

Sustainable Formulation and Physicochemical Characterization of a Multifunctional Hair Cream Using Natural Ingredients

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DOI: <https://doi.org/10.51244/IJRSI.2026.1303000155>

Received: 23 March 2026; Accepted: 28 March 2026; Published: 09 April 2026

ABSTRACT

The increasing demand for eco-friendly and health-conscious cosmetic products has driven interest in the development of naturally derived hair-care formulations. This study focused on the green synthesis and characterization of a multifunctional organic hair cream using extracts from onion, garlic, aloe vera, turmeric, neem leaves, hibiscus flower, lemon grass, and curry leaves which are obtained using maceration method. Three 100g cream samples were obtained using varying percentage of herb organic extracts (5%, 10%, 15%). The formulated creams were subjected to physicochemical, biological, phytochemical analysis and performance evaluations including pH, viscosity, spreadability, moisture content, antimicrobial assays etc. Results indicated that only sample C (15%) was physically stable, with desirable texture, among the three samples with all the samples having pH values within the scalp's acceptable range. The viscosity and spreadability suggested ease of application and good consistency, while the biological tests revealed mild antimicrobial and antifungal activities in sample A and B with higher antimicrobial and antifungal activities in sample C, contributing to scalp protection. Comparative hair strength improvement tests showed that the cream containing higher concentrations of the crude extract enhanced hair strength and sheen more effectively than synthetic creams. This study concludes that the use of organic ingredients such as those employed in this work should be encouraged in hair-care product development, as it provides safe, effective, and environmentally sustainable alternatives to synthetic formulations. This green approach represents a promising direction for future cosmetic innovations.

Keywords: Green Synthesis, Hair cream, Bioactive compound, Phytochemical analysis

INTRODUCTION

Hair in humans serves as an essential physiological and socio-cultural component of human identity.^[1] It is a defining feature in mammals and has critical functions, including skin protection, production of sebum, apocrine sweat and pheromones, thereby serving aesthetic, protective, and communicative functions.^[2] In many cultures, including African societies, hair appearance is strongly associated with personal confidence, social status, and beauty thereby making it both emotive, symbolic and also an inseparable part of their identity.^[3,4,5] Maintaining healthy hair requires the use of formulations that can protect the hair shaft, nourish the scalp, prevent breakage, and enhance growth.^[6] As a result, hair products including supplements, serum, shampoos and hair creams have become one of the most widely used cosmetic products worldwide.^[7,8]

Over the years there has become need for green practices in accordance with the United Nation's sustainable development goals (SDGs), which involves and encourages the adoption of concepts like Green chemistry that involves multiple principles such as; prevention of waste, design safer chemical and products, use renewable feedstock, design less hazardous chemical synthesis etc.^[9] This raises concern over conventional hair creams

which often contain synthetic additives such as mineral oils, parabens, sulfates, artificial fragrances, and silicones.^[10,11] Although these chemical ingredients may offer short-term sensory benefits, several studies have associated them with long-term adverse effects including scalp irritation, hair dryness, follicular damage, and environmental toxicity due to poor biodegradability.^[12,13] These growing concerns about the safety of synthetic cosmetic ingredients and their environmental impact have led to a global shift toward natural, plant-based, and eco-friendly alternatives.

Green synthesis, which is an emerging concept in cosmetic formulation and material science,^[14,15] emphasizes the production of valuable compounds and products using environmentally friendly solvents, renewable biomaterial, non-toxic reagents, and energy-efficient processes.^[16,17] In hair care science, green synthesis provides an avenue for producing safer and multifunctional hair creams enriched with bioactive compounds from medicinal plants.

Medicinal plants are naturally rich in flavonoids,^[18] polyphenols,^[19] phenolic acids,^[20] terpenoids,^[21] saponins,^[22] tannins,^[23] and essential oils,^[24] which exhibit strong antioxidant,^[25] antimicrobial,^[26] anti-inflammatory,^[27] moisturizing,^[28] and hair growth-promoting properties.^[29] Incorporating these phytochemicals into a hair cream through green synthesis provides multiple benefits: strengthening of the hair shaft, restoration of moisture, reduction of dandruff, protection against UV and oxidative stress, prevention of breakage, and stimulation of healthy hair growth.^[30,31]

A multifunctional hair cream integrates various activities like moisturizing, conditioning, antimicrobial protection, antioxidant activity, and hair growth enhancement into a single product. This makes it very relevant in tropical regions like Nigeria, where harsh weather (e.g., harmattan), humidity, and high temperatures predispose the hair to dryness, frizz, scalp infections, and breakage.

Characterization of green-synthesized hair creams is crucial for determining their physicochemical properties, stability, functional performance, and safety.^[32,33] Parameters such as pH, viscosity, spreadability, emulsion stability, phytochemical composition, antioxidant capacity, microbial load, are essential for evaluating product quality.^[34,35,36]

This project titled “Green Synthesis and Characterization of a Multifunctional Hair Cream” focuses on formulating a natural hair cream from medicinal plant extracts using environmentally friendly methods, followed by comprehensive characterization to assess its suitability and effectiveness for cosmetic application. The study aligns with global trends toward sustainable personal care products and responds to increasing consumer demand for safe, natural, and multifunctional hair care solutions.

MATERIALS AND METHODS

Materials:

Curry leave, ixora coccinea, neem leave, onions, hibiscus flower, turmeric, aloe-vera, garlic, lemon grass, cetyl alcohol (plant based), coconut oil, shea butter, palm kernel oil, bees wax, olive oil, distilled water, stearic acid, emulsifying wax (plant based), glycerin, lavender oil fragrance, tea-tree oil, rosemary oil, sodium benzoate (preservative). Extraction Solvents: 90% ethanol, distilled water

Apparatus: 500ml glass beaker, one spatula, one glass stirrer

Instruments: Water-bath system, double boiler

Method

Selection and Preparation of Plant Materials

The plant materials were selected based on their medicinal use especially for hair growth and scalp treatment, antimicrobial and anti-inflammatory effects, antioxidant and moisturizing properties. They were sourced from local farms, washed with distilled water and air-dried at room temperature for 7 days.

Extraction of Bio-Active Components

The bioactive extraction of the compounds was done using maceration method (50:50 v/v) involving ethanol and water as solvent. After the drying period, each dried plant materials were soaked in an air-tight container containing ethanol and another containing water (both 1000ml) as solvent for a period of 5 days while being shaken occasionally; twice each day. The mixture was filtered with a muslin cloth and 850ml of the extract was obtained. The organic extracts were placed in a water-bath system at a regulated temperature of 80°C for a period of 9 hours until 90% of the solvent was evaporated. After the evaporation, thick dark-brown slurry which weighed 20g was obtained.

Organic Cream Formulation

In the preparation for the formulation of the cream, the apparatus were sanitized with hot water to prevent contamination and allowed to air dry properly under room temperature. All the materials were weighed using a digital scale for accuracy. The oil phase was prepared by assembling all the oil phase materials into a double boiler and stirred gently until fully melted at temperature of 70°C. Consequently, the water phase was prepared by putting all water-soluble materials into a bowl containing distilled water, glycerin, and the crude extracts. They were then gently warmed in another double boiler until it reached a temperature of 45°C. After that, the two phases were assembled together by slowly and gently pouring the oil phase into the water-phase and blending with a stick blender for 5 minutes until a creamy homogenous mixture was gotten.

Furthermore, essential oils were added to the mixture at a lower temperature of 40°C in order to prevent degradation and blended for one minute before being poured into a pre-sterilized recyclable plastic container and left uncovered until completely cooled to avoid condensation.

Table 1 below show the percentage composition (%w/w) of the additives in 100g of prepared samples A, B & C.

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Water Phase Additives of Samples (%w/w)			
	A	B	C
Aloe-vera gel	25	25	25
Crude org. extract	5	10	15
Glycerine	5	5	5
Oil Phase Additives Samples (%w/w)			
Sheabutter	8	6	5
Coconut oil	8	6	5
Palm Kernel oil	7	7	6
Olive oil	5	5	5
Stearic acid	5	4	3
Beeswax	3	3	2
Cetyl alcohol	5	5	5

Emulsifier (plant origin)	10	10	10
Cooling Phase Additives Samples (%w/w)			
Tree oil	1	1	1
Lavender fragrance	1	1	1
Rosemary oil	1	1	1
Preservative (Sodium benzoate)	1	1	1
Distilled water	10	10	10

The formulated hair cream samples were characterized to determine their physiochemical, phytochemical, and biological properties. The three samples (A, B, and C) were prepared containing 5%, 10%, and 15% concentrations of the crude extract. Characterization is carried out to evaluate the effects of the crude extract concentration on the product’s quality, stability, and biological activity. Functional group and bio-active compounds were analyzed using Buck M530 FTIR USA (FTIR) and Scitek GC-102 Gas Chromatograph (GC-FID) respectively.

RESULTS

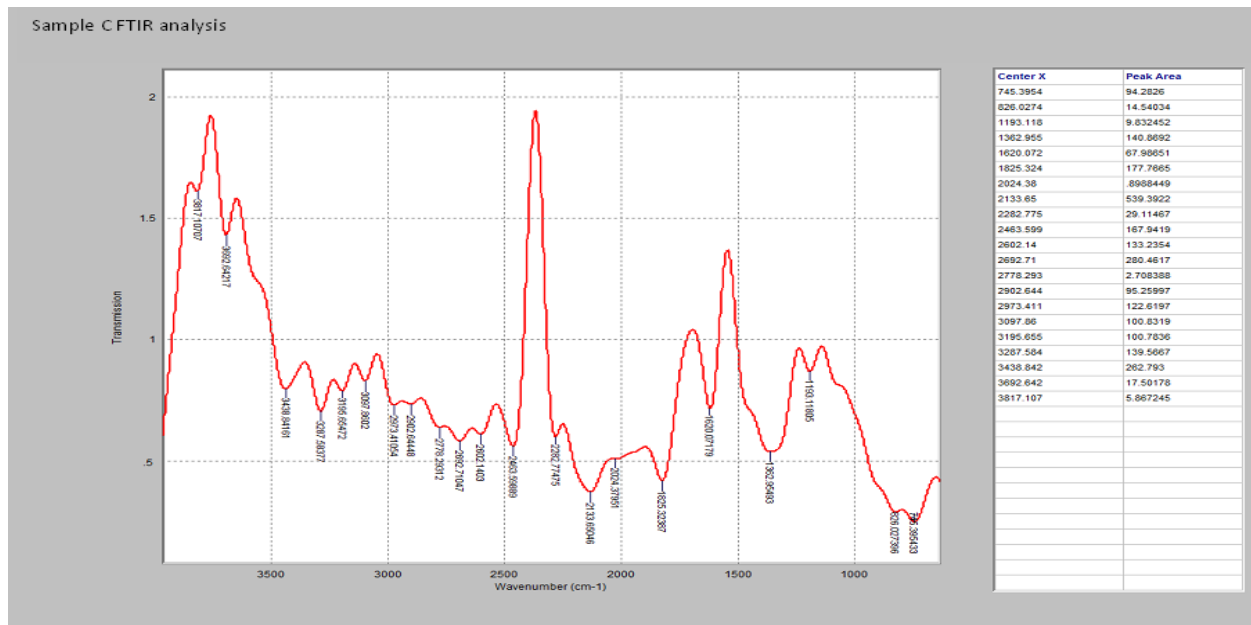


Figure 1: FTIR Spectrum of Sample C.

Table 2: Functional Group Identification of Sample C via Fourier Transform Infrared (FTIR) Spectroscopy.

Center X (c/m)	Peak Area	Functional Group
732.5869	16.4794	C-H
880.6337	52.05566	C-H
1177.917	2.771351	C-O

1295.598	61.3926	C-O
1416.391	141.9471	COO
1651.56	39.33721	C=O
1854.221	208.5013	C=O
1968.054	353.9565	C=O
2528.652	1.526115	COOH
2687.9	118.6499	COOH
2846.22	170.9841	C-H
2984.028	217.5224	C-H
3247.555	170.5753	O-H
3432.179	266.0305	O-H
3520.527	16.54901	O-H
3702.799	20.61243	O-H
3835.48	1.678015	O-H

Table 3: Phytochemical Composition and Classification of Sample C using GC-FID Analysis.

Compound	Chemical Class	Subclass
Rosmarinic acid	Polyphenol	Hydroxycinnamic acid ester
Catechin	Flavonoid	Flavan-3-ol
Syringic acid	Phenolic acid	Hydroxybenzoic acid
Apigenin	Flavonoid	Flavone
Resveratrol	Polyphenol	Stilbene
Flavan-3-ol (Flavon-3-ol)	Flavonoid	Flavanol
Genistein	Flavonoid	Isoflavone
Daidzein	Flavonoid	Isoflavone
Daidzin	Flavonoid	Isoflavone glycoside
Butein	Flavonoid	Chalcone
Naringenin	Flavonoid	Flavanone
Luteolin	Flavonoid	Flavone

Cinnamic acid	Phenolic acid	Hydroxycinnamic acid
Kaempferol	Flavonoid	Flavonol
Epigallocatechin (EGC)	Flavonoid	Flavan-3-ol
Epicatechin (Epicatechin)	Flavonoid	Flavan-3-ol
Quercetin	Flavonoid	Flavonol
Gallocatechin-3-gallate (GCG)	Flavonoid	Flavan-3-ol gallate
Robinetin	Flavonoid	Flavonol
Myricetin	Flavonoid	Flavonol
Ellagic acid	Polyphenol	Dilactone derivative of gallic acid
Nobiletin	Flavonoid	Polymethoxylated flavone
Baicalin	Flavonoid	Flavone glycoside (Baicalein-7-O-glucuronide)
Tangeretin	Flavonoid	Polymethoxylated flavone
Artemetin	Flavonoid	Polymethoxylated flavone
Naringin	Flavonoid	Flavanone glycoside
Lunamarin	Alkaloid / Phenolic derivative	Marine plant secondary metabolite
Cinnamic acid (duplicate)	Phenolic acid	Hydroxycinnamic acid
Vinnillic acid (Vanillic acid)	Phenolic acid	Hydroxybenzoic acid
Coumaric acid	Phenolic acid	Hydroxycinnamic acid
Ferulic acid	Phenolic acid	Hydroxycinnamic acid
Flavone	Flavonoid	Parent flavone structure
Gentisic acid	Phenolic acid	Dihydroxybenzoic acid
Sinapinic acid	Phenolic acid	Hydroxycinnamic acid

Table 4: Physiochemical Characteristics and Stability Profile of Samples A, B, and C.

Parameter	Method Used	Sample A (5% organic extract)	Sample B (10% organic extract)	Sample C (15% organic extract)
Appearance	Visual inspection	Greasy, yellow colour	Greasy, mild greenish-yellow colour	Smooth, creamy off-white colour

Odor	Sensory	Faint herbal scent	Mild herbal scent	Strong herbal scent
pH (25°C)	pH meter	4.97	5.06	5.13
Viscosity	Falling sphere	520cP	518cP	515cP
Moisture Content	Oven drying	30.07%	30.10%	31.12%
Spreadability	Glass slide method	9.0 g.cm/s	7.3 g.cm/s	6.5 g.cm/s
Emulsion Stability	Storage under room temperature(30 Days)	Stable after 30 days	Stable after 30 days	Stable after 30 days
Foaming Ability	Cylinder shake test	3.5 cm	3.9 cm	3.8 cm
Thermal Stability	Oven storage (45°C, 5 hours)	Unstable with lots of oil at the surface after 24 hr	Unstable with oil at the surface after 5 days	Stable

Table 5: Comparative Evaluation of the Biological, Antimicrobial, and Dermatological Activities of Samples A, B, and C.

Bio Test	Method Used	Sample A (5% organic extract)	Sample B (10% organic extract)	Sample C (15% organic extract)
Antimicrobial activity (bacteria, E.coli and staph)	Agar well diffusion	11mm (E. coli), 10mm (S. aureus)	15mm (E. coli), 15mm (S. aureus)	19mm (E. coli), 21mm (S. aureus)
Antifungal activity	Agar diffusion	12mm	14mm	17mm
Hair-growth activity (in vivo, using human hair)	Topical application for 21 days	Very little growth after 20 days	Moderate growth after 15 days	Fast visible regrowth after 10 days
Skin irritation/patch test	Human volunteer test (24hrs)	Mild tingling	No irritation	No irritation
Moisturizing effect (after 30mins)	Swelling(water absorption) test	36.6%	42.4%	82.1%
Hair strength improvement test	Elastic recovery/stretch-return test	17.4%	48.7%	75.1%
Dandruff inhibition activity (malassezia furfur)	Agar plate assay	8mm	12mm	21mm

DISCUSSION

In the FTIR analysis, the strong C-H and C=O absorption bands confirm the lipid nature of the formulation, consistent with oils and fatty acid esters. The broad O-H band shows hydrogen-bonded hydroxyl groups from natural extract components and water, supporting moisturizing potential. The presence of -COO and -COOH

groups suggests partial esterification and free fatty acids which can influence cream pH and softness. The coexistence of hydroxyl, carbonyl, and aliphatic groups implies a balance of hydrophilic and lipophilic moieties, enhancing the cream's spreadability, moisturizing, and emollient behavior. The spectral pattern confirms successful blending of organic oils, fatty acids, and plant-derived active materials without major chemical degradation.

In conclusion, the FTIR result demonstrates that the hair cream contains functional groups (O-H, C-H, C=O, COO, and C-O) consistent with esters, fatty acids, alcohols, and natural extract constituents. These functional groups collectively account for the product's moisturizing, conditioning, and protective properties.

In the GC-FID analysis of the sample C, it is clear that flavonoid is the major compound followed by phenolic acid, while polyphenol is the least. The major functions of flavonoids on the hair includes antioxidant protection, hair growth stimulation, anti-inflammatory effect, antimicrobial action, strengthening of hair strands, improving hair moisture and conditioning, protection against UV damage. The major function of phenolic acid on the hair are antioxidant protection, strengthen hair strands, stimulates hair growth, anti-inflammatory action, antimicrobial effects and UV protection. While the major function of polyphenol on hair are antioxidant protection, stimulates hair growth, anti-inflammatory action, antimicrobial, strengthen hair fibres and protects the hair against UV. It is therefore concluded that the hair cream sample contains the necessary bioactive compounds the hair needs for its growth and general maintenance.

In the physicochemical analysis, samples A and B showed greasy appearance on visual inspection likely due to higher oil composition. There was observed increase in in herbal scent from sample A to C as percentage of crude herb extract increased. Their pH was within scalp-friendly range (4.5-7.0) with progressive increase likely due to increase in organic extract content. Their viscosity and moisture content showed likewise similarity in range as they possessed identical emulsifier and water content which are additives responsible for the respective properties. The emulsion stability was also similar as as they possessed same percentage composition of emulsifier. The spreadability showed decrease from sample A to C as the percentge of the oil phase additives reduced progressively showing that oil Phase is responsible for that property. The foaming ability also shows equivalent range likely due to constant Cety alcohol content which is responsible for the characteristic from literature. Sample A and B also showed lascj of stability over long high temperature exposure leading to visible separation of the phases.

In the biological testing, sample A (5%) showed mild inhibition zones indicating limited activity, sample B (10%) exhibited moderate inhibition, suggesting better antimicrobial potential while sample C (15%) demonstrated the highest inhibitory effect, confirming that higher concentrations of the plant extracts enhance biological effectiveness. This suggests that the combined extract possesses antimicrobial and antifungal properties beneficial for scalp protection and dandruff control.

CONCLUSIONS

This study shows a successfully formulated and characterized organic hair cream incorporating crude extracts of onion, garlic, aloe-vera, turmeric, neem leaves, hibiscus flower, lemon grass, Ixora coccinea and curry leaves at different concentrations of 5%, 10%, and 15%. The results of the physicochemical characterization showed that sample A and B did not possess all the desirable physical properties such as smooth texture, good consistency, acceptable viscosity, etc. with the exception of sample C.

The GC-FID analysis confirmed the presence of important bioactive compounds which are flavonoids, phenols, and polyphenols which are all known to promote hair growth, prevent hair loss, and protect against scalp infections. The FTIR analysis confirmed the presence of some functional groups which are hydroxyl, carboxylate, ester, ketone, carboxylic acid while the biological characterization demonstrated that all the samples exhibited antimicrobial and antifungal activity against common scalp pathogens, with sample C showing the highest inhibitory effect. This indicates that the effectiveness of the hair cream increases with the concentration of the natural plant extracts.

Furthermore, comparative analysis among the three experimental formulations (5%, 10%, and 15% extract concentrations) showed a concentration-dependent improvement in hair strength, moisture retention, and overall conditioning effect. The formulation containing 15% extract demonstrated superior performance which is due to the concentration of the extract and the effects of the combined organic extracts. Overall, this study concludes that the formulated organic hair cream (sample C) is safe, stable, and biologically active, and fit for hair and scalp treatment. The results justify the use of multiple herbal extracts as natural alternatives to synthetic ingredients in cosmetic formulations.

The use of organic ingredients such as those employed in this study should be encouraged in hair-care product development. These natural components which includes onions, garlic, aloe-vera, turmeric, neem leaves, hibiscus flower, lemon grass, *Ixora coccinea* and curry leaves provide safe, effective, and environmentally friendly alternatives to synthetic additives commonly found in commercial hair creams. Their incorporation not only enhances the conditioning and strengthening properties of the hair but also imparts mild antimicrobial and antifungal activities that promote scalp health.

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