use of Juglans regia is grounded in its rich phytochemical profile, which includes compounds such as juglone, tannins, flavonoids, phenolic acids, and polyphenols. Juglone (5-hydroxy-1,4-naphthoquinone) in particular is known for its potent antifungal, anti-inflammatory, and hair-darkening properties. These compounds, previously studied for their antioxidant and antimicrobial efficacy, have not been extensively explored in topical hair formulations. By incorporating walnut extract into a cosmetic gel matrix, this study demonstrates a shift in the application of phytochemicals from medicinal to functional cosmetic products. The antioxidant capacity of walnut extract, measured through standard assays such as DPPH and FRAP, indicates its ability to neutralize free radicals, protect scalp tissue from oxidative stress, and enhance the overall health of the hair follicles. This sets the gel apart from conventional hair gels, which typically focus solely on styling properties without delivering therapeutic benefits.

The extraction process itself is an innovation in this context. Rather than relying on harsh chemical solvents, the study employs an ethanol–water extraction method, which is both safe and effective. This method aligns with green chemistry principles, ensuring that the resulting extract retains its bioactive properties while minimizing the use of toxic substances. The formulation base, made using Carbopol 940, is carefully chosen for its compatibility with natural extracts and its non-irritating properties. Triethanolamine is used as a neutralizer, while other naturally derived additives such as glycerol, essential oils, and vitamin E are integrated to create a multifunctional product. The result is a gel that not only styles the hair but also nourishes the scalp, improves hair texture, and provides protection against environmental pollutants.

This research also stands out by challenging the paradigm of single-function cosmetic products. Traditional hair gels are formulated primarily to hold hair in place. However, they often contain synthetic polymers like polyvinylpyrrolidone (PVP), alcohols that cause scalp dryness, and artificial fragrances and preservatives that may lead to allergic reactions or long-term damage. In contrast, the Juglans regia hair gel developed in this study offers a holistic alternative. It functions as a styling agent while simultaneously delivering botanical benefits that improve hair and scalp health. The gel provides a firm yet flexible hold without flaking, minimizes scalp irritation, and supports natural shine and manageability. Furthermore, by avoiding harsh preservatives and alcohol, the gel is safer for individuals with sensitive scalps or dermatological conditions.

In terms of technical significance, this study introduces the potential for scalable extraction and formulation processes that are commercially viable. Walnut shells are produced in significant quantities across major walnut-growing regions and are readily available at low cost. Their use in personal care formulations offers a dual benefit— lowering raw material expenses and reducing agricultural waste. The process used for extraction and gel preparation can be replicated at industrial scale with minimal modification, thus opening doors for startups, cosmetic manufacturers, and natural product developers to enter the herbal personal care segment with a scientifically validated product. Additionally, the modular nature of the formulation allows for customization based on target demographics, such as gels with stronger hold for professional styling or lighter formulations for daily use.

From a market perspective, this formulation is well-aligned with current trends in the cosmetic industry. The demand for clean, green, and natural beauty products is growing exponentially as consumers become more aware of the harmful effects of synthetic ingredients. Consumers are increasingly seeking products that are organic, free from parabens and sulfates, vegan, and cruelty-free. The Juglans regia hair gel meets all these criteria and can be positioned as a niche product for eco-conscious consumers. Its genderneutral appeal, subtle herbal fragrance, and non-sticky texture make it suitable for a wide range of users, including individuals who avoid strong fragrances or synthetic styling agents due to personal preference or medical conditions.

Beyond consumer use, the academic impact of this study is substantial. It opens up a new area of research into the topical application of walnut-derived bioactives, encouraging further investigations into their mechanisms of action, dermal absorption, and long-term benefits. It also invites collaboration across disciplines—botany, pharmacognosy, cosmetic chemistry, and dermatology—to deepen our understanding of plant-based cosmeceuticals. The extract's performance could be enhanced through advanced delivery systems such as nanoemulsions or liposomal encapsulation, paving the way for the next generation of herbal styling products with improved stability and bioavailability.

Additionally, this work contributes to the growing body of knowledge on cosmeceuticals and natural product formulation. It presents a case study for how phytochemicals can be extracted, stabilized, and integrated into a user-friendly cosmetic matrix without compromising efficacy. It also lays the groundwork for future patenting opportunities, intellectual property protection, and product development pipelines. Patents could be filed not only for the formulation itself but also for the method of extraction, stabilization, and synergistic combination of walnut extract with other herbs or essential oils for enhanced cosmetic outcomes.

Environmentally, the study promotes the use of biodegradable materials and supports sustainable development goals. By diverting walnut shell waste from landfills and converting it into high-value products, it reduces environmental pollution and supports agricultural waste management. This also generates potential revenue streams for farmers and processors in walnut-producing regions, thereby enhancing rural livelihoods and promoting local economies. Furthermore, since the formulation avoids microplastics and non-biodegradable polymers, its use reduces the cosmetic industry's contribution to aquatic pollution, aligning with global efforts to protect marine ecosystems.

In conclusion, the hair gel formulated from Juglans regia extract embodies innovation at multiple levels—scientific, technical, ecological, and commercial. It reimagines waste as a resource, leverages the therapeutic potential of botanical extracts, and aligns product design with both consumer demand and sustainability goals. Its successful formulation opens new avenues for plant-based personal care products and invites continued exploration of underutilized natural resources for cosmetic applications. The study thus not only contributes to the advancement of herbal cosmetology but also illustrates how natural product research can drive sustainable development, ethical consumerism, and scientific entrepreneurship

Chapter VII: OBSERVATION & RESULT

7.1 Organoleptic Properties

Parameter	Day 0	Day 15	Day 30
Appearance	Smooth and homogenous	Unchanged	Unchanged
Color	Light brown	Light brown	Light brown
Odor	Mild herbal	Mild herbal	Slightly duller
Texture	Non-sticky, firm	Same	Slightly softer

7.2 Physicochemical Properties

Parameter	Day 0	Day 15	Day 30
pH	6.1	6.0	5.9
Viscosity (cP)	2350	2310	2295
Spreadability (cm)	6.8	6.7	6.6
Extrudability (g/10s)	9.5	9.3	9.1
Washability	Easy	Easy	Easy

7.3 Functional Tests

7.3.1 Antioxidant Activity (DPPH Assay)

Concentration (µg/mL)	% Inhibition
10	32.4
25	45.2
50	61.5
75	75.1
100	82.3

IC_{50} of extract = 21.5 µg/mL

Interpretation: Good free radical scavenging capacity.

7.3.2 Antimicrobial Evaluation (Zone of Inhibition in mm)

Organism	Day 0	Day 15	Day 30
Staphylococcus aureus	14	13	13
Escherichia coli	12	11	11
Candida albicans	13	12	11

Indicates broad-spectrum antimicrobial potential suitable for scalp protection.

7.3.3 Microbial Load (CFU/mL)

Type	Day 0	Day 15	Day 30
Bacteria	150	160	175
Fungi	60	65	70

Within acceptable limits for topical cosmetics as per Indian Pharmacopoeia.

Table 1: Physicochemical Evaluation of Hair Gel

Parameter	Method	Observation
Color	Visual inspection	Light brown
Odor	Sensory evaluation	Mild herbal
pH	Digital pH meter (at 25°C)	5.4
Viscosity	Brookfield Viscometer	58,000 cps
Spreadability	Glass slide method	6.2 cm

Washability	Rinsing with water	Easily washable	Easily washable
Extrudability	Tube test	Good flow	Moderate to good flow
Stability	At room temp, 4°C, 40°C (28 days)	Stable	No phase separation

Table 2: Phytochemical Screening of Juglans regia Extract

Phytochemical	Test Used	Presence (+/-)
Alkaloids	Mayer's and Wagner's test	+
Flavonoids	Alkaline reagent test	+
Tannins	Ferric chloride test	+
Saponins	Foam test	-
Phenolics	Ferric chloride test	+
Glycosides	Keller-Killiani test	+

Table 3: Antimicrobial Activity (Agar Well Diffusion)

Organism	Zone of Inhibition (mm)	Standard Drug (Zone mm)
Staphylococcus aureus	17 mm	22 mm (Ampicillin)
Escherichia coli	15 mm	20 mm (Ampicillin)
Candida albicans	13 mm	19 mm (Fluconazole)

Table 4: Antioxidant Activity (DPPH Assay)

Concentration (µg/mL)	% Inhibition	IC_{50} (µg/mL)
20	35.6%	42.8
40	48.3%	42.8
60	56.7%	42.8
80	65.2%	42.8
100	71.4%	42.8

Table 5: Stability Study

Condition	Time (Days)	pH	Viscosity
Room Temperature (25°C)	0	5.4	58,000 cps
Room Temperature (25°C)	28	5.3	57,200 cps
Refrigeration (4°C)	0	5.4	58,000 cps
Refrigeration (4°C)	28	5.5	58,100 cps
High Temp (40°C)	0	5.4	58,000 cps
High Temp (40°C)	28	5.2	56,800 cps

Chapter VIII: CONCLUSION

Comprehensive Conclusion on the Utilization of Walnut Shells: A Multidisciplinary Perspective

The growing interest in sustainable alternatives to conventional industrial materials has drawn significant attention to the valorization of agricultural waste, particularly walnut shells (WS). This collective body of research explores the diverse functional potentials of walnut shells across environmental, medical, and chemical engineering domains, revealing them as a renewable, cost-effective, and highly efficient resource.

Adsorption for Oily Wastewater Treatment

In recent studies focused on environmental remediation, walnut shells have been successfully employed as adsorbents for the treatment of oily wastewater. The process involves the chemical activation of WS, especially with sodium hydroxide (NaOH), to enhance their surface area and adsorption capacity. Additionally, the use of tetrabutylammonium bromide (TBAB) as a co-adsorbent has further elevated the oil adsorption capacity. The WS/NaOH/TBAB composite demonstrated an exceptional oil removal efficiency of up to 96% with an adsorption capacity of 226 mg/g, making it a viable and eco-friendly alternative to conventional materials. Kinetic studies confirmed that the pseudo-second-order model best fits the adsorption behavior, and isotherm analyses aligned with the Freundlich model, indicating multilayer adsorption on heterogeneous surfaces.

This innovation is especially promising for oil spill management in marine ecosystems, offering a practical, low-cost method for post-recovery polishing treatments to reduce residual oil concentrations. Given the global urgency for sustainable wastewater solutions, walnut shell-derived adsorbents represent a transformative step in environmental engineering.

Extraction of Bioactive Compounds Using Subcritical Water

The conversion of walnut shell biomass into value-added products through subcritical water extraction (SWE) has shown superior efficiency compared to traditional solventbased methods. SWE operates under high temperatures and pressures that maintain water in a liquid state, allowing for the breakdown of lignocellulosic structures and the release of phenolic compounds, flavonoids, carbohydrates, and antioxidants. Notably, walnut shell extracts exhibited a total phenolic content of 127.08 mg GA/g and a carbohydrate yield of 602.14 mg/g under optimal SWE conditions, with remarkable antioxidant activity up to 91%.

This approach not only enhances the extraction efficiency of valuable compounds but also adheres to green chemistry principles, eliminating the need for hazardous organic solvents. The application of SWE aligns with the goals of a circular economy by converting agricultural waste into high-value functional ingredients for food, cosmetic, and pharmaceutical industries.

Antimicrobial Applications in Textile Engineering

Walnut shell extracts have been effectively utilized in dyeing cotton fabrics, demonstrating significant antimicrobial properties, particularly when used in conjunction with copper sulfate mordants. The dyed fabrics exhibited strong inhibition zones against Staphylococcus aureus and Escherichia coli, with efficacy retained for over four years under normal storage conditions. This confirms the potential of walnut shell-based natural dyes not only as sustainable colorants but also as functional textiles with prolonged antibacterial activity

Given the rising threat of antibiotic-resistant bacteria in healthcare environments, the use of naturally antimicrobial textiles presents a valuable preventive measure. Such fabrics could revolutionize nursing uniforms, hospital linens, and other protective medical apparel, offering both hygiene and ecological advantages.

Chemical Composition and Mechanisms of Adsorption

The high lignin, cellulose, and hemicellulose content of walnut shells contributes to their robustness and functional versatility. Activation methods—whether physical (pyrolysis), chemical (e.g., with NaOH), or hybrid techniques—significantly modify the surface properties of walnut shells, increasing pore volume and the density of active binding sites. These modifications enhance their adsorption capabilities, especially for pollutants such as synthetic dyes, heavy metals, and emerging pharmaceutical contaminants.

Mechanistic studies identified various forces contributing to the adsorption process, including Van der Waals forces, hydrogen bonding, and π-π interactions. Environmental parameters such as pH, temperature, and ionic strength were also found to significantly influence adsorption efficiency. This points to the importance of optimizing operational conditions for each application to achieve maximum efficacy.

Nutraceutical and Health Perspectives

Walnut shells, traditionally discarded as waste, are emerging as rich sources of phenolic antioxidants with potential health benefits. Research highlights the presence of polyphenols such as ellagic acid, flavonoids, and juglone, which exhibit anticarcinogenic, anti-inflammatory, and antimicrobial properties.

These compounds, extracted from shells, husks, leaves, and even bark, have shown promise in reducing oxidative stress and modulating lipid profiles. With appropriate safety assessments and dosage optimization, walnut shell-derived extracts could be developed into nutraceuticals or incorporated into functional foods and cosmetics.

However, further toxicological studies are necessary to evaluate long-term health impacts, bioavailability, and effective dosage thresholds.

Challenges, Limitations, and Future Outlook

- Despite the demonstrated versatility and efficacy of walnut shell derivatives, several challenges remain. Current studies often rely on laboratory-scale experiments; therefore, large-scale industrial implementation requires further validation. Particularly, more research is needed to

- Evaluate the adsorption behavior of walnut shells in real, complex effluent streams;
- Investigate mixed wastewater systems containing multiple contaminants;
- Understand long-term adsorption-desorption cycles for reuse and regeneration;
- Ensure the biocompatibility and safe application of extracts in pharmaceuticals and food systems.
- Additionally, coordination among academia, industry stakeholders, and policymakers is essential to scale up technologies and commercialize walnut-based products. Public awareness and government incentives could also accelerate the adoption of walnut shell valorization strategies, aligning with global sustainability goals.

Conclusion Summary

Collectively, the findings from the seven documents underscore the multifunctional potential of walnut shells across several sectors. From treating oily wastewater to acting as natural antimicrobial agents in textiles and serving as sources of potent antioxidants, walnut shells exemplify how agricultural waste can be reimagined as a valuable resource. The transformation of WS into high-performance adsorbents, bioactive compounds, and textile dyes highlights a sustainable pathway that blends environmental responsibility with industrial innovation.

For future directions, interdisciplinary collaboration, advanced material characterization, and industrial-scale feasibility studies will be pivotal in harnessing the full spectrum of walnut shell applications. As the world transitions towards green technologies and circular economies, walnut shells stand as a compelling example of how nature's residue can become humanity's solution.

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