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Plant-Based Hydrogel Composition for Dermatological Application and Method of Preparation

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Abstract

This study investigates the integration of herbal extracts into topical acne treatments, focusing on formulation development and pharmacological aspects. A comprehensive literature review will identify herbal extracts with established anti-acne properties, including antibacterial, anti-inflammatory, and sebum-regulating effects. Factors such as solubility, permeability, and stability influencing topical delivery will be assessed to guide the selection of suitable extraction methods and formulation strategies. The development process involves incorporating selected herbal extracts into various topical dosage forms like gels, creams, and emulsions, ensuring stability, enhanced bioavailability, and optimal physicochemical characteristics. Pharmacological evaluation includes an in-depth analysis of the mechanisms underlying the anti-acne effects of herbal extracts, examining interactions with relevant molecular targets and biological processes involved in acne pathophysiology. The formulations' antibacterial, anti-inflammatory, and sebum-regulating properties will be assessed through in vitro and ex vivo experiments. The findings aim to provide valuable insights into the pharmacological mechanisms of natural resources, facilitating the development of novel, safe, and effective topical acne therapies.

Keywords

Herbal extracts, Topical acne formulations, Formulation development, Pharmacological mechanisms, Anti-acne properties

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INTRODUCTION

Acne vulgaris is a long-lasting skin inflammation that affects anyone of any age and social status. The exact etiology is unknown, but it is thought to involve interactions between several bacterial strains, hormonal imbalances, and inflammatory processes. Propionibacterium acnes, Staphylococcus aureus, and Escherichia coli are among the most important microbial species in acne vulgar [1]. P. acnes, an anaerobic Gram-positive bacterium that thrives in areas rich in sebum and causes inflammation through the production of enzymes that break down sebum, is regarded as the major causative agent. S. aureus colonizes the skin and aggravates existing acne lesions through the excretion of virulence factors, whereas E. coli, which has also been discovered in some instances of acne vulgaris, can potentially participate in the inflammatory process [2].

The pilosebaceous unit, which includes sebaceous glands, hair follicles, and related structures, is closely related to the development of acne vulgaris. Excess sebum, an oily material generated by the sebaceous glands, is one of the primary causes of acne. Excess sebum, along with aberrant keratinization of the follicular epithelium, causes the production of microcomedones, the precursor lesions of acne. Furthermore, colonization of hair follicles by Propionibacterium acnes promotes inflammation and the production of inflammatory lesions [3].

Hormonal fluctuations that occur, especially during puberty, are factors that highly contribute to the pathogenesis of acne. They accelerate the stimulation of sebaceous glands by androgen testosterone to produce even more sebum and deteriorate the condition of acne. Other hormonal factors such as menstrual cycles, pregnancy, and polycystic ovarian syndrome influence the development of acne. In addition to hormonal influences, there is another major genetic predisposition. A family history of acne increases the likelihood of developing the condition [4].

Other environmental factors, such as diet, stress, pollution, and medications, influence the severity of the disease. Foods with a high glycemic index, dairy products, and diets high in processed sugars and fat are among the many foods implicated in aggravating acne [5]. Psychological stress can exacerbate acne through a variety of pathways, such as hormonal and inflammatory mediators, whereas environmental exposure to pollutants and comedogenic substances can affect follicular occlusion and inflammatory changes.

Conventional treatments for this condition often include oral or topical medications to curb bacterial growth, control sebum production, and reduce swelling [6]. Salicylic acid, a topical treatment option, is a synthetic beta-hydroxy acid (BHA) with keratolytic activity that is effective against both non-inflammatory acne lesions and those characterized by inflammation [7].

Both conventional and alternative therapies have been investigated for effective control of acne vulgaris. Conventional therapies include topical and oral drugs designed to reduce bacterial growth, regulate sebum production, and reduce irritation. One such topical therapy is salicylic acid, a synthetic beta-hydroxy acid (BHA) having keratolytic, antimicrobial, and anti-inflammatory effects [8]. By assisting in the breakdown and elimination of extra skin cells that might clog pores and display antibacterial and anti-inflammatory properties, salicylic acid is useful in treating both inflammatory and non-inflammatory acne infections [9].

In recent years, natural remedies have gained popularity as alternative treatments or supportive interventions for acne vulgaris. Aloe vera gel contains polysaccharides, antioxidants, and plant steroids that can reduce inflammation and soothe and moisturize the skin [10]. This method can remove redness, calm down irritation, and swelling caused by acnes while supplying its deficient water balance due to other cures of pimples [11].

During the past few years, natural drugs have been considered possible alternative or adjuvant treatments for acne vulgaris. The plant has Aloe vera gel, which is full of polysaccharides, antioxidants, and plant sterols, and has anti-inflammatory, soothing, and moisturizing properties that reduce the redness, itching, and swelling of acneous lesions [12]. Green tea extract obtained from Camellia sinensis: a plant demonstrates antimicrobial, anti-inflammatory, and antioxidant properties that help balance sebum production and prevent the growth of P. acnes organisms with inflammation around acne lesions [13].

Tea tree oil is an essential oil extracted from the Australian native Melaleuca alternifolia, which has become popular for its antibacterial and anti-inflammatory properties in relation to acne treatment. Neem extract is derived from the leaves of the neem tree (Azadirachta indica) and has antibacterial properties that reduce inflammation associated with acne [14]. Witch hazel extract made out of Hamamelis virginiana: A plant is valued for its tightening ability and anti-inflammatory features, potentially preventing the build-up of excess sebum, which blocks the skin pores and limits the growth of microorganisms causing pimples.

Furthermore, many acne products may contain other additives, such as emollients and stabilizers, to improve their efficacy, storage capabilities, and overall beauty. Glycerin is a humectant that can absorb moisture in the skin and preserve it; polysorbate-20 disperses lipid-soluble pharmacologically active agents in solutions, preservatives such as phenoxyethanol inhibit the growth of bacteria and fungi, and flavonoids such as quercetin and kaempferol are natural anti-inflammatory antioxidants used as complementary or alternative therapies to synthetic actives [15].

Acne formulations contain different excipients, in addition to these active ingredients, to enhance their effectiveness, stability, and overall aesthetic appeal. Glycerin is a humectant that attracts and holds moisture in the skin, while polysorbate 20 is a non-ionic surfactant and emulsifier that aids in the dispersion of oil-soluble active compounds, thereby enhancing their distribution and action within the formulation [16]. Common preservatives used include phenoxyethanol, which prevents microbial growth and extends the shelf life of this product. Certain natural flavonoids, such as quercetin and kaempferol, found in different plants, fruits, vegetables, and herbs, have been studied for their anti-inflammatory and antioxidant properties, and are potential complementary or natural substitutes for synthetic active agents [17].

Despite the fact that acne vulgaris pathogenesis is complex with contributions from a variety of factors,

including bacterial species, imbalances in hormones, and inflammatory processes, utilizing both traditional and natural therapies have been found to be useful. By targeting various elements involved in acne formation, including microbial colonization and inflammation regulation, these remedies relieve signs of the disease while promoting quick recovery, thus improving the general wellbeing of the skin. However, it is essential for one to seek advice from health care providers about designing tailored treatments that match patients' needs, severity of pimples' condition, and possible hazards associated with using unrelated conditions or alternatively, they use this option.

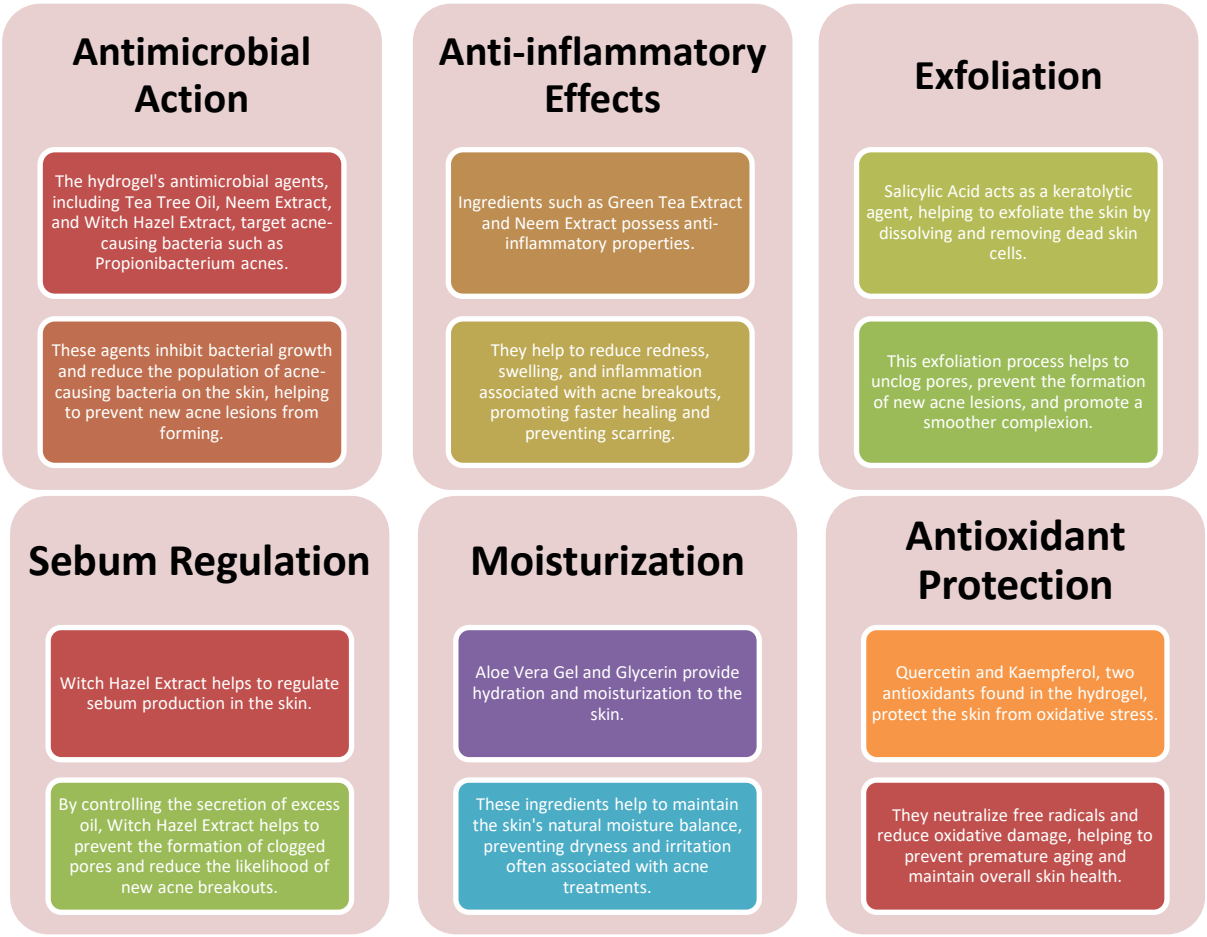


Fig 1: Pharmacological Properties of each ingredient.

MATERIALS AND METHODS

Materials:

- The aloe vera gel used in carrying out representative examples was procured from Patanjali Ayurved Limited.
- Green Tea extracts, Neem extract, Witch hazel extract, and Tea tree oil can be procured from any vendor dealing with such materials. In this regard, the extracts and oil to perform representative examples have been procured from BRM Herbals, Tilak Bazar, Khari Baoli, Chandni Chowk, Delhi.

Procedure:

- The workstation was prepared by cleaning and sanitizing glassware and equipment.
- Each ingredient was weighed and accurately measured using a weighing balance and glass beaker.
- Heat-distilled water was placed in a glass beaker on a hot plate/stirrer until it reached a temperature–70-80°C.
- While stirring continuously at a moderate speed, glycerol and polysorbate 20 were slowly added to heated water to facilitate dissolution.
- Once fully dissolved, add Salicylic Acid, Green Tea Extract, Tea Tree Oil, Neem Extract, Witch Hazel Extract, Quercetin, and Kaempferol to the solution and mix thoroughly until homogenized.
- The mixture was allowed to cool to room temperature with gentle stirring.

- The pH of the formulation was adjusted using pH adjusters (citric acid for lowering pH and sodium hydroxide for increasing pH) to achieve the desired pH range suitable for skin application (usually 5.5 to 6.5).
- Once the pH was adjusted, A. vera gel and phenoxyethanol were added to the solution and mixed thoroughly for incorporation.
- pH measurements were performed to confirm that the pH was within the desired range.
- The prepared hydrogels were transferred to sterile packaging containers using aseptic techniques to prevent contamination.
- Label each container with its formulation name, ingredients, usage instructions, and expiry date.
- The packaged hydrogel was stored in a cool, dry place, away from direct sunlight, until further use.

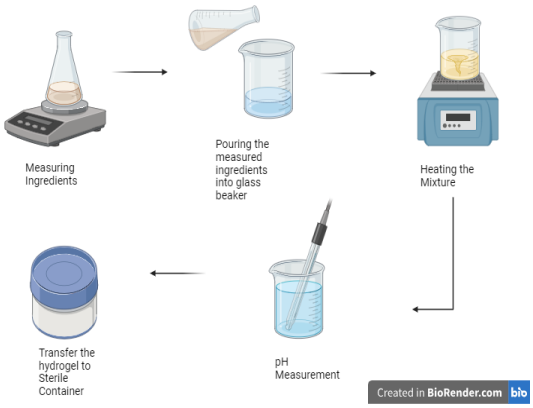


Fig 2: schematic diagram of preparation of anti-acne hydrogel formulation

Fig 3: Methodology of the hydrogel formulation

RESULT AND DISCUSSION

Table 1: Composition of developed formulation

Ingredient	Role	Formulation Code (F1)	Formulation Code (F2)	Formulation Code (F3)	Formulation Code (F4)
Aloe Vera Gel	Hydration, soothing	5%	4%	6%	5%
Salicylic Acid	Exfoliation, unclogging pores	1%	1.5%	1%	1%
Green Tea Extract	Antioxidant, anti-inflammatory	2%	1.5%	2%	2%
Tea Tree Oil	Antimicrobial, anti-inflammatory	0.5%	0.5%	0.3%	0.7%
Neem Extract	Antimicrobial, anti-inflammatory	2%	1.5%	1.8%	2.5%
Witch Hazel Extract	Sebum regulation, astringent	2%	2.2%	1.8%	2%
Glycerin	Moisturization, humectant	5%	6%	4%	5%
Polysorbate 20	Emulsifier	1%	0.8%	1.2%	1%
Phenoxyethanol	Preservative	0.5%	0.4%	0.6%	0.5%
Quercetin	Antioxidant	0.1%	0.2%	0.1%	0.1%
Kaempferol	Antioxidant	0.1%	0.1%	0.15%	0.05%
Distilled water	vehicle	q.s	q.s	q.s	q.s

The table provides a thorough summary of a topical acne treatment that has been designed, outlining each ingredient's function and concentration across four formulation codes (F1, F2, F3, and F4), and the targeted effects it is intended to have on key areas of acne pathophysiology. Salicylic Acid, which is present in concentrations of 1% to 1.5%, helps to exfoliate dead skin cells and unclog pores, while Aloe Vera Gel, which is present in concentrations of 4% to 6%, hydrates and soothes the skin. Targeting bacteria and inflammation linked to acne, green tea extract, tea tree oil, neem extract, and witch hazel extract provide antimicrobial and anti-inflammatory properties. Quercetin and kaempferol provide antioxidant support, and other components, such as glycerin, polysorbate 20, and phenoxyethanol, guarantee formulation stability [18].

Overall, the formulation represents a methodical attempt to fully address a range of acne-related issues. The formulation addresses the main causes of acne, such as inflammation, bacterial growth, and pore blockages, by carefully selecting the components and amounts of each. For those looking for an efficient way to control their acne-prone skin, the topical treatment offers a promising combination of moisturizing, exfoliating, antibacterial, and antioxidant characteristics.

Table 2: Evaluation of the formulation

S.No.	Formulation code	F1	F2	F3	F4
1	Appearance and Color	Normal	Normal	Normal	Normal
2	pH	6.1	5.9	6.1	6.0
3	Spreadability	6.59	6.38	6.8	6.7
4	Washability	good	good	good	good
5	Consistency	Smooth	Smooth	Smooth	Smooth

The assessment table assesses the appearance, pH, spreadability, washability, and consistency of the topical acne treatment. This demonstrates that every composition maintains a typical appearance and has pH levels that are within tolerable bounds, reducing the possibility of discomfort. These formulations are easily washable to improve cleanliness and have high spreadability to provide equal coverage and absorption. The application experience is made comfortable by a smooth consistency, which improves user happiness and compliance. The appropriateness of the treatment for skincare

applications is highlighted in the assessment table, which also recommends additional optimization to better fulfill customer expectations [19].

Table 3: Anti-bacterial activity of the ingredients

Ingredient	Staphylococcus aureus (mm)	Propionibacterium acnes (mm)	Escherichia coli (mm)
Aloe Vera Gel	3.0 ± 0.2	2.8 ± 0.8	2.2 ± 0.5
Salicylic Acid	3.2 ± 0.7	3.0 ± 0.6	2.5 ± 0.4
Green Tea Extract	3.5 ± 0.9	2.8 ± 0.2	2.0 ± 0.6
Tea Tree Oil	3.5 ± 0.1	3.5 ± 0.3	2.5 ± 0.8
Neem Extract	2.5 ± 0.3	2.5 ± 0.5	2.2 ± 0.6
Witch Hazel Extract	2.5 ± 0.2	2.5 ± 0.3	2.2 ± 0.5
Glycerin	0	0	0
Polysorbate 20	0	0	0
Phenoxyethanol	2.5 ± 0.1	3.0 ± 0.3	2.0 ± 0.8
Quercetin	2.5 ± 0.2	2.5 ± 0.3	2.0 ± 0.6
Kaempferol	2.5 ± 0.1	2.5 ± 0.2	1.5 ± 0.8

Table 3 provides an extensive examination of the antimicrobial characteristics of several substances used in topical acne treatment. The most effective component is salicylic acid, which has strong antibacterial action and is especially effective against Propionibacterium acnes. Strong antibacterial properties are also demonstrated by tea tree oil, which continuously inhibits every strain that has been tested. Despite not having any direct antibacterial action, glycerin and polysorbate 20 were necessary. Because of its broad-spectrum antibacterial action, green tea extract enhances the formulation strategy of focusing on microorganisms linked to acne. The antibacterial arsenal of therapy is further strengthened by the use of Neem and Witch Hazel extracts, whose combined antibacterial qualities and synergistic benefits address the pathophysiology of acne [20].

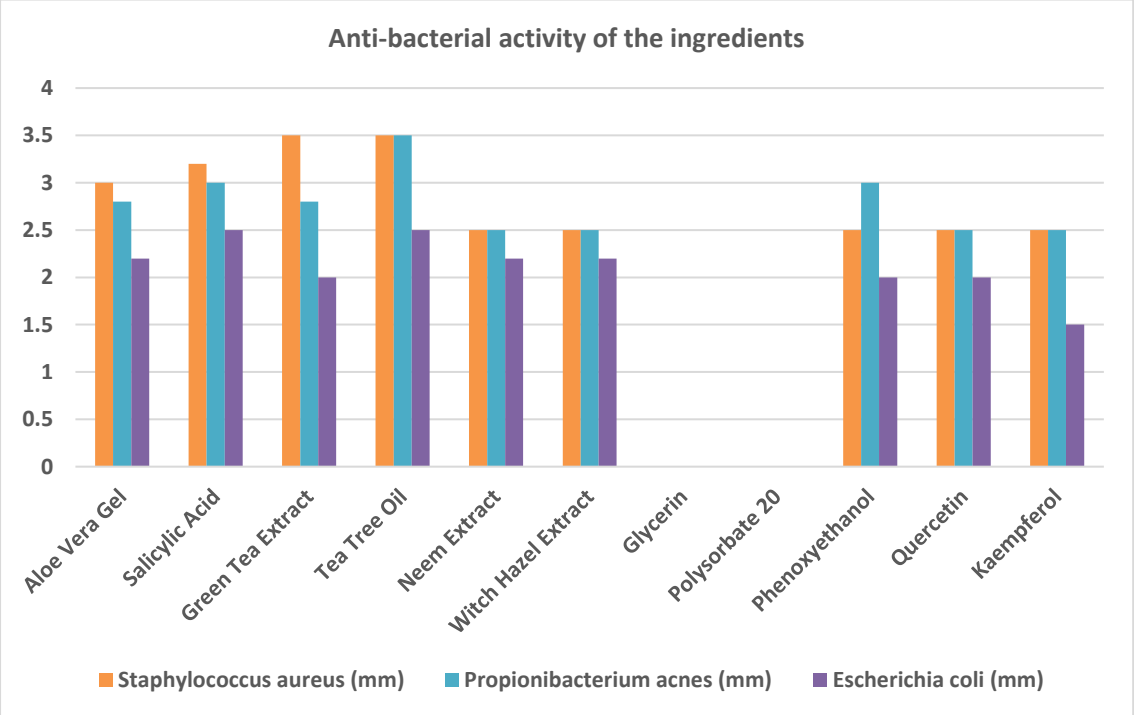


Table 4: Anti-bacterial activity of the formulation

Formulation Code	Staphylococcus aureus (mm)	Propionibacterium acnes (mm)	Escherichia coli (mm)
Formulation 1	28.0 ± 0.5	26.5 ± 0.4	26.0 ± 0.3
Formulation 2	27.5 ± 0.4	27.0 ± 0.5	25.8 ± 0.6
Formulation 3	29.0 ± 0.3	28.5 ± 0.4	26.5 ± 0.5
Formulation 4	30.0 ± 0.4	29.5 ± 0.6	28.0 ± 0.4

The antibacterial efficacy of several topical acne therapy formulations against the three major bacterial strains is shown in Table 4. The most potent formulation, number 4, showed the largest inhibition zones against Propionibacterium acnes and Staphylococcus aureus, demonstrating strong antibacterial activity. Despite having significantly smaller inhibition zones, Formulation 2 exhibited strong antibacterial activity against all tested strains. Although Formulation 3's effectiveness against Propionibacterium acnes is noteworthy, it lags somewhat behind that of Formulation 4. The formulation composition may have an impact on the treatment efficacy against particular bacterial strains, as indicated by Formulation 1's lowest inhibition zones [21].

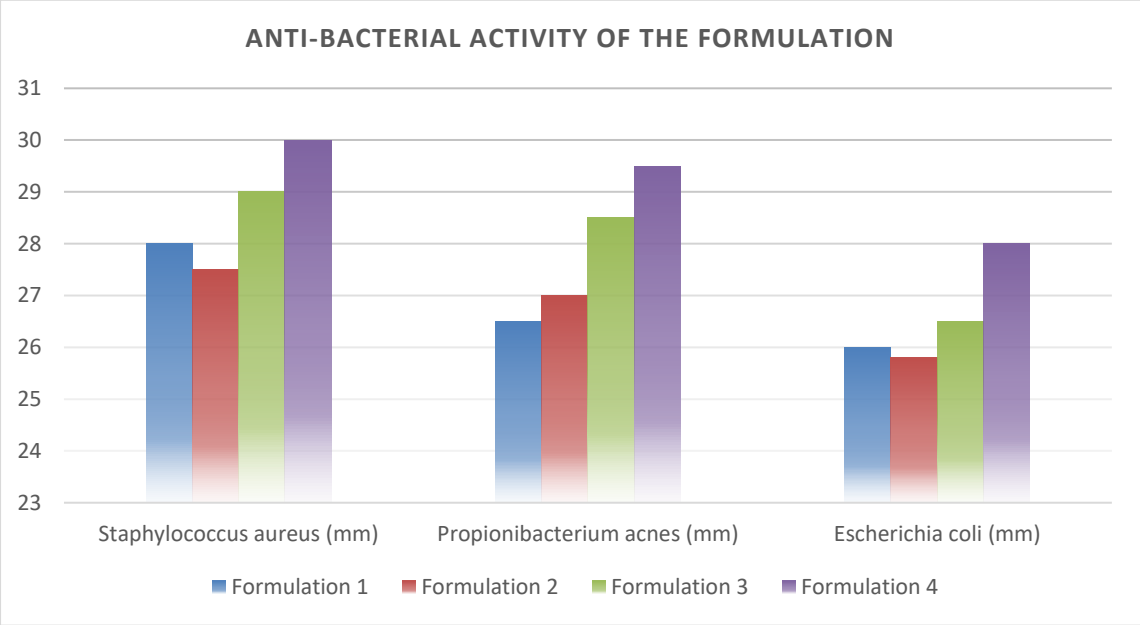
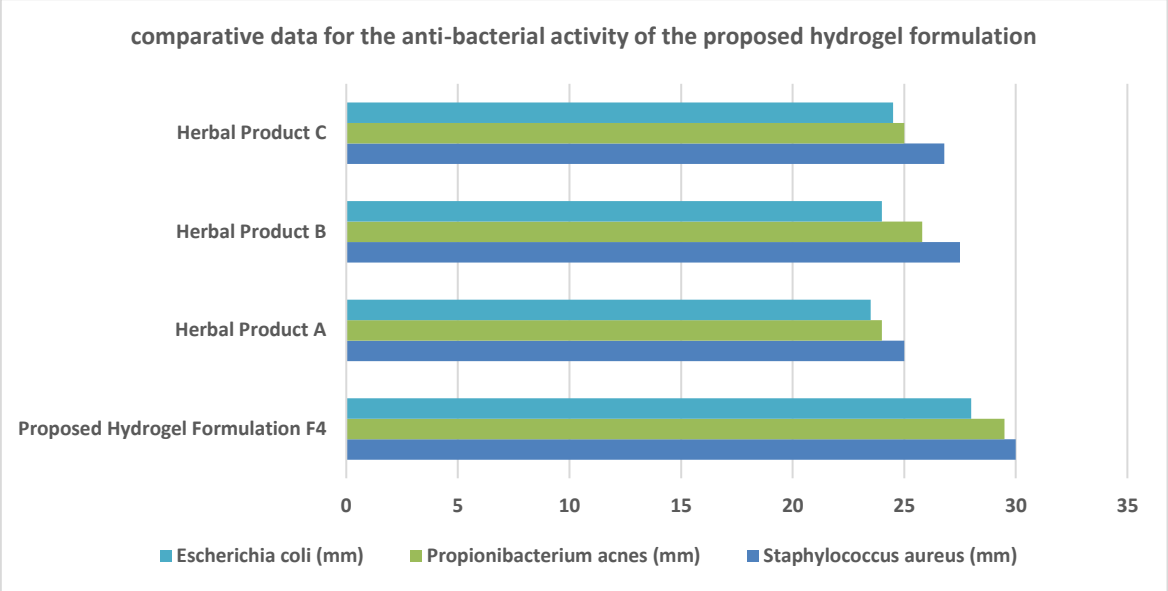


Table 5: comparative data for the anti-bacterial activity of the proposed hydrogel formulation

Product	Staphylococcus aureus (mm)	Propionibacterium acnes (mm)	Escherichia coli (mm)
Proposed Hydrogel Formulation F4	30.0 ± 0.4	29.5 ± 0.6	28.0 ± 0.4
Herbal Product A	25.0 ± 0.3	24.0 ± 0.4	23.5 ± 0.5
Herbal Product B	27.5 ± 0.4	25.8 ± 0.5	24.0 ± 0.3
Herbal Product C	26.8 ± 0.6	25.0 ± 0.3	24.5 ± 0.4

The antibacterial efficacy of a hydrogel formulation known as "Proposed Hydrogel Formulation F4" was compared in a study of three bacterial strains linked to acne: Escherichia coli, Propionibacterium acnes, and Staphylococcus aureus. According to these findings, the Proposed Hydrogel Formulation F4 exhibited the highest antibacterial efficacy against these pathogens, exhibiting the largest inhibition zones. Conversely, lower inhibition zones in the herbal preparations indicated a lower level of antibacterial activity. This implies that the Proposed Hydrogel Formulation F4 is a better alternative for treating acne because of its ability to suppress bacterial growth [22].



Research interest in the creation of potent topical formulations for the treatment of acne vulgaris remains high. Addressing the multifactorial aspect of acne pathogenesis, which includes aberrant keratinization, elevated sebum production, inflammation, and bacterial colonization (Propionibacterium acnes), remains a problem. To target these different underlying processes, the formulations described in this study were designed to include a synergistic mixture of synthetic chemicals and natural extracts [23].

This study examined the intricate process involved in the development of topical treatments for acne vulgaris. Acne is a complex dermatological problem that requires formulas that can effectively treat its underlying causes while preserving patient safety and comfort. The formulations described in this study were created through extensive testing and optimization to achieve delicate equilibrium. Among all the formulations tested, Formulation 4 shown the most potential against germs that cause acne. This demonstrates how crucial formulation development is to providing acne patients with the best possible treatment results [24].

Aloe vera gel was included as a main component in the formulations, taking use of its well-established anti-inflammatory, antioxidant, and moisturizing qualities. Because aloe vera gel can encourage the creation of collagen, fibroblast proliferation, and wound healing, it has been traditionally used to treat a variety of skin diseases. Another essential ingredient was glycerin, which functions as a humectant and moisturizer to improve skin barrier integrity and offset the drying effects of salicylic acid and other active substances [25].

The formulations were made by combining active ingredients with herbal extracts that have antibacterial and anti-inflammatory properties in a synergistic fashion. Each chemical's effectiveness was looked at separately (Table 3), which gave information on how each may help treat acne. For instance, salicylic acid and tea tree oil showed potent antibacterial effect against common acne pathogens, consistent with earlier findings. These findings support the logic behind the addition of these elements and provide insight into the particular roles they play in the formulations. This highlights how important it is to select chemicals for acne treatments that have been shown to be effective by research [26].

The formulas included a number of natural extracts that may have anti-acne qualities. Tea tree oil, which comes from Melaleuca alternifolia, has been shown to have anti-inflammatory and antibacterial properties against P. acnes. It is thought that terpinen-4-ol, its main constituent, has antibacterial properties by rupturing bacterial cell membranes and preventing growth. With its abundance of polyphenolic components, such as epigallocatechin-3-gallate (EGCG), green tea extract shows promise as a treatment for acne because of its antibacterial, anti-inflammatory, and antioxidant properties. Furthermore, green tea extracts have demonstrated promise in controlling sebum production, a major contributing cause to the onset of acne. Neem extract has demonstrated antibacterial, anti-inflammatory, antioxidant, and sebum-regulating qualities. It contains active chemicals such as nimbin and azadirachtin. Because of its astringent and antioxidant qualities, witch hazel extract may be able

to decrease inflammation and regulate the production of sebum in acne lesions [27].

Salicylic acid is a well-known keratolytic substance that was added with the intention of clearing clogged pores and encouraging desquamation. Its antibacterial and anti-inflammatory properties also aid in the treatment of acne. Two dietary flavonoids with strong anti-inflammatory and antioxidant capabilities, quercetin and kaempferol, were added to reduce inflammation and oxidative stress linked to the genesis of acne. Additionally, these flavonoids have demonstrated encouraging photoprotective properties that may lessen UV-induced skin damage and premature aging, two issues that acne sufferers frequently worry about [28].

The formulations' antimicrobial efficacy was assessed against common skin pathogens such as Escherichia coli, P. acnes, and Staphylococcus aureus. As compared to the other formulations, Formulation 4 showed the largest inhibition zones against all three bacterial strains, indicating that the formulations had significant antibacterial activity. The synergistic effects of the several antimicrobial agents, including tea tree oil (0.7%), neem extract (2.5%), salicylic acid (1%), and phenoxyethanol (0.5%), are responsible for Formulation 4's enhanced antibacterial activity [29].

A comparison of the formulations revealed significant differences in their antibacterial efficacy (Table 4). Strong antibacterial activity was demonstrated by Formulation 4, which consistently outperformed the other formulations against every tested strain of bacteria [30]. This demonstrates how effective Formulation 4's special component combination and concentration are in stopping the development of germs that cause acne. These comparison analyses provide insight on the significance of formulation optimization and its direct relationship to treatment success, offering recommendations for future formulation approaches [31].

After comparing the suggested hydrogel formulation (F4) with three current herbal treatments (A, B, and C), it was shown to have better antibacterial action against all three tested bacterial strains. This demonstrates how the created formulation, which targets both the inflammatory and microbiological aspects of the condition, has the potential to be a successful topical therapy for acne [32].

The experiment assessed the antibacterial activity of the formulations as well as a number of physicochemical characteristics (Table 2). All of the recipes had acceptable spreadability, pH, look, and consistency, although subtle differences were observed. Formulation 4 exhibited superior spreadability and a somewhat elevated pH in comparison to the other formulations. Since pH and spreadability might affect skin compatibility and user experience, these findings have significance for formulation design. Consequently, Formulation 4's favorable physicochemical properties could be useful for patient acceptance and treatment adherence [33].

It is noteworthy that although the formulations shown encouraging antibacterial activity in vitro, more research is required to determine their clinical effectiveness and safety profiles through carefully planned clinical studies. During the creation and testing of a product, factors including skin irritation, allergic responses, and any interactions between the active components should be closely monitored and taken into consideration. Furthermore, especially in susceptible populations, the long-term safety and possible systemic absorption of some components, such salicylic acid, should be taken into account [34]. Additionally, continuing study should concentrate on formulation parameter optimization, including pH, stability, and component compatibility. To guarantee constant potency and effectiveness of the natural extracts and active components used in the formulations, standardization and quality control methods are essential. Investigating other delivery methods, including liposomes or nanoparticles, may help improve the active drugs' focused delivery and bioavailability. The investigation's findings demonstrate the potential of herbal formulations, particularly Formulation 4, as effective treatments for acne vulgaris [35]. Further research must concentrate on shedding more light on the stability, safety, and therapeutic efficacy of these formulations in human subjects. Investigating possible synergistic interactions between herbal extracts and traditional acne therapies might lead to improved patient results and new therapeutic opportunities. To enable a broader incorporation of these formulations into acne treatment regimens, more research is required to validate their long-term effectiveness and safety profiles in real clinical settings [36].

The hydrogel compositions, which are a combination of artificial and natural extracts, have encouraging antibacterial activity against the main acne-causing bacterial strains. These active ingredients target a number of processes that lead to the development of acne, including inflammation, bacterial colonization, abnormal keratinization, and regulation of sebum production. The study highlights Formulation 4's superiority, the usefulness of certain compounds, and the significance of formulation improvement. These findings encourage further attempts to

develop safer and more potent topical treatments for acne vulgaris, even if additional clinical studies are required to evaluate the safety and efficacy of these formulations.

CONCLUSION

The goal of the research was to create and assess topical hydrogel formulations for acne vulgaris while concentrating on the intricate pathophysiology of the condition, which includes bacterial colonization, increased sebum production, aberrant keratinization, and inflammation. Particularly in its robust antibacterial action against bacterial strains such as Escherichia coli, Propionibacterium acnes, and Staphylococcus aureus, Formulation 4 demonstrated outstanding potential. Natural extracts having therapeutic properties, such as anti-inflammatory, wound-healing, antioxidant, and sebum-regulating properties, were also incorporated into the formulations.

Evaluations were conducted on physicochemical parameters, including appearance, pH, spreadability, washability, and consistency. Promising characteristics in Formulation 4 could enhance user compliance and treatment adherence. Stability, standardization, formulation parameter optimization, and quality control procedures ought to be the primary objectives of continuing research. Examining novel delivery techniques such as liposomes or nanoparticles could enhance the bioavailability and active drug delivery.

To sum up, Formulation 4 and other hydrogel formulations have demonstrated encouraging potential as topical treatments for acne vulgaris, focusing on several pathways that contribute to the development of acne. By addressing unmet needs and challenges in acne therapy, the findings support further efforts to develop innovative, scientifically validated topical therapies for acne vulgaris, which may improve patient outcomes and the overall quality of life for patients with acne.

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