Design And Evaluation of Biodegradable Polyherbal Shampoo Granule Pods for Hair Care Applications

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***Abstract*—Conventional liquid shampoos commonly contain synthetic surfactants, preservatives, and plastic packaging that may cause scalp irritation and contribute to environmental pollution. Growing consumer awareness has increased the demand for herbal and biodegradable alternatives that are effective, mild, and sustainable.**

The present study aimed to formulate and evaluate polyherbal shampoo granules incorporated into biodegradable pods as an eco-friendly and plastic-free hair cleansing system.

Polyherbal shampoo granules were prepared using powdered herbal ingredients including *Acacia concinna* (Shikakai), *Sapindus* spp. (Reetha), *Phyllanthus emblica* (Amla), *Hibiscus rosa-sinensis*, *Trigonella foenum-graecum* (Fenugreek), *Murraya koenigii* (Curry leaves), *Bacopa monnieri* (Brahmi), and *Beta vulgaris* (Beetroot). Wet granulation was performed using gum acacia as a natural binder. Biodegradable pods were prepared using agar-agar as a film-forming agent and glycerol as a plasticizer. The formulated granules and pods were evaluated for phytochemical constituents, physicochemical properties, foaming ability, wetting time, cleansing efficiency, and stability under different storage conditions.

Phytochemical screening confirmed the presence of saponins, flavonoids, tannins, terpenoids, anthocyanins, and betacyanins. The shampoo granules exhibited good flow properties with a Carr's index of 9.98% and Hausner's ratio of 1.11. The formulation showed a scalp-friendly pH of 6.2 and low moisture content (0.66%). Performance evaluation demonstrated satisfactory foaming ability (foaming index: 100 mL), moderate foam stability (60% retention after 5 minutes), rapid wetting time (1.4 s), and approximately 80% cleansing efficiency. The pods remained physically stable under tested storage conditions.

The developed biodegradable herbal shampoo granule pods represent a promising, mild, and environmentally sustainable alternative to conventional liquid shampoos, combining effective cleansing with eco-friendly packaging.

***Keywords*—Polyherbal shampoo, Biodegradable pods, Herbal shampoo granules, Eco-friendly cosmetics, Sustainable packaging.**

I. INTRODUCTION

Shampoos are among the most widely used cosmetic products and play a vital role in maintaining scalp hygiene, hair cleanliness, and overall hair health. In addition to cleansing, modern shampoos are expected to provide conditioning, nourishment, and protection against environmental damage[1]. The global demand for hair care products continues to grow due to changing lifestyles, increased awareness of personal grooming, and the availability of specialized formulations targeting various hair and scalp conditions[2].

Despite their effectiveness, most commercially available shampoos are formulated using synthetic surfactants such as sodium lauryl sulfate (SLS) and sodium laureth sulfate (SLES), along with preservatives, fragrances, and silicones[3]. Although these ingredients offer excellent cleansing and foaming properties, prolonged use has been associated with adverse effects such as scalp irritation, dryness, hair breakage, and sensitivity reactions[4]. In addition, residues from synthetic surfactants contribute to aquatic toxicity and environmental pollution after disposal[5], [6].

A. Limitations of Conventional Shampoos

Conventional liquid shampoos suffer from several limitations. Synthetic surfactants tend to remove natural sebum from the scalp, leading to dryness and irritation. Preservatives and additives used to maintain product stability may cause allergic reactions in sensitive individuals[7], [8]. Furthermore, most shampoos are packaged in plastic bottles, which significantly contribute to non-biodegradable waste

and environmental burden[9]. These concerns have encouraged both consumers and researchers to explore safer, greener, and more sustainable alternatives.

B. Herbal Shampoos as a Natural Alternative

Herbal shampoos have gained considerable attention as a natural and milder alternative to synthetic formulations. Traditional systems of medicine have long utilized plant-based powders for hair cleansing and nourishment. Herbs such as *Acacia concinna* (Shikakai) and *Sapindus* spp. (Reetha) are rich in saponins, which act as natural surfactants capable of removing dirt and excess oil without damaging the scalp. *Phyllanthus emblica* (Amla), *Hibiscus rosa-sinensis*, *Trigonella foenum-graecum* (Fenugreek), *Bacopa monnieri* (Brahmi), and *Murraya koenigii* (Curry leaves) are traditionally known for their antioxidant, conditioning, and hair-strengthening properties.[10], [11], [12], [13]

Polyherbal formulations combine the benefits of multiple herbs to achieve synergistic effects, enhancing cleansing efficiency while maintaining scalp compatibility. However, many herbal shampoos are still marketed as liquid formulations, which require preservatives and plastic packaging, thereby reducing their environmental advantages.

C. Need for Solid and Sustainable Shampoo Systems

In recent years, solid and semi-solid shampoo systems such as powders, bars, and granules have emerged as promising alternatives to liquid shampoos[14], [15]. Solid formulations offer advantages such as reduced need for preservatives, improved stability, ease of transportation, and lower environmental impact[16]. Among these, shampoo granules provide controlled dosing, rapid wetting, and easy dispersion in water.

In parallel, there is a growing need to replace conventional plastic packaging with biodegradable materials. Biodegradable pods prepared from natural polymers offer an innovative solution by serving both as a delivery system and as eco-friendly packaging. Such pods dissolve or disintegrate during use, eliminating plastic waste and supporting sustainable cosmetic practices[17].

D. Introduction to Shampoo Granules

Shampoo granules represent an emerging solid dosage form in cosmetic science designed to overcome the limitations associated with conventional liquid shampoos[18]. Unlike liquid formulations, shampoo granules consist of free-flowing, solid particulate systems that rapidly disperse in water during use to generate cleansing and foaming action[19]. These systems combine the advantages of solid formulations, such as improved stability and reduced preservative requirements, with the ease of application typically associated with liquid shampoos.

Granular shampoo formulations offer several formulation and consumer benefits. The solid nature of granules minimizes microbial growth, thereby reducing the need for synthetic preservatives[19]. In addition, granules allow accurate dosing, improved shelf stability, ease of transportation, and reduced packaging volume. When prepared using herbal ingredients, shampoo granules further enhance product safety by eliminating harsh surfactants and chemical additives[20].

E. Ideal Properties of Shampoo Granules

An ideal shampoo granule formulation should possess the following properties to ensure effective performance and user acceptability:

- Good flowability to allow uniform dosing and easy handling
- Rapid wetting and dispersion in water
- Adequate foaming and foam stability
- Mild cleansing action without scalp irritation
- pH compatible with scalp and hair (approximately 5–7)
- Low moisture content to ensure stability during storage
- Non-sticky, non-dusty nature
- Absence of residue after rinsing
- Compatibility with biodegradable packaging systems

These properties ensure that shampoo granules perform comparably to liquid shampoos while offering

added advantages in terms of stability and sustainability.

F. Mechanism of Action of Shampoo Granules

The cleansing action of shampoo granules is primarily governed by the presence of surfactant molecules, which in herbal formulations are mainly derived from saponin-rich plant materials such as *Sapindus* spp. (Reetha) and *Acacia concinna* (Shikakai)[10], [11]. When shampoo granules come into contact with water, they rapidly hydrate and disintegrate, releasing the active phytoconstituents.

Saponins reduce the surface tension of water and form micelles that entrap oily sebum, dirt, and particulate matter present on the scalp and hair shaft. These micelles are subsequently removed during rinsing[21]. Along with cleansing, herbal constituents such as flavonoids, tannins, and antioxidants from Amla, Hibiscus, Fenugreek, and Brahmi provide conditioning, strengthening, and protective effects to the hair and scalp[12], [22].

The granular form ensures controlled release of these components, uniform dispersion in water, and efficient interaction with the hair surface, resulting in effective cleansing without excessive stripping of natural oils.

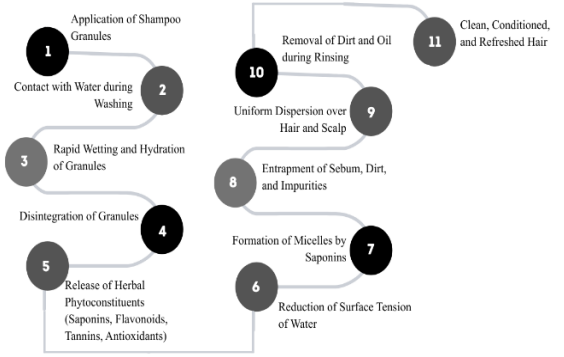

Fig. 1. Schematic Representation of Mechanism of Action of Shampoo Granules

G. Advantages of Shampoo Granules over Conventional Liquid Shampoos

Shampoo granules offer several advantages compared to conventional liquid shampoos:

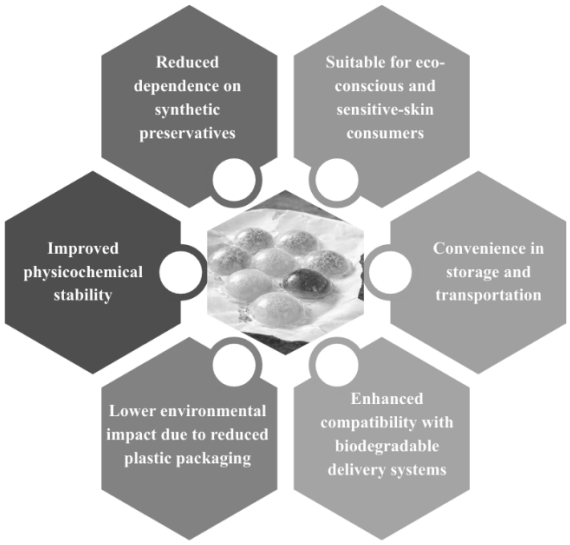

Fig. 2. Advantages of Shampoo Granules

These advantages make shampoo granules a promising alternative dosage form in the development of sustainable cosmetic products.

H. Introduction to Biodegradable Shampoo Pods

Biodegradable shampoo pods represent an innovative approach to address the environmental concerns associated with conventional shampoo packaging. Traditional liquid shampoos are predominantly packed in plastic bottles, which contribute significantly to non-biodegradable waste and environmental pollution[9]. In contrast, biodegradable pods are designed to act as both a delivery system and a packaging alternative, thereby minimizing plastic usage.

These pods are typically prepared using natural, biodegradable polymers that are safe for topical application and capable of dissolving or disintegrating during use. When combined with solid or granular shampoo formulations, biodegradable pods provide controlled dosing, improved product hygiene, and enhanced user convenience. Additionally, pod-based systems reduce the risk of spillage, overdosing, and contamination during storage and handling.

The integration of shampoo granules with biodegradable pods offers a dual advantage: effective herbal hair cleansing and environmentally sustainable packaging. Such systems align with the growing demand for eco-friendly cosmetic products and

support the principles of sustainable development in personal care formulations.

II. RESEARCH GAP

Herbal shampoos have been extensively studied as natural alternatives to synthetic hair cleansing products due to their mild action, reduced scalp irritation, and traditional acceptance[16]. Most reported herbal shampoo formulations, however, are developed in liquid form and are commonly packaged in plastic containers, which diminishes their environmental benefits. In addition, liquid formulations often require preservatives and stabilizers to maintain product stability, which may compromise the overall "natural" profile of the product[20].

Solid shampoo systems such as powders[20] and bars[14] have recently gained attention; however, limited scientific literature is available on the development of shampoo granules as a distinct and convenient solid dosage form. Shampoo granules offer advantages such as improved flowability, controlled dosing, rapid wetting, and ease of handling, yet their potential in herbal hair care formulations remains underexplored.

Furthermore, while biodegradable packaging materials have been proposed as sustainable alternatives to plastic[17], their integration with herbal shampoo formulations particularly in the form of biodegradable pods acting as both carrier and packaging has received minimal attention in formulation-based studies. The combined development of polyherbal shampoo granules with biodegradable pod-based delivery systems represents a novel and environmentally responsible approach that is not sufficiently addressed in existing literature.

III. OBJECTIVES OF THE STUDY

The present study was undertaken with the following objectives:

1. To formulate polyherbal shampoo granules using selected traditional herbal ingredients with cleansing and conditioning properties.
2. To develop biodegradable shampoo pods using natural polymeric materials as an eco-friendly packaging and delivery system.
3. To evaluate the formulated shampoo granules for physicochemical properties such as flow characteristics, moisture content, and pH.
4. To assess the performance characteristics of the formulation, including foaming ability, wetting time, cleansing efficiency, and foam stability.
5. To study the stability of the developed shampoo granule pods under different storage conditions.

IV. MATERIALS AND METHODS

A. Materials

All herbal ingredients used in the formulation were procured from reliable local sources and were of good quality. The plant materials were authenticated based on their botanical characteristics before use. The excipients and chemicals used in the study were of analytical grade.

Herbal Ingredients

Table I. List Herbal Ingredients used in the formulation

Sr. No.	Herb	Botanical Name	Family	Role in Formulation
1	Shikakai	*Acacia concinna*	Fabaceae	Natural cleanser, shine
2	Reetha	*Sapindus* spp.	Sapindaceae	Natural surfactant
3	Amla	*Phyllanthus emblica*	Phyllanthaceae	Antioxidant, nourishment
4	Hibiscus	*Hibiscus rosa-sinensis*	Malvaceae	Conditioner, hair growth
5	Fenugreek	*Trigonella foenum-graecum*	Fabaceae	Anti-dandruff, reduces hair fall
6	Curry leaves	*Murraya koenigii*	Rutaceae	Prevents greying
7	Brahmi	*Bacopa monnieri*	Plantaginaceae	Strengthens hair roots
8	Beetroot	*Beta vulgaris*	Amaranthaceae	Antioxidant, natural color

Excipients

- Gum acacia – Natural binder for granule formation

- Agar-agar – Biodegradable film-forming polymer for pod preparation
- Glycerol – Plasticizer to impart flexibility to pod films
- Distilled water – Solvent

B. Preformulation Studies

Preformulation studies were carried out to assess the suitability of the selected herbal ingredients and excipients for the development of shampoo granules. These studies provided preliminary information regarding the physical characteristics, compatibility, and behaviour of the materials prior to formulation.

Organoleptic Evaluation

All herbal powders were evaluated for organoleptic properties such as colour, odour, texture, and appearance. The powders exhibited characteristic colour and odour specific to their botanical origin and were free from visible impurities, indicating acceptable quality for formulation use.

Particle Size and Flow Characteristics

The powdered herbal ingredients were passed through sieve no. 60 to obtain uniform particle size. Visual observation indicated that the powders were free-flowing but exhibited poor flowability when used alone, which justified the need for granulation to improve handling and flow properties.

Solubility and Dispersibility Behaviour

The solubility and dispersibility of the herbal powders were assessed qualitatively by dispersing them in distilled water. The powders showed partial solubility and good dispersibility upon agitation, indicating their suitability for shampoo formulations that require rapid wetting and dispersion during use.

pH Compatibility

Aqueous dispersions of the herbal powder blend were prepared, and the pH was measured using a digital pH meter. The pH was found to be within the mildly acidic to neutral range, indicating compatibility with scalp and hair and suitability for topical application[23].

Compatibility Considerations

Based on the physicochemical nature of the selected herbal ingredients and excipients, along with literature evidence, no incompatibility was anticipated between the herbal powders and the excipients used in the formulation. Gum acacia was selected as a natural binder due to its good compatibility with herbal materials, while agar-agar and glycerol were selected for biodegradable pod preparation owing to their safety and biodegradability.

C. Formulation of Polyherbal Shampoo Granules

All herbal powders were dried, pulverized, and passed through sieve no. 60 to ensure uniform particle size. The accurately weighed herbal powders were blended thoroughly using the geometric dilution method. A binder solution of gum acacia (5% w/v) was prepared using distilled water and added slowly to the powder mixture with continuous trituration to obtain a cohesive wet mass.

The wet mass was passed through sieve no. 16 to form wet granules. These granules were dried in a hot air oven at 50 °C until a constant weight was achieved. The dried granules were then passed through sieve no. 22 to obtain uniform-sized granules and stored in airtight containers for further evaluation.

Composition of Herbal Shampoo Granules

Table II. Formulation of Polyherbal Shampoo Granules (Batch Size: 100 g)

Ingredient	Quantity (g)	Role
Shikakai powder	20	Cleansing
Reetha powder	20	Foaming agent
Amla powder	15	Antioxidant
Hibiscus powder	10	Conditioning
Fenugreek powder	10	Anti-dandruff
Curry leaves powder	5	Prevents greying
Brahmi powder	10	Hair strengthening

Beetroot powder	5	Colouring agent
Gum acacia	5	Binder

D. Preparation of Biodegradable Shampoo Pods

Biodegradable pods were prepared using agar-agar as the film-forming agent. Agar-agar (2–3% w/v) was dissolved in boiling distilled water with continuous stirring. Glycerol (0.5–1% v/v) was added as a plasticizer to impart flexibility to the film.

The hot solution was poured into pre-sterilized silicone molds and allowed to dry at room temperature for 24–48 hours to form thin films. Once dried, shampoo granules were placed between two films, and the edges were sealed using gentle heat to form pods. The prepared pods were stored in desiccators until further evaluation.

Composition of Biodegradable Pods

Table III. Formulation of Biodegradable Shampoo Pods (Film Casting Solution Basis: 100 mL)

Material	Quantity	Role
Agar-agar	2–3g	Film-forming agent
Glycerol	0.5–1g	Plasticizer
Distilled water	q.s. to 100 mL	Solvent

E. Evaluation of Polyherbal Shampoo Granules

The prepared polyherbal shampoo granules were evaluated on the following parameters:

- Bulk Density
- Tapped Density
- Carr's Index
- Hausner's Ratio
- Moisture Content
- pH Determination[24]

F. Performance Evaluation

The shampoo was evaluated for its performance based on the following parameters:

- Foaming Index and Foam Stability
- Wetting Time
- Dirt Dispersion Test
- Cleansing Ability[23]

G. Stability Studies

Stability studies were carried out by storing the shampoo granule pods at different temperatures (5 °C, 25 °C, and 40 °C). The samples were periodically evaluated for physical appearance, moisture content, pH, and foaming ability.

V. RESULTS AND DISCUSSION

A. Phytochemical Evaluation

Preliminary phytochemical screening of the polyherbal shampoo granules confirmed the presence of major bioactive constituents such as saponins, flavonoids, tannins, terpenoids, anthocyanins, and betacyanins. The presence of saponins from *Sapindus* spp. (Reetha) and *Acacia concinna* (Shikakai) supports the natural surfactant activity of the formulation, which is essential for effective cleansing. Flavonoids and tannins contribute antioxidant and protective effects on the scalp, while anthocyanins and betacyanins derived from Hibiscus and Beetroot impart antioxidant activity and aesthetic appeal. These results justify the selection of the herbal ingredients for shampoo formulation.

Table no. IV Results of Phytochemical Evaluation

Sr. no.	Phytochemical Tested	Result
1	Terpenoids	Present
2	Flavonoids	Present
3	Tannins	Present
4	Saponin	Present
5	Anthocyanins	Present
6	Betacyanine	Present

B. Physicochemical Properties of Shampoo Granules

Bulk Density and Tapped Density

The bulk density and tapped density of the shampoo granules were found to be 0.482 g/cm³ and 0.536 g/cm³, respectively. These values indicate efficient packing behaviour and uniform particle size

distribution. Adequate density characteristics are important for ensuring ease of handling, storage, and dosing of granules.

Flow Properties

Flow properties of the shampoo granules were evaluated using Carr's index and Hausner's ratio. The Carr's index was found to be 9.98%, and the Hausner's ratio was 1.11. Both values indicate excellent flowability of the granules. Improved flow properties can be attributed to the wet granulation process and the use of gum acacia as a binder, which reduced inter-particle friction and improved granule cohesiveness.

Fig. 3. Determination of Moisture Content of Polyherbal Shampoo Granules

Image showing the sample residue obtained during moisture content analysis of the formulated shampoo granules.

Moisture Content

The moisture content of the shampoo granules was determined to be 0.66%. Low moisture content is desirable for herbal formulations as it minimizes microbial growth and enhances product stability during storage. The low moisture level observed indicates effective drying of granules and suitability for long-term storage under normal conditions.

pH Evaluation

The pH of the shampoo granules was found to be 6.2, which falls within the ideal range for scalp and hair care products. A mildly acidic to neutral pH helps maintain the natural acid mantle of the scalp, reduces irritation, and prevents excessive hair dryness. This pH profile supports the mild and skin-friendly nature of the formulation.

C. Performance Evaluation of Shampoo Granules

Foaming Index and Foam Stability

The foaming index of the shampoo granules was observed to be 100 mL, indicating good foaming ability. Foam stability studies showed approximately 60% foam retention after 5 minutes. Adequate foaming and moderate foam stability are essential for consumer acceptability, as foam aids in the uniform distribution of the shampoo over hair and scalp. The foaming behaviour can be attributed to the presence of saponin rich herbal ingredients.

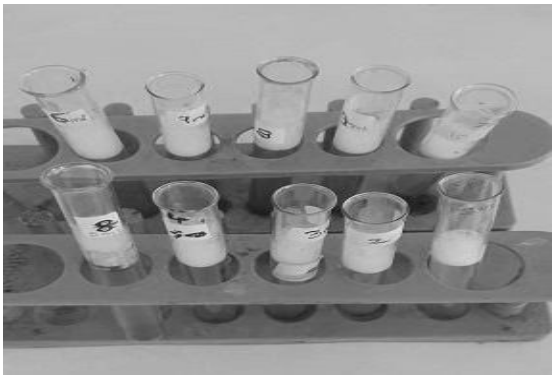

Fig. 4. Determination of Foaming Index of Polyherbal Shampoo Granules

Experimental setup used for evaluation of foaming index using graduated test tubes containing aqueous dispersion of shampoo granules.

Wetting Time

The wetting time of the shampoo granules was found to be 1.4 seconds, indicating rapid wetting and dispersion upon contact with water. Short wetting time is a desirable characteristic of shampoo granules, as it ensures quick reconstitution during use and enhances user convenience.

Solid Content

The solid content of optimized herbal shampoo granules formulation was found to be 25.47% w/w which indicates good foaming and cleaning properties.

Dirt Dispersion and Cleansing Efficiency

The dirt dispersion test demonstrated that approximately 80% of the dirt was removed, indicating good cleansing efficiency of the formulation. Effective dirt dispersion reflects the ability of the shampoo to remove oily sebum and particulate impurities from hair without excessive stripping of natural oils. This supports the mild yet effective cleansing action of the polyherbal formulation.

Evaluation of Biodegradable Shampoo Pods

The biodegradable pods prepared using agar-agar and glycerol exhibited satisfactory physical integrity and flexibility. The pod films were uniform and capable of securely enclosing the shampoo granules. Upon use, the pods were observed to disintegrate effectively, allowing the release of shampoo granules without leaving visible residue. The use of biodegradable pod-based packaging eliminates the need for plastic containers and supports environmentally sustainable cosmetic practices.

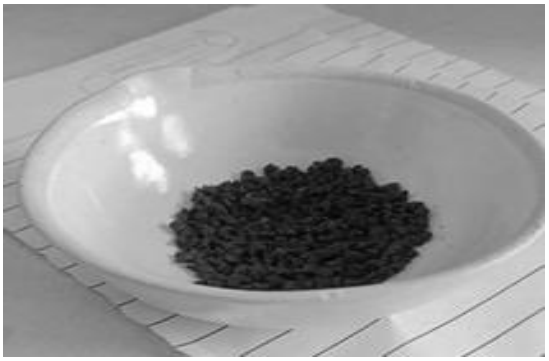

Fig. 5. Determination of Solid Content of Polyherbal Shampoo Granules

Image showing the dried solid residue obtained after evaporation of the aqueous shampoo dispersion.

Stability Studies

Stability studies were conducted by storing the shampoo granule pods at different temperatures (5 °C, 25 °C, and 40 °C). The formulation did not exhibit any significant changes in physical appearance, pH, moisture content, or foaming behaviour during the study period. These observations indicate that the shampoo granule pods possess acceptable stability under the tested storage conditions.

Safety Evaluation

The formulation was found to be non-irritant to skin and eyes during safety evaluation. The absence of synthetic surfactants, harsh preservatives, and artificial additives contributes to the safety profile of the polyherbal shampoo granules, making them suitable for routine hair care applications.

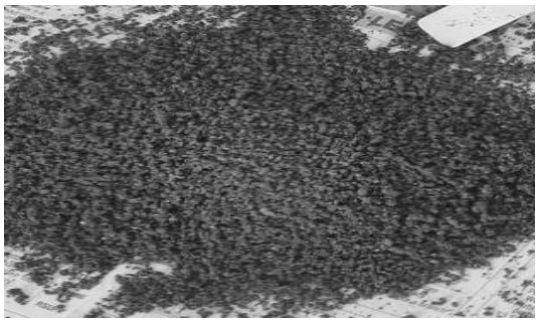

Fig. 6. Prepared Polyherbal Shampoo Granules

Photograph of the final prepared shampoo granules obtained after wet granulation and drying process.

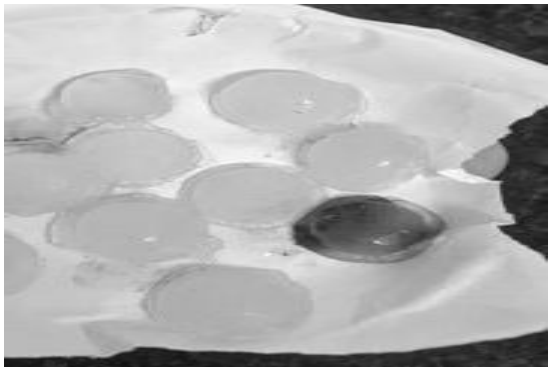

Fig. 7. Prepared Biodegradable Shampoo Pods Containing Polyherbal Shampoo Granules

Biodegradable shampoo pods prepared using agar-based film enclosing the shampoo granules.

VI. CONCLUSION

The present study successfully demonstrated the design and evaluation of biodegradable polyherbal shampoo granule pods as an eco-friendly and mild hair cleansing system. The formulated shampoo granules exhibited desirable physicochemical properties, including excellent flow characteristics, low moisture content, and a scalp compatible pH. Performance evaluation confirmed satisfactory foaming ability, rapid wetting, effective cleansing efficiency, and acceptable foam stability, indicating good functional performance during use. The incorporation of biodegradable pods provided a sustainable alternative to conventional plastic packaging while ensuring convenient dosing and safe handling of the formulation.

Overall, the developed system combines the benefits of traditional herbal ingredients with modern sustainable formulation approaches, making it a promising alternative to conventional liquid shampoos.

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