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FORMULATION AND EVALUATION OF A XANTHAN GUM-BASED HERBAL HAIR GEL CONTAINING *ALLIUM SATIVUM* OIL FOR ANTIMICROBIAL AND ANTIDANDRUFF APPLICATIONS

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ABSTRACT

Background: Dandruff is a common scalp disorder associated with microbial proliferation, irritation, and excessive scaling. Increasing concerns regarding the adverse effects associated with prolonged use of synthetic antidandruff agents have stimulated interest in the development of herbal alternatives. *Allium sativum* (garlic) oil possesses well-documented antimicrobial activity and may serve as a potential natural ingredient for topical scalp formulations.
Objective: The present study aimed to formulate and evaluate a xanthan gum-based herbal hair gel containing *Allium sativum* oil and to assess its physicochemical characteristics, *In vitro* drug release and antimicrobial activity.
Methods: Four gel formulations (F1–F4) were prepared using varying concentrations of xanthan gum as the gelling agent. The formulations were evaluated for physical appearance, pH, spreadability, viscosity, and drug content. The antimicrobial activity of *Allium sativum* oil and the optimized hair gel formulation was determined by the broth dilution method against *Staphylococcus aureus*, *Escherichia coli*, *Candida albicans*, and *Aspergillus niger*. The optimized formulation was further subjected to *In vitro* drug diffusion studies using a dialysis membrane.
Results: All formulations were homogeneous, smooth, and exhibited acceptable physicochemical properties. The pH of the formulations ranged from 5.01 ± 0.05 to 5.12 ± 0.08, indicating compatibility with scalp application. Drug content ranged from 89.4 ± 0.72% to 93.2 ± 0.58%, while viscosity increased with increasing xanthan gum concentration. Based on the overall evaluation, formulation F3 was selected as the optimized formulation. The optimized gel exhibited 91.20% cumulative drug release within 60 min. Antimicrobial studies revealed that both *Allium sativum* oil and formulation F3 containing *Allium sativum* oil effectively inhibited the growth of the tested bacterial and fungal strains, demonstrating retention of antimicrobial activity following formulation.
Conclusion: The developed xanthan gum-based *Allium sativum* oil gel exhibited favorable physicochemical properties, efficient drug release, and significant antimicrobial activity. The optimized formulation shows effective natural topical antidandruff preparation for scalp care applications.

KEYWORDS: *Allium sativum* oil, antidandruff, xanthan gum, antimicrobial activity, herbal hair gel.

INTRODUCTION

Dandruff is a common scalp disorder characterized by excessive shedding of scalp corneocytes, resulting in visible flakes, itching, and irritation. Although not a serious medical condition, its chronic and recurrent nature can negatively affect appearance, self-esteem, and quality of life. Dandruff is generally considered a mild form of seborrheic dermatitis and is associated with multiple factors including sebum production, microbial colonization, scalp barrier dysfunction, and environmental influences. Among these, scalp microorganisms, particularly *Malassezia* species, play a significant role in the development and persistence of dandruff.[1]

Current treatment strategies mainly involve the use of antifungal and keratolytic agents such as ketoconazole, zinc pyrithione, selenium sulfide and salicylic acid. While these agents effectively control dandruff symptoms, prolonged use may lead to scalp dryness, irritation, erythema, and poor patient compliance. These limitations have encouraged the search for safer and more acceptable alternatives, especially those derived from natural sources.[2]

Medicinal plants have long been utilized in traditional healthcare systems due to their diverse biological activities. Among them, *Allium sativum* (garlic) has attracted considerable attention because of its potent antimicrobial, antioxidant, and anti-inflammatory properties. *Allium sativum* contains several sulphur-containing compounds, including allicin, alliin, and ajoene, which are responsible for its therapeutic activity. Allicin, the major bioactive constituent, exhibits broad-spectrum antibacterial and antifungal activity by interfering with essential microbial enzymes and metabolic processes. Owing to these properties, garlic oil represents a promising natural candidate for the management of dandruff and other scalp infections.[3]

The effectiveness of a topical antidandruff preparation depends not only on the active ingredient but also on the delivery system employed. Gel formulations are widely preferred for scalp application due to their non-greasy nature, ease of application, good spreadability, and prolonged contact time at the site of action. Furthermore, gels provide better patient acceptability and can be formulated to achieve desirable physicochemical characteristics.[4]

Xanthan gum is a natural polysaccharide extensively used as a gelling and stabilizing agent in pharmaceutical formulations. It is biocompatible, biodegradable, non-toxic, and capable of producing stable gels with suitable viscosity and spreadability. These characteristics make xanthan gum an attractive polymer for the development of herbal topical formulations.[5]

Despite the recognized antimicrobial potential of garlic, studies on garlic oil-based antidandruff gels are limited. Therefore, the present study aimed to formulate and evaluate a xanthan gum-based herbal hair gel containing *Allium sativum* oil. The developed formulations were evaluated for their physicochemical properties, *In vitro* diffusion, and antimicrobial activity to assess their potential as a natural antidandruff preparation.

MATERIALS AND METHODS

Materials

Allium sativum oil and *Aloe vera* gel were procured from Hebsur Herbals Store, Hubballi, Karnataka, India. Xanthan gum, sodium benzoate, propylene glycol, glycerin, and citric acid were obtained from Molychem India LLP, Mumbai, India. Analytical-grade chemicals and reagents were purchased from S.D. Fine-Chem Ltd., Mumbai, India. Mueller–Hinton Agar (MHA), Mueller–Hinton Broth (MHB), Potato Dextrose Agar (PDA), and Potato Dextrose Broth (PDB) were procured from HiMedia Laboratories Pvt. Ltd., Mumbai, India. Standard microbial strains *Escherichia coli* (NCIM 2065), *Staphylococcus aureus* (NCIM 2079), *Aspergillus niger* (NCIM 1004), and *albicans* (NCIM 3628) were obtained from the National Collection of Industrial Microorganisms (NCIM), Pune, India.

Quantification of *Allium sativum* Oil by UV Spectroscopy

A standard stock solution of *Allium sativum* oil was prepared in ethanol and scanned between 200–400 nm using a UV–Visible spectrophotometer to determine the wavelength of maximum absorbance (λmax). Appropriate dilutions (20–200 µg/mL) were prepared using phosphate buffer (pH 7.4), and absorbance was measured at λmax. A calibration curve was constructed by plotting absorbance against *Candida* concentration.[7]

Determination of Minimum Inhibitory Concentration (MIC)

The antimicrobial activity of Allium sativum oil was evaluated by the broth dilution method. Serial two-fold dilutions ranging from 200 to 6.25 µg/mL were prepared in sterile broth media. Microbial inoculum was added to each tube, while growth and media controls were maintained. Following incubation, tubes were examined for visible turbidity, and the lowest concentration showing no microbial growth was recorded as the MIC. *Escherichia coli* and *Staphylococcus aureus* were evaluated using Mueller–Hinton Broth and incubated at 37 ± 2°C for 24 h, whereas *Aspergillus niger* and *Candida albicans* were evaluated using Potato Dextrose Broth and incubated at 28 ± 2°C for 48–72 h.[12,13]

Formulation of *Allium sativum* Oil Hair Gel

Xanthan gum was dispersed in distilled water and allowed to hydrate for 24 h to obtain a uniform gel base. *Aloe vera* gel, propylene glycol, and glycerin were incorporated with continuous stirring, followed by the addition of sodium benzoate as preservative. *Allium sativum* oil was then incorporated slowly into the hydrated gel base with continuous stirring to ensure uniform dispersion. Finally, citric acid was added to adjust the pH and obtain a stable herbal gel formulation. Different formulations (F1–F4) were prepared by varying the concentration of xanthan gum while keeping other ingredients constant.[14–16]

Table 1: Formulation of Allium sativum Oil Hair Gel (F1–F4)

Sl.no	Ingredients	F1	F2	F3	F4
1	Xanthan gum	0.7 gm	1gm	1.3gm	1.5gm
2	*Allium sativum* oil	1ml	1ml	1ml	1ml
3	*Aloe vera* gel	1gm	1gm	1gm	1gm
4	Sodium benzoate	0.5gm	0.5gm	0.5gm	0.5gm
5	Propylene glycol	5 ml	5 ml	5 ml	5 ml
6	Glycerin	3 ml	3 ml	3 ml	3 ml
7	Citric acid	0.25gm	0.25gm	0.25gm	0.25gm
8	Distilled water	Q.S	Q.S	Q.S	Q.S

Evaluation of *Allium sativum* Oil Hair Gel

Physical Appearance

The formulated gels (F1–F4) were visually evaluated for colour, appearance, consistency, homogeneity, and the presence of any grittiness, lump formation, or phase separation. The formulations were examined under normal daylight conditions, and observations were recorded to assess their aesthetic characteristics and uniformity.[17]

pH Determination

The pH of the gel formulations was determined using a calibrated digital pH meter. One gram of gel was dispersed in 100 mL of distilled water and allowed to stand for 30 min to attain equilibrium. The electrode was immersed in the dispersion, and the pH was recorded at room temperature. Measurements were performed in triplicate, and the mean value ± standard deviation (SD) was reported.[14,17]

Spreadability Study

Spreadability was determined using the parallel-plate method. Approximately 1 g of gel was placed at the center of a glass slide, over which a second slide of identical dimensions was carefully positioned. A weight of 150 g was placed on the upper slide for 1 min to facilitate uniform spreading. The diameter of the spread gel was measured in centimeters along two perpendicular directions, and the average value was calculated. The study was carried out in triplicate and expressed as mean ± SD.[18]

Drug Content Determination

Drug content was determined by UV–Visible spectrophotometric analysis. Accurately weighed hair gel equivalent to 1 g was transferred to a volumetric flask containing phosphate-buffered saline (PBS, pH 7.4) and stirred continuously to ensure complete extraction of the active constituent. The solution was filtered through Whatman filter paper No. 1 and suitably diluted with PBS (pH 7.4). The absorbance was measured at 250 nm using a UV–Visible spectrophotometer against PBS as blank. Drug content was calculated from the previously established calibration curve and expressed as percentage drug content. The analysis was performed in triplicate, and results were reported as mean ± SD.[17,19]

Viscosity Measurement

The rheological behavior of the hair gel formulations was evaluated using a Brookfield Viscometer (DV-2P). Approximately 50 g of gel was transferred into the sample container and allowed to equilibrate at room temperature (25 ± 2°C). Viscosity measurements were performed using spindle TL6 at rotational speeds of 2, 4, 5, and 10 rpm. The corresponding viscosity values were recorded after achieving a stable reading. All measurements were carried out in triplicate and expressed in centipoise (cP) as mean ± SD.[20,21]

***In vitro* Drug Diffusion Study**

The *In vitro* drug diffusion study of the optimized formulation (F3) was carried out using a dialysis membrane diffusion technique. The dialysis membrane was soaked overnight in distilled water prior to use to ensure complete hydration. Approximately 5 g of gel was placed inside the hydrated dialysis membrane, which was securely tied at both ends and suspended in 50 mL of phosphate-buffered saline (PBS, pH 7.4) maintained at room temperature under continuous magnetic stirring at 100 rpm.

At predetermined time intervals (0, 10, 20, 30, 40, 50, and 60 min), 5 mL samples were withdrawn from the receptor compartment and immediately replaced with an equal volume of fresh PBS (pH 7.4) to maintain sink conditions. The collected samples were suitably diluted and analyzed spectrophotometrically at 250 nm. The cumulative percentage drug release was calculated using the calibration curve, and a plot of cumulative percentage drug release versus time was constructed to evaluate the diffusion profile of the optimized formulation.[20,22]

Determination of Minimum Inhibitory Concentration (MIC) of Optimized Gel Formulation

The antimicrobial activity of the optimized formulation (F3) was evaluated by the broth dilution method under aseptic conditions. A stock solution of the gel formulation was prepared by dispersing an accurately weighed quantity of gel in dimethyl sulfoxide (DMSO) to obtain a concentration of 0.4 mg/mL.

Sterile test tubes containing 1 mL of the respective broth medium were arranged, and serial two-fold dilutions of the formulation were prepared to obtain final concentrations ranging from 200 to 6.25 µg/mL. Appropriate microbial inoculum (10 µL) was added to each test tube. A growth control containing inoculated broth without sample and a sterility control containing uninoculated broth were maintained simultaneously.

For antibacterial evaluation, *Escherichia coli* (NCIM 2065) and *Staphylococcus aureus* (NCIM 2079) were cultured in Mueller–Hinton Broth and incubated at 37 ± 2°C for 18–24 h. For antifungal evaluation, *Aspergillus niger* (NCIM 1004) and *Candida albicans* (NCIM 3628) were cultured in Potato Dextrose Broth and incubated at 28 ± 2°C for 48–72 h. Following incubation, the tubes were examined visually for microbial growth. The lowest concentration of the formulation that completely inhibited visible growth was recorded as the minimum inhibitory concentration (MIC).[23,24]

RESULTS AND DISCUSSION

Quantification of *Allium Sativum* Oil by UV Spectroscopy

The UV absorption spectrum of *Allium sativum* oil was recorded in the wavelength range of 200–400 nm to determine the wavelength of maximum absorbance (λmax). The oil exhibited a characteristic absorption maximum at 250 nm, which was selected as the analytical wavelength for quantitative estimation. A standard calibration curve of *Allium sativum* was

subsequently constructed in phosphate-buffered saline (PBS, pH 7.4) over the concentration range of 20–200 µg/mL. The absorbance increased proportionally with increasing concentration, demonstrating compliance with Beer–Lambert's law within the selected range. The calibration plot showed good linearity with a regression equation of y = 0.0051x – 0.0865 and a correlation coefficient (R^2 = 0.9942). The high correlation coefficient confirmed the reliability of the analytical method for quantitative estimation of *Allium sativum* oil during drug content and diffusion studies. The standard calibration curve is shown in Figure 1.

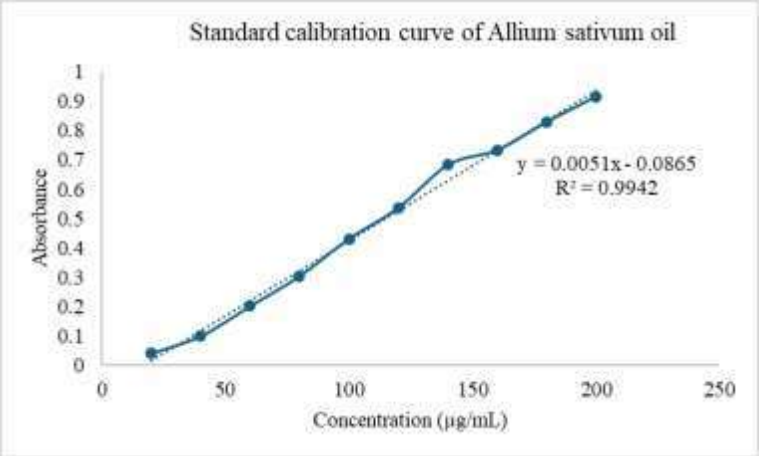

Figure 1. Standard calibration curve of *Allium sativum* oil in phosphate-buffered saline (pH 7.4) at 250 nm.

Determination of Minimum Inhibitory Concentration (MIC) of *Allium sativum* Oil

The antimicrobial activity of *Allium sativum* oil was evaluated against *Staphylococcus aureus*, *Escherichia coli*, *Candida albicans* and *Aspergillus niger* using the broth dilution method. The concentrations tested ranged from 6.25 to 200 µL/mL, and the results are presented in Table 2.

The *Allium sativum* oil demonstrated significant antimicrobial activity against all tested microorganisms. Complete inhibition of growth was observed at a concentration of 100 µL/mL for *Staphylococcus aureus* and Candida albicans, whereas *Escherichia coli* and *Aspergillus niger* were inhibited at 50 µL/mL. The comparatively lower MIC observed against *Escherichia coli* and *Aspergillus niger* suggests greater susceptibility of these organisms to the bioactive sulphur-containing constituents present in garlic oil.

Among the tested microorganisms, the highest MIC value observed was 100 µL/mL. Therefore, this concentration was considered the minimum concentration capable of inhibiting the growth of all selected microbial strains. These findings confirm the broad-spectrum antibacterial and antifungal activity of *Allium sativum* oil and support its potential application as a natural antidandruff formulation. Representative MIC observations are presented in Figure 2.

Table 2. Minimum inhibitory concentration (MIC) of *Allium sativum* oil against selected bacterial and fungal strains

Sl. no	Concentration of *Allium sativum* oil (µl/ml)	Microbial Growth			
		Staphylococcus aureus	***Escherichia coli***	***Candida albicans***	***Aspergillus niger***
1	200	-	-	-	-
2	100	-	-	-	-
3	50	+	-	+	-
4	25	+	+	+	+
5	12.50	+	+	+	+
6	6.25	+	+	+	+
7	Positive control	+	+	+	+
8	Negative control	-	-	-	-

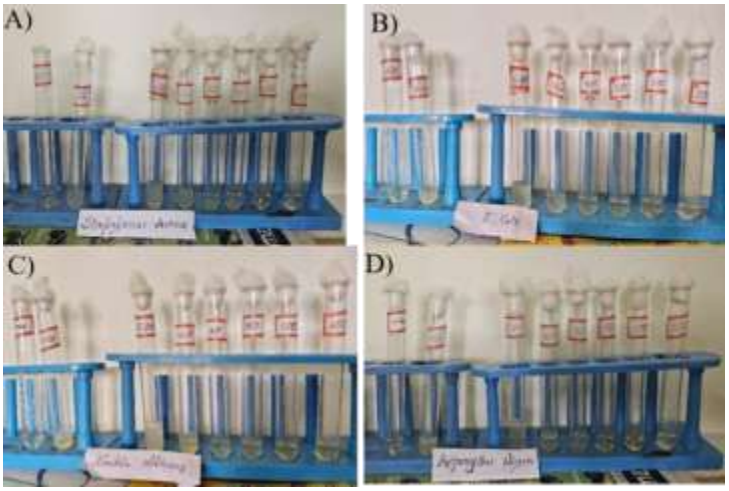

Figure 2. Determination of minimum inhibitory concentration (MIC) of *Allium sativum* oil against (a) *Staphylococcus aureus*, (b) *Escherichia coli*, (c) *Candida albicans*, and (d) *Aspergillus niger*.

Formulation of *Allium sativum* Oil Hair Gel

Four hair gel formulations (F1–F4) containing *Allium sativum* oil were successfully prepared using xanthan gum as the gelling agent. The concentration of xanthan gum was varied while maintaining all other formulation components constant. The prepared gels were visually examined for appearance, consistency, and homogeneity.

All formulations exhibited acceptable physical characteristics and appeared smooth, homogeneous, and free from visible particulate matter or phase separation. An increase in gel consistency was observed with increasing xanthan gum concentration. Formulations containing lower polymer concentrations (F1 and F2) exhibited comparatively lower viscosity, whereas formulations containing higher polymer concentrations (F3 and F4) produced thicker gel matrices. The prepared formulations are shown in Figure 3.

Figure 3. Prepared *Allium sativum* oil hair gel formulations (F1–F4) containing different concentrations of xanthan gum

Evaluation of *Allium sativum* Oil Hair Gel

Physical Appearance

The prepared *Allium sativum* oil hair gel formulations (F1–F4) were evaluated visually for colour, consistency, homogeneity, and overall appearance. All formulations were found to be smooth, homogeneous, and free from visible lumps, grittiness, or phase separation. The gels exhibited a light yellowish appearance owing to the presence of garlic oil and *Aloe vera* gel. Furthermore, all formulations possessed satisfactory consistency and gel structure suitable for topical scalp application, indicating successful incorporation of the formulation components and good formulation stability.

pH Determination

The pH of the formulated hair gels was found to be in the range of 5.01 ± 0.05 to 5.12 ± 0.08 (Table 3). Minor variations in pH were observed among the formulations, which may be attributed to differences in xanthan gum concentration. Importantly, all formulations exhibited pH values close to the physiological pH of the scalp and hair, suggesting their suitability for topical application without causing irritation or disruption of the scalp environment. The results indicate that the developed formulations are compatible with scalp tissues and suitable for prolonged use.

Spreadability

Spreadability is an important parameter that influences ease of application and patient compliance. The spreadability values of the formulations ranged from 5.9 ± 0.10 to 8.2 ± 0.18 g·cm/s (Table 3). A gradual decrease in spreadability was

observed with increasing xanthan gum concentration, which may be attributed to the corresponding increase in viscosity of the gel matrix. Despite this reduction, all formulations exhibited satisfactory spreading characteristics, facilitating uniform distribution over the scalp surface and ensuring ease of application.

Drug Content

Drug content analysis revealed that the formulations contained 89.4 ± 0.72% to 93.2 ± 0.58% of the incorporated *Allium sativum* oil (Table 3). The relatively narrow range of drug content values indicates efficient incorporation of *Allium sativum* oil and uniform distribution throughout the gel matrix. Among the formulations, F3 exhibited the highest drug content, suggesting optimal entrapment and distribution of the active ingredient. The results confirm the reproducibility of the formulation method and satisfactory content uniformity among the prepared gels.

Table 3. Physicochemical evaluation of *Allium sativum* oil hair gel formulations

Formulation	Spreadability (g·cm/s)	pH	Drug Content (%)
F1	8.2 ± 0.18	5.12 ± 0.08	89.4 ± 0.72
F2	7.6 ± 0.15	5.08 ± 0.10	91.1 ± 0.65
F3	6.8 ± 0.12	5.04 ± 0.09	93.2 ± 0.58
F4	5.9 ± 0.10	5.01 ± 0.05	92.5 ± 0.61

Viscosity Measurement

The viscosity of the formulations was evaluated using a Brookfield viscometer at different rotational speeds, and the results are presented in Table 4. Viscosity increased progressively with increasing xanthan gum concentration, confirming the effectiveness of xanthan gum as a gelling and viscosity-enhancing polymer. Formulation F4 exhibited the highest viscosity, whereas F1 showed the lowest viscosity values.

A decrease in viscosity was observed with increasing rotational speed in all formulations, indicating pseudoplastic or shear-thinning behavior. Such rheological characteristics are desirable for hair gel formulations, as they permit easy spreading during application while maintaining sufficient consistency during storage. The observed viscosity profile demonstrates the suitability of xanthan gum for the development of stable scalp-applied gel formulations.

Table 4. Viscosity of *Allium sativum* oil hair gel formulations (cP)

Formulation	2 rpm	4 rpm	5 rpm	10 rpm
F1	13518	7826	6251	3503
F2	15034	8907	6892	4719
F3	16805	9913	7618	5734
F4	18405	10795	8414	6511

Based on the physicochemical evaluation, formulation F3 was selected as the optimized formulation for further studies. The formulation exhibited a favorable balance between spreadability, viscosity, pH, and drug content. Although F4 demonstrated higher viscosity, its lower spreadability could potentially affect ease of application. Conversely, F1 and F2 exhibited lower viscosities and drug content values. Therefore, F3 was considered the most suitable formulation for topical scalp delivery and was selected for *In vitro* diffusion and antimicrobial evaluation.

***In vitro* Drug Diffusion Study of Optimized Formulation (F3)**

The *In vitro* drug diffusion study of formulation F3 was performed using a dialysis membrane in phosphate-buffered saline (pH 7.4). The formulation exhibited a progressive increase in cumulative drug release throughout the study period, reaching 91.20% at the end of 60 min (Table 5 and Figure 5).

An initial rapid release phase was observed during the early stages of the study, followed by a gradual and sustained release pattern. This behavior may be attributed to the diffusion of *Allium sativum* oil from the hydrated xanthan gum matrix into the dissolution medium. The high cumulative drug release obtained within the study period indicates efficient release of the active constituents and suggests the potential of the formulation to provide adequate drug availability at the site of application.

Table 5. Cumulative drug release profile of optimized formulation F3.

Time (min)	Cumulative Drug Release (%)
0	0
10	27.28
20	46.35
30	64.78
40	79.69
50	86.19
60	91.20

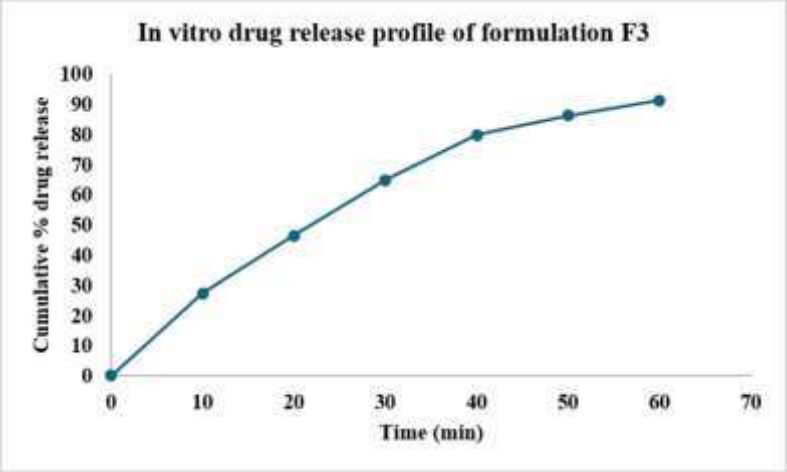

Figure 5. *In vitro* drug diffusion profile of optimized *Allium sativum* oil hair gel formulation (F3)

Determination of Minimum Inhibitory Concentration (MIC) of Optimized Formulation (F3)

The antimicrobial activity of the optimized formulation (F3) was evaluated against selected bacterial and fungal pathogens using the broth dilution method. The MIC values obtained are presented in Table 6.

The formulation demonstrated effective antimicrobial activity against all tested microorganisms. Complete inhibition of growth was observed at 100 µg/mL for *Staphylococcus aureus* and *Candida albicans*, whereas *Escherichia coli* and *Aspergillus niger* exhibited inhibition at 50 µg/mL. The antimicrobial profile of the gel formulation was comparable to that observed for pure *Allium sativum* oil, indicating that incorporation of the oil into the xanthan gum matrix did not adversely affect its biological activity.

The retention of antimicrobial efficacy following formulation confirms successful incorporation and release of the bioactive sulphur-containing constituents of *Allium sativum* oil. These findings support the potential application of the developed herbal hair gel as a topical antidandruff preparation possessing broad-spectrum antibacterial and antifungal activity.

Table 6. Minimum inhibitory concentration (MIC) of optimized *Allium sativum* oil gel formulation (F3).

Concentration (µg/mL)	*Staphylococcus aureus*	*Escherichia coli*	*Candida albicans*	*Aspergillus niger*
200	–	–	–	–
100	–	–	–	–
50	+	–	+	–
25	+	+	+	+
12.5	+	+	+	+
6.25	+	+	+	+
Positive Control	+	+	+	+
Negative Control	–	–	–	–

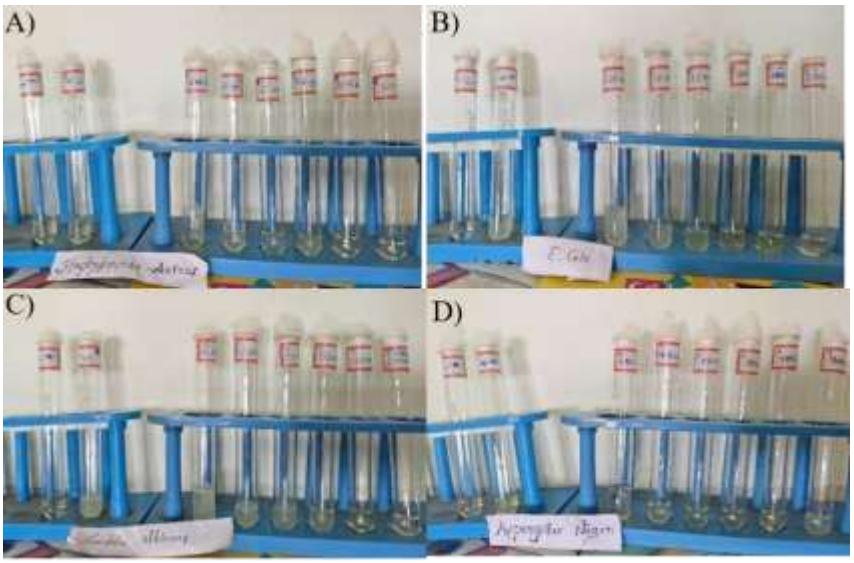

Figure 6. Determination of minimum inhibitory concentration (MIC) of optimized *Allium sativum* oil hair gel formulation (F3) against (a) *Staphylococcus aureus*, (b) *Escherichia coli*, (c) *Candida albicans*, and (d) *Aspergillus niger*.

DISCUSSION

The present study successfully developed a xanthan gum-based herbal gel containing *Allium sativum* oil for potential antidandruff application. *Allium sativum* oil was selected as the active ingredient due to its well-established antimicrobial activity, particularly against microorganisms associated with scalp disorders. The developed UV spectrophotometric method exhibited satisfactory linearity within the selected concentration range, confirming its suitability for quantitative estimation of garlic oil during formulation evaluation and diffusion studies.

The physicochemical evaluation demonstrated that all prepared formulations possessed acceptable characteristics for topical application. The gels were homogeneous, smooth, and free from phase separation, indicating good compatibility between the formulation components. Furthermore, the pH values remained within the physiological range of the scalp, suggesting that the formulations are unlikely to cause irritation during application. Such pH compatibility is important for maintaining the natural scalp barrier and supporting overall scalp health.

Xanthan gum concentration had a pronounced influence on the rheological and application properties of the formulations. Increasing polymer concentration resulted in higher viscosity and lower spreadability, which is consistent with the formation of a denser polymeric network. All formulations exhibited pseudoplastic behavior, characterized by a reduction in viscosity with increasing shear rate. This rheological property is advantageous for topical gels, as it facilitates easy spreading during application while maintaining sufficient consistency after administration. The observed relationship between viscosity and spreadability highlights the importance of polymer optimization in achieving desirable formulation performance.

Drug content analysis confirmed efficient incorporation of *Allium sativum* oil within the gel matrix and demonstrated satisfactory content uniformity among the formulations. Among the prepared formulations, F3 exhibited the most favourable balance of physicochemical properties, including suitable viscosity, acceptable spreadability, scalp-compatible pH, and the highest drug content. These characteristics justified its selection as the optimized formulation for further evaluation.

The optimized formulation exhibited efficient drug release, achieving more than 90% cumulative release within 60 min. The release pattern suggests effective diffusion of the active constituents from the hydrated xanthan gum matrix, thereby ensuring their availability at the site of application. Efficient release of garlic oil is particularly important for topical antimicrobial formulations, as therapeutic activity depends on the availability of active constituents at the scalp surface.

The antimicrobial studies confirmed the broad-spectrum activity of both pure garlic oil and the optimized gel formulation against the tested bacterial and fungal pathogens. The retention of antimicrobial activity following formulation indicates that incorporation into the xanthan gum matrix did not adversely affect the bioactive constituents responsible for microbial inhibition. The ability of the optimized gel to maintain antimicrobial efficacy, combined with its favorable physicochemical characteristics and drug release behavior, highlights its potential as a natural topical preparation for dandruff management and scalp care.

Overall, the findings demonstrate that xanthan gum is a suitable natural polymer for the development of garlic oil-based topical gels. The optimized formulation exhibited desirable physicochemical properties, efficient drug release, and preserved antimicrobial activity, supporting its potential application as a herbal antidandruff formulation. Further studies involving long-term stability evaluation, skin compatibility assessment, and *in vivo* efficacy studies are warranted to establish its therapeutic usefulness.

CONCLUSION

A xanthan gum-based herbal gel containing *Allium sativum* oil was successfully formulated and evaluated. The developed formulations exhibited acceptable physicochemical properties, including suitable pH, spreadability, viscosity, and drug content. Among the formulations, F3 was identified as the optimized formulation based on its balanced physicochemical characteristics and highest drug content. The optimized gel showed efficient drug release and retained the antimicrobial activity of *Allium sativum* oil against the tested bacterial and fungal pathogens. The results suggest that the developed *Allium sativum* oil hair gel has potential as a natural topical antidandruff formulation for scalp care and management of microbial scalp conditions.

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Conflicts of Interest

The authors declare no conflict of interest

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