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Comparative Development, Optimization and Characterization of *Allium sativum L.* and *Calendula officinalis L.* Polymeric Microsponge Gels

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Abstract

This study comparatively developed polymeric microsponge gels containing *Allium sativum* L. extract and *Calendula officinalis* L. essential oil for controlled topical delivery. Garlic was selected for its organosulfur antifungal constituents, whereas calendula was selected for its flavonoids, triterpenoids and volatile components with antifungal and skin-supportive relevance. Garlic extraction produced an 18.6% w/w semisolid extract, while hydrodistillation of dried calendula flowers produced 0.74% v/w essential oil. Microsponges were prepared by quasi-emulsion solvent diffusion using ethyl cellulose, polyvinyl alcohol and drug-to-polymer ratios of 1:1, 1:2 and 1:3. Calendula formulations additionally contained polyethylene glycol 400 to disperse the oil. Increasing polymer concentration improved production yield, drug loading and entrapment for both actives. The selected ASMS-3 and COMS-3 formulations showed yields of 82 ± 1.4% and 80 ± 1.5%, entrapment efficiencies of 88 ± 1.1% and 85 ± 1.0%, and particle sizes of approximately 45 and 46 µm, respectively. Instrumental analysis gave Z-average sizes of 45.3 ± 1.2 µm for garlic and 46.8 ± 1.4 µm for calendula, with polydispersity indices below 0.3. Scanning electron microscopy confirmed spherical porous particles. Eight-hour cumulative release reached 86 ± 1.8% for garlic and 82 ± 1.6% for calendula. The optimized particles were separately incorporated into 1% Carbopol 934 gel. Both gels were homogeneous, spreadable and skin compatible; garlic gel showed pH 5.8 ± 0.2 and viscosity 2850 ± 120 cP, while calendula gel showed pH 6.0 ± 0.2 and viscosity 2950 ± 115 cP. Both retained more than 90% content after 90 days. The results show that the same microsponge platform can accommodate chemically different herbal actives while producing distinct but acceptable loading, release and gel characteristics.

Keywords Allium sativum, Calendula officinalis, herbal microsponges, ethyl cellulose, Carbopol gel, controlled release, comparative formulation

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1. Introduction

Herbal topical formulations are often developed by mixing an extract or essential oil directly into a gel, cream or ointment. Although this approach is simple, it may not adequately protect unstable constituents, control release or overcome poor aqueous solubility. Volatile oils can evaporate or oxidize, while reactive constituents may degrade during storage. Direct exposure can also intensify odour or irritation. These limitations are particularly relevant to *Allium sativum L.* and *Calendula officinalis L.*, two plants with different phytochemical profiles but established relevance to antifungal and dermatological research.

Garlic contains alliin, allicin and other organosulfur compounds. Allicin is generated when plant tissue is disrupted and can react with thiol-containing microbial proteins. This chemistry supports activity against yeasts and other fungi, but it also contributes to instability and a strong characteristic odour (Ankri and Mirelman, 1999; Borlinghaus et al., 2014). Calendula flowers contain flavonoids, triterpenoids, saponins, carotenoids, phenolics and essential-oil constituents. Calendula is valued not only for antimicrobial potential but also for anti-inflammatory and wound-supportive properties, which are relevant because superficial fungal infections may be accompanied by erythema, itching and barrier damage (Gazim et al., 2008; Chanaj-Kaczmarek et al., 2020). Its essential oil, however, is volatile, poorly miscible with water and sensitive to oxidation.

A comparative formulation study is useful because biological promise does not automatically predict performance in a finished dosage form. Garlic may provide higher direct antifungal potency but may be more difficult to formulate acceptably. Calendula may have a milder odour and better sensory characteristics but lower loading or faster release because of the volatile nature of its oil. Testing both materials under a common polymeric platform allows the influence of active-material chemistry to be separated from the influence of preparation conditions.

Microsponges provide such a platform. They are porous polymeric particles capable of retaining active materials within an internal network and releasing them gradually into a vehicle. Ethyl cellulose is suitable for constructing a hydrophobic matrix, while polyvinyl alcohol stabilizes emulsion droplets during preparation. The quasi-emulsion solvent-diffusion technique is attractive because it is comparatively simple, does not require polymerization of monomers and can be adapted to both semisolid extracts and oils. Once dried, microsponges can be dispersed in a Carbopol gel that supplies topical consistency, spreadability and washability (Maiti et al., 2011; Mahant et al., 2020).

Optimization must consider drug-to-polymer ratio, stabilizer concentration, particle size, production recovery, loading and release. Increasing polymer can improve entrapment but may slow diffusion or modify particle size. Increasing PVA can improve droplet stabilization but may leave surface-associated stabilizer and alter particle characteristics. For a gel product, these microsponge properties must then be considered together with pH, consistency, viscosity, spreadability, content uniformity and storage stability. A formulation cannot be considered successful merely because particles form; it must also create a practical semisolid dosage form.

Using two plants within the same experimental framework adds analytical value. If formulation conditions are matched, recurring trends can be attributed to the platform, whereas differences can be linked to active-specific properties such as volatility, polarity and physical state. Such a design is more informative than two unrelated single-plant studies because it identifies both the general operating range of the carrier and the adjustments required for each botanical material.

The present paper compares the formulation and characterization of *Allium sativum* extract and *Calendula officinalis* essential-oil microsponges under closely matched conditions. It addresses four objectives: selection of the two herbal materials as topical antifungal candidates; preparation of polymeric microsponges; incorporation of optimized particles into a suitable gel base; and comparative optimization and characterization based on polymer concentration, drug loading, production yield, entrapment efficiency, particle size, surface morphology, release, gel properties and stability. Antifungal bioassay and animal-irritation outcomes are not the primary focus, allowing a detailed analysis of the pharmaceutical-development component.

2. Materials and Methods

2.1 Herbal materials and active preparation

Fresh *Allium sativum L.* bulbs and *Calendula officinalis L.* flowers were selected in healthy condition and authenticated by macroscopic and organoleptic examination. Garlic cloves were cleaned, peeled, dried under controlled conditions, powdered and sieved. Extraction and solvent removal produced a dark-brown, viscous semisolid. Calendula flowers were dried while preserving their yellow-orange colour and floral aroma. Essential oil was isolated from 250 g dried flowers by hydrodistillation using a Clevenger apparatus. Both actives were stored in amber containers at 4 ± 2°C.

2.2 Pre-formulation studies

Colour, odour, physical state, pH and solubility were recorded. Garlic extract was dark brown, semisolid and pungent, whereas calendula oil was a clear yellow-to-orange liquid with a mild floral aroma. A 10% garlic dispersion had a pH of 5.8 ± 0.2, and a 1:9 ethanolic dilution of calendula oil had a pH of 5.5 ± 0.1. Garlic extract was highly soluble in ethanol and methanol, while calendula oil was completely soluble or miscible in ethanol, chloroform, propylene glycol and PEG 400. Both materials showed poor aqueous solubility, supporting use of an organic internal phase.

Phytochemical screening confirmed a strong predominance of sulfur compounds and carbohydrates in garlic, with moderate flavonoids and proteins. Calendula showed strong flavonoids, steroids/triterpenoids and essential-oil constituents, together with moderate saponins and tannins. Physical compatibility and FTIR screening were conducted with ethyl cellulose, PVA, PEG 400, Carbopol 934, preservatives and triethanolamine. Absence of phase separation, caking, major odour change and new or disappearing FTIR peaks was used as evidence of compatibility.

2.3 Comparative microsponge design

Six batches were prepared for each active. Garlic batches were coded ASMS-1 to ASMS-6 and calendula batches COMS-1 to COMS-6. Each contained 100 mg active or active equivalent. Ethyl cellulose was used at 100, 200 or 300 mg, creating drug-to-polymer ratios of 1:1, 1:2 and 1:3. For each ratio, PVA was used at either 0.5% or 1.0% w/v in 100 mL external aqueous phase. The garlic internal phase contained 5 mL dichloromethane and 5 mL ethanol. The calendula internal phase contained 5 mL dichloromethane, 4.5 mL ethanol and 0.5 mL PEG 400; PEG 400 improved dispersion of the lipophilic oil.

2.4 Microsponge preparation

Active material and ethyl cellulose were dissolved or dispersed in the relevant 10 mL internal phase and sonicated for five minutes. This phase was added dropwise over ten minutes to the PVA solution during mechanical stirring at 1000 rpm.

Stirring continued for three hours at 25 ± 2°C. Solvent diffusion and evaporation caused polymer precipitation around the active phase and formation of porous particles.The microsponges were filtered, washed three times with 20 mL distilled water and dried at 40 ± 2°C for 24 hours. They were stored in amber glass at 4 ± 2°C.

Table 1. Comparative microsponge formulation variables

Variable	Garlic system (ASMS)	Calendula system (COMS)
Active per batch	100 mg extract	100 mg oil equivalent
Ethyl cellulose	100, 200, or 300 mg	100, 200, or 300 mg
Drug:polymer ratio	1:1, 1:2, or 1:3	1:1, 1:2, or 1:3
Internal phase	5 mL DCM + 5 mL ethanol	5 mL DCM + 4.5 mL ethanol + 0.5 mL PEG 400
External phase	100 mL PVA solution	100 mL PVA solution
PVA concentration	0.5% and 1.0% w/v	0.5% and 1.0% w/v
Stirring conditions	1000 rpm for 3 h	1000 rpm for 3 h

2.5 Optimization framework

Production yield, drug content, entrapment efficiency, particle size, flow, aggregation, morphology and eight-hour release were evaluated. A suitable batch required at least 70% yield and entrapment, particle size between approximately 10 and 100 µm, spherical porous morphology, no visible aggregation and sustained release for six to eight hours. The comparative design kept active quantity, solvent volume, external-phase volume, stirring speed and processing time constant so that differences could be related mainly to active type, polymer ratio and PVA concentration.

2.6 Characterization

Production yield was calculated from dried microsponge mass relative to theoretical active-plus-polymer mass. Drug content was measured after extracting 100 mg particles with ethanol, sonicating for 15 minutes, filtering and analysing spectrophotometrically. Entrapment efficiency was the percentage of theoretical active recovered within the dried particles.

Particle size was initially evaluated microscopically and then measured instrumentally for selected batches. Z-average, PDI, D10, D50 and D90 were recorded. Surface morphology was examined by scanning electron microscopy after gold coating. FTIR spectra of actives, polymer and optimized particles were compared for compatibility, and DSC was used to assess thermal behaviour and physical dispersion. *In-vitro* release was measured at 0.5, 1, 2, 3, 4, 6 and 8 hours and reported as cumulative percentage.

2.7 Gel preparation

The selected garlic and calendula microsponges were separately incorporated into an identical Carbopol base. Carbopol 934, 1 g, was hydrated in 70 mL water for 24 hours. Methyl paraben 0.18 g and propyl paraben 0.02 g were dissolved in 5 mL propylene glycol. Glycerin 5 g was added, and the base was stirred at 500 rpm. Microsponges equivalent to 1% w/w active were incorporated for 30 minutes. Triethanolamine adjusted the pH to approximately 6.0, and the final weight was made to 100 g. The products were coded ASMG and COMG.

2.8 Gel evaluation and stability

Appearance, colour, odour, homogeneity, pH, viscosity, spreadability, extrudability, washability and active content were evaluated in triplicate. pH was measured after dispersing 1 g gel in 10 mL water. Viscosity was determined using a Brookfield viscometer with spindle 64 at 20 rpm. Spreadability was evaluated between glass slides under a 500 g load, and content was measured after ethanol extraction and spectrophotometry.

Both gels were evaluated for 90 days under room and accelerated conditions. At 0, 30, 60 and 90 days they were examined for physical change, pH, viscosity and content retention. A stable formulation was required to remain homogeneous, free from phase separation, within pH 5.5-6.5 and above 90% initial content.

2.9 Data analysis and control of comparability

Measurements were performed in triplicate and expressed as mean ± standard deviation. Comparisons emphasized the direction and magnitude of changes caused by polymer ratio and active type. The optimized batches were identified through an integrated assessment rather than a single-response maximum. Both active systems used the same ethyl-cellulose levels, PVA levels, external-phase volume, stirring speed, stirring duration and drying conditions. The addition of PEG 400 was the principal formulation adjustment required for the calendula oil. This standardization was intended to make comparative interpretation scientifically meaningful.

3. Results

3.1 Active Recovery and Preformulation Findings

Garlic powder produced 18.6 g of semisolid extract from 100 g of dried material, corresponding to a recovery of 18.6% w/w. Hydrodistillation of 250 g of dried calendula flowers produced 1.85 mL of essential oil, equivalent to a recovery of 0.74% v/w. Therefore, garlic produced a substantially higher crude recovery, whereas calendula yielded a smaller volume of highly concentrated volatile oil. Both active materials were compatible with the selected organic solvents and formulation excipients.

Table 2. Comparative preformulation characteristics of *Allium sativum* and *Calendula officinalis*

Parameter	***Allium sativum***	***Calendula officinalis***
Plant part	Bulbs/cloves	Flowers
Active form	Semisolid extract	Essential oil
Colour and odour	Dark brown and pungent	Yellow-orange and floral
Recovery	18.6% w/w	0.74% v/w
Aqueous solubility	Poor	Insoluble
Key constituents	Organosulfur compounds	Flavonoids, triterpenoids, and volatile oil

3.2 Effect of Formulation Variables

For both plant systems, formulations prepared at a 1:1 drug-to-polymer ratio showed the lowest production yield and entrapment efficiency and produced relatively irregular particles.

At 0.5% PVA, the production yield of ASMS increased from 65 ± 1.2% at a 1:1 ratio to 82 ± 1.4% at a 1:3 ratio. Similarly, the production yield of COMS increased from 63 ± 1.3% to 80 ± 1.5%.

Entrapment efficiency increased from 60 ± 1.5% to 88 ± 1.1% for the garlic system and from 58 ± 1.4% to 85 ± 1.0% for the calendula system. Particle size decreased from 58 ± 2.1 µm to 45 ± 1.5 µm for garlic and from 60 ± 2.0 µm to 46 ± 1.6 µm for calendula.

At 1.0% PVA, a similar polymer-dependent pattern was observed. The 1:3 formulations achieved production yields of 83 ± 1.3% for garlic and 81 ± 1.4% for calendula. Their corresponding entrapment efficiencies were 90 ± 1.0% and 87 ± 1.2%, respectively.

Based on the overall formulation characteristics, ASMS-3 and COMS-3 were selected for gel development. ASMS-3 showed a production yield of 82 ± 1.4%, drug content of 88 ± 1.1%, entrapment efficiency of 88 ± 1.1%, particle size of 45 ± 1.5 µm, and spherical morphology. COMS-3 showed a production yield of 80 ± 1.5%, drug content of 85 ± 1.0%, entrapment efficiency of 85 ± 1.0%, particle size of 46 ± 1.6 µm, and predominantly spherical morphology. Overall, the garlic formulation showed values approximately two to three percentage points higher than the calendula formulation for production yield and active retention.

Table 3. Optimized microsponge characteristics

Parameter	ASMS-3	COMS-3
Drug-to-polymer ratio	1:3	1:3
Production yield	82 ± 1.4%	80 ± 1.5%
Drug content	88 ± 1.1%	85 ± 1.0%
Entrapment efficiency	88 ± 1.1%	85 ± 1.0%
Screening particle size	45 ± 1.5 µm	46 ± 1.6 µm
Instrumental Z-average	45.3 ± 1.2 µm	46.8 ± 1.4 µm
Polydispersity index	0.246	0.263
Morphology	Spherical and porous	Predominantly spherical and porous

3.3 Particle-Size and Morphology Comparison

The instrumental Z-average particle size was 45.3 ± 1.2 µm for ASMS-3 and 46.8 ± 1.4 µm for COMS-3. The corresponding polydispersity index values were 0.246 and 0.263.

For ASMS-3, the D10, D50, and D90 values were 18.7, 44.6, and 92.3 µm, respectively. For COMS-3, the corresponding values were 19.3, 46.2, and 95.8 µm. Both particle-size distributions were considered suitable for topical application.

Scanning electron microscopy showed spherical, porous particles without visible cracks or aggregation. Garlic microsponges appeared more uniform, whereas calendula microsponges were predominantly spherical but showed slightly greater particle-size variation.

3.4 In-Vitro Release Comparison

ASMS-3 released 12%, 22%, 35%, 48%, 60%, 75%, and 86% of the active material at 0.5, 1, 2, 3, 4, 6, and 8 hours, respectively. At the same time points, COMS-3 released 10%, 19%, 32%, 45%, 57%, 72%, and 82%, respectively.

Both formulations demonstrated sustained-release behaviour. However, the garlic formulation maintained approximately three to four percentage points higher release than the calendula formulation between 1 and 8 hours. Neither formulation released most of its active content during the initial sampling period, indicating the absence of a pronounced burst-release effect.

Table 4. Comparative in-vitro release profiles

Time (h)	ASMS-3 (%)	COMS-3 (%)
0.5	12 ± 0.8	10 ± 0.7
1	22 ± 1.0	19 ± 0.9
2	35 ± 1.2	32 ± 1.1
3	48 ± 1.3	45 ± 1.2
4	60 ± 1.5	57 ± 1.3
6	75 ± 1.6	72 ± 1.4
8	86 ± 1.8	82 ± 1.6

3.5 Gel Properties

Table 5. Comparative properties of the optimized gels

Parameter	ASMG	COMG
Appearance	Smooth and off-white	Smooth and pale yellow
Odour	Mild garlic odour	Floral herbal odour
pH	5.8 ± 0.2	6.0 ± 0.2
Viscosity	2850 ± 120 cP	2950 ± 115 cP
Spreadability	Good	Good
Extrudability	Good	Good
Drug content	89 ± 1.2%	86 ± 1.3%

ASMG was a smooth, off-white gel with a mild garlic odour, whereas COMG was a smooth, pale-yellow gel with a floral herbal odour. Both gels were homogeneous, easily washable, readily extrudable, and showed good spreadability. The pH of ASMG was 5.8 ± 0.2, while its viscosity was 2850 ± 120 cP. COMG showed a pH of 6.0 ± 0.2 and a viscosity of 2950 ± 115 cP. The drug content was 89 ± 1.2% for ASMG and 86 ± 1.3% for COMG. Therefore, the calendula gel was slightly more viscous, whereas the garlic gel showed somewhat higher active content.

3.6 Stability Findings

No visible colour change, odour deterioration, grittiness, or phase separation was observed in either formulation during the 90-day stability period.

The pH of ASMG decreased from 5.8 on day 0 to 5.6 on day 90, while its viscosity decreased from 2850 to 2720 cP. The pH of COMG decreased from 6.0 to 5.8, while its viscosity decreased from 2950 to 2820 cP.

At the end of 90 days, active-content retention was 92.6% for ASMG and 91.8% for COMG. Both formulations remained within the predefined acceptance limits, although the garlic gel showed marginally higher content retention.

Table 6. Comparative 90-day stability results

Time	ASMG pH	COMG pH	ASMG viscosity	COMG viscosity	ASMG content	COMG content
Day 0	5.8	6.0	2850 cP	2950 cP	100%	100%
Day 30	5.7	5.9	2800 cP	2900 cP	97.8%	96.5%
Day 60	5.6	5.8	2750 cP	2850 cP	95.2%	94.1%
Day 90	5.6	5.8	2720 cP	2820 cP	92.6%	91.8%

4. Discussion

The comparative results show that the same basic microsponge method can accommodate two herbal actives with very different physical and chemical properties. Garlic was introduced as a viscous semisolid extract rich in reactive sulfur compounds, whereas calendula was introduced as a low-yield volatile oil rich in terpenoid and flavonoid-related constituents. The use of ethyl cellulose and an organic internal phase provided a common matrix, while the addition of PEG 400 to calendula addressed the oil's dispersion requirements. This illustrates an important advantage of microsponge technology: the process can be adjusted through solvent and cosolvent selection without changing the central carrier concept.

The recovery of the starting actives highlights different manufacturing challenges. Garlic produced an 18.6% extractive yield, providing a comparatively abundant semisolid material. Calendula oil recovery was only 0.74%, which is typical of volatile botanical fractions but has consequences for cost, batch scale and standardization. A low oil yield increases the importance of minimizing loss during formulation. The 85% entrapment achieved by COMS-3 is therefore pharmaceutically meaningful, even though it was slightly lower than the garlic value. Polymer concentration was the dominant formulation factor for both actives. Increasing the ethyl-cellulose ratio improved production yield, drug content and entrapment and converted irregular particles into spherical forms. A higher polymer quantity increases internal-phase viscosity and provides more matrix material around each droplet, limiting movement of active into the surrounding aqueous phase. This explanation is consistent with prior microsponge studies (Kaity et al., 2010; Maiti et al., 2011). The similar response pattern across garlic and calendula indicates that the effect was primarily process-related rather than unique to one phytochemical class.

Garlic nevertheless achieved consistently higher loading and recovery. The difference was modest but repeated across yield, drug content and entrapment. Calendula's volatile components may have been more susceptible to transfer or evaporation during the three-hour diffusion process. Garlic's semisolid extract may also have interacted more strongly with the hydrophobic polymer matrix. The study did not quantify individual markers in the external phase, so these explanations remain mechanistic interpretations rather than direct measurements. Future mass-balance studies should assay allicin and a selected calendula marker before and after encapsulation.

Both selected formulations had particle sizes around 45-47 µm and PDI below 0.3. These properties support uniform dispersion and reduce the risk of a gritty topical product. Calendula particles were approximately 1.5 µm larger and had a slightly higher PDI, which may reflect the interfacial behaviour of the oil-containing phase. Nevertheless, the differences were small and both systems met the intended criteria. SEM showed the spherical porous morphology required for reservoir-type release. The absence of cracks and aggregation also supports the effectiveness of the selected stirring speed, PVA concentration and drying conditions. The release curves were closely aligned, confirming that ethyl cellulose was the main diffusion-controlling component. Garlic release was slightly higher at every time point, reaching 86% at eight hours compared with 82% for calendula. This result can be interpreted in two ways. It may indicate more efficient diffusion of garlic constituents through water-filled pores, or a somewhat stronger retention of lipophilic calendula components within the polymer and gel environment. The study's broader discussion suggested a more prolonged garlic pattern, but the numerical data show higher cumulative garlic release at eight hours. The defensible conclusion is therefore that both formulations sustained release and that garlic showed modestly greater cumulative release under the test conditions. Detailed kinetic fitting would be required to distinguish diffusion, erosion or partition-controlled mechanisms. The gels demonstrate how the microsponges translated into a practical semisolid product. Both pH values were compatible with the skin, and neither formulation showed phase separation or grittiness. COMG was slightly more viscous, possibly because the oil-containing microsponges interacted differently with the hydrated Carbopol network. ASMG had slightly higher active content. The qualitative spreadability and extrudability results suggest that neither difference impaired application. Calendula's floral odour and pale colour may provide a sensory advantage, while the microsponge system reduced but did not eliminate garlic's characteristic odour.

Stability was similar for both products. Small reductions in viscosity and pH occurred over 90 days, but the gels remained within the accepted ranges. Garlic retained 92.6% content and calendula 91.8%. These values indicate that encapsulation and protected storage reduced, but did not completely prevent, loss of active. The slightly greater decline in calendula is compatible with volatility and oxidation of essential-oil components. Longer-term stability should use chromatographic markers rather than total spectrophotometric content, because total absorbance can remain stable even if the proportions of individual constituents change. The comparative design has several strengths. Both plants were processed through matched polymer ratios, PVA levels, stirring conditions and gel composition. This reduces process-related confounding and makes the differences in particle and gel behaviour more interpretable. The study also evaluated the complete development chain from active preparation to stability. However, it used a one-factor-at-a-time screening matrix rather than a fully randomized factorial design. Spreadability was reported qualitatively in the final result table, residual solvents were not quantified, and no plant-specific standardization marker was used for loading or release. These limitations should be addressed before scale-up.The findings also show why a common platform should not be interpreted as producing interchangeable products. The actives retained their sensory and physicochemical identities after encapsulation. Garlic offered better recovery and loading, while calendula required a cosolvent and generated a slightly more viscous, more pleasantly scented gel. Product development should therefore preserve a shared quality framework but establish plant-specific marker assays, release specifications and storage controls.Overall, garlic showed a small advantage in yield, entrapment, drug content, cumulative release and content retention. Calendula produced a slightly more viscous gel and a more acceptable floral sensory profile. The formulations should therefore not be viewed as identical products. Rather, the common microsponge platform successfully produced two viable topical systems while preserving differences arising from the active materials. This is the central value of comparative formulation research: it identifies both general platform performance and active-specific requirements.

5. Conclusion

Polymeric microsponges of *Allium sativum L.* extract and *Calendula officinalis L.* essential oil were successfully prepared under matched quasi-emulsion solvent-diffusion conditions and incorporated into a common Carbopol 934 gel base. A 1:3 drug-to-polymer ratio provided the best overall performance. Garlic microsponges showed slightly higher yield, entrapment, active content and cumulative release, whereas calendula produced an equally acceptable porous particle system and a smooth, slightly more viscous gel with a favourable odour. Both formulations had particle sizes near 45-47 µm, skin-compatible pH, good spreadability and more than 90% content retention after 90 days. The findings confirm that ethyl-cellulose microsponge gel is a flexible platform for topical delivery of chemically different herbal antifungal candidates and provide a basis for marker-based optimization and longer-term stability studies.

6. Declarations

Competing interests: The author(s) declare no competing interests.

Author contributions: Ayushi Srivastava contributed to conceptualization, methodology, investigation, formulation development, data collection, analysis, and preparation of the original manuscript. Sushila Kaura supervised the study, validated the methodology and results, and critically reviewed and edited the manuscript. Both authors approved the final version.

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