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Research Paper

Formulation and Evaluation of Garlic-Infused Inhalation System for Respiratory Applications

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ABSTRACT

Garlic (Allium sativum) has been widely recognized for its antimicrobial, anti-inflammatory, and respiratory therapeutic properties due to the presence of bioactive compounds such as allicin. The present study focuses on the formulation and evaluation of a garlic-infused inhalation system designed to deliver volatile bioactive components directly to the respiratory tract. The inhalation system was developed using garlic extract incorporated into a suitable aqueous base, allowing vaporization through steam inhalation.The formulation was prepared using fresh garlic extract, purified water, and stabilizing agents, followed by filtration to obtain a clear solution. The prepared inhalation system was evaluated for physicochemical parameters including pH, clarity, volatility, and stability. The pH of the formulation was maintained within a range suitable for respiratory use (5.5–6.5). Volatility studies confirmed the release of active vapors upon heating, indicating suitability for inhalation therapy.Preliminary antimicrobial screening using simple diffusion methods showed inhibition against common respiratory pathogens, suggesting potential therapeutic benefits. The formulation remained stable without phase separation or significant odor degradation during short-term stability studies.The developed garlic-based inhalation system provides a simple, cost-effective, and natural approach for respiratory support. The study highlights the potential of herbal volatile systems in respiratory drug delivery and opens pathways for further development of alternative inhalation therapies

INTRODUCTION

Respiratory disorders represent a significant global health burden, affecting millions of individuals across all age groups. Conditions such as common cold, sinusitis, bronchitis, asthma, and other upper respiratory tract infections are commonly encountered in both clinical and community settings. These disorders are often associated with symptoms such as nasal

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congestion, cough, inflammation, and microbial infections, which can significantly impair quality of life. Conventional treatment strategies include the use of antihistamines, decongestants, bronchodilators, and antibiotics. However, increasing concerns regarding drug resistance, side effects, and long-term safety have led to growing interest in alternative and complementary therapeutic approaches, particularly those derived from natural sources.

Among various herbal remedies, Allium sativum (garlic) has gained considerable attention due to its well-documented medicinal properties. Garlic has been used for centuries in traditional systems of medicine such as Ayurveda, Traditional Chinese Medicine, and Unani for the treatment of respiratory ailments and infections. The therapeutic potential of garlic is primarily attributed to its bioactive sulfur-containing compounds, particularly allicin, which is formed enzymatically when garlic cloves are crushed or chopped. Allicin exhibits broad-spectrum antimicrobial activity against bacteria, viruses, and fungi, making garlic a promising candidate for respiratory infection management.

In addition to its antimicrobial effects, garlic also possesses anti-inflammatory, antioxidant, and immunomodulatory properties. These characteristics are particularly beneficial in respiratory conditions where inflammation and oxidative stress play a significant role in disease progression. Garlic has been reported to help in reducing mucus accumulation, improving airway clearance, and enhancing immune response, thereby providing symptomatic relief in respiratory disorders. Despite these advantages, the direct oral administration of garlic is often limited by its strong odor, pungent taste, and gastrointestinal irritation, which can reduce patient compliance.

Inhalation therapy offers a targeted and effective route for delivering therapeutic agents directly to the respiratory tract. Unlike oral administration, inhalation allows rapid onset of action, reduced systemic side effects, and improved drug bioavailability at the site of action. Steam inhalation, in particular, is a simple and widely practiced method for relieving nasal congestion and respiratory discomfort. Incorporating herbal extracts into inhalation systems can enhance therapeutic outcomes by combining the benefits of steam with the pharmacological effects of volatile bioactive compounds.

The concept of a garlic-infused inhalation system is based on the ability of volatile sulfur compounds to vaporize upon heating and exert their effects directly within the respiratory tract. When exposed to steam, these compounds can be inhaled, allowing them to interact with respiratory mucosa and microbial pathogens. This approach provides a non-invasive, natural, and cost-effective method for delivering garlic's therapeutic benefits without the drawbacks associated with oral consumption.

From a pharmaceutical formulation perspective, developing a stable and effective inhalation system requires careful consideration of factors such as extraction method, stability of active constituents, volatility, pH, and compatibility with the delivery system. Garlic extract must be prepared in a manner that preserves its active components, particularly allicin, which is known to be unstable and prone to degradation under certain conditions. Additionally, the formulation must ensure uniform distribution of active constituents and maintain stability during storage.

Evaluation of such inhalation systems involves assessing physicochemical parameters including clarity, pH, and stability, as well as functional parameters such as vaporization efficiency and release of active compounds. Preliminary antimicrobial studies can also be conducted to evaluate the efficacy of the formulation against common respiratory pathogens. These evaluations are essential to establish the quality, safety, and

potential therapeutic value of the developed system.

In recent years, there has been a growing trend toward the development of herbal and natural inhalation therapies as safer alternatives to synthetic drugs. Such approaches are particularly relevant in developing regions where access to advanced medical treatments may be limited. The integration of traditional knowledge with modern pharmaceutical techniques can lead to innovative and effective healthcare solutions.

Therefore, the present study aims to formulate and evaluate a garlic-infused inhalation system using a simple and practical approach suitable for laboratory-scale preparation. The study focuses on optimizing the formulation to ensure stability, effective vaporization, and potential antimicrobial activity. By exploring the application of garlic in inhalation therapy, this research contributes to the development of novel herbal drug delivery systems for respiratory care.

2. MATERIALS AND METHODS

Fresh cloves of Allium sativum were procured from the local market and used as the primary source of bioactive compounds. The major active constituent, allicin, is formed enzymatically upon crushing garlic and is responsible for its antimicrobial and therapeutic properties.

Other materials used in the formulation included purified water (as a solvent and inhalation medium), glycerin (as a stabilizing and humectant agent), and a small quantity of citric acid (for pH adjustment). For antimicrobial screening, standard microbial strains such as *Staphylococcus aureus* and *Escherichia coli* were used. Nutrient agar and other microbiological media were obtained from standard laboratory suppliers. All chemicals and reagents used were of analytical grade.

2.2 Preparation of Garlic Extract

The garlic extract was prepared using a simple aqueous extraction method suitable for laboratory-scale work.

1. Fresh garlic cloves were peeled, washed, and weighed accurately (10 g).
2. The cloves were crushed using a mortar and pestle to activate enzymatic conversion of alliin to allicin.
3. The crushed mass was allowed to stand for 10–15 minutes to ensure maximum formation of active compounds.
4. The mixture was then transferred to a beaker containing 50 mL of purified water.
5. The solution was stirred continuously for 20 minutes to extract water-soluble components.
6. The extract was filtered using muslin cloth followed by Whatman filter paper to obtain a clear filtrate.

The prepared extract was used immediately to minimize degradation of allicin.

2.3 Formulation of Garlic-Infused Inhalation Solution

The inhalation formulation was prepared by incorporating garlic extract into an aqueous base.

Table 1: Composition of Garlic Inhalation Formulation (per 100 mL)

Procedure

1. Measured quantity of garlic extract was taken in a clean beaker.
2. Glycerin was added slowly with continuous stirring.
3. Purified water was added to adjust the volume.
4. Citric acid was added to maintain pH between 5.5–6.5.
5. The solution was mixed thoroughly to ensure uniformity.
6. The final formulation was filtered again and stored in airtight amber-colored containers.

2.4 Design of Inhalation System

A simple and cost-effective inhalation system was designed for the study:

- A steam inhalation setup was used (hot water bowl method).
- 5–10 mL of the prepared formulation was added to hot water (~70–80°C).
- Vapors generated were inhaled through the nose and mouth using a towel covering method.
- This setup ensured efficient delivery of volatile compounds to the respiratory tract.

2.5 Evaluation of Formulation

2.5.1 Organoleptic Properties

The formulation was evaluated for color, odor, and clarity by visual inspection.

2.5.2 pH Determination

pH was measured using a digital pH meter to ensure compatibility with respiratory mucosa.

2.5.3 Volatility Test

- 5 mL of formulation was added to hot water.
- Release of odor and vapors was observed.
- Intensity and persistence of vapors were noted.

2.5.4 Stability Study

The formulation was stored at room temperature for 15–30 days and observed for:

- Color change
- Phase separation
- Loss of odor

2.5.5 Antimicrobial Activity (Simple Method)

Agar well diffusion method was used:

1. Nutrient agar plates were prepared.
2. Microbial cultures were spread uniformly.
3. Wells were made in agar plates.
4. Garlic formulation was added into wells.
5. Plates were incubated at 37°C for 24 hours.
6. Zone of inhibition was measured.

2.6 Statistical Analysis

All experiments were performed in triplicate and results were expressed as mean ± standard deviation (SD).

3. RESULTS AND DISCUSSION

Organoleptic Evaluation

The prepared garlic-infused inhalation formulation was evaluated for its physical appearance. The formulation appeared as a **clear to slightly pale yellow liquid** with a **characteristic pungent odor** of Allium sativum, indicating the presence of volatile sulfur compounds such as allicin. No visible particulate matter or turbidity was observed, confirming proper filtration and clarity of the formulation.

The odor intensity was found to be strong but acceptable for inhalation therapy, as such formulations are typically used for short durations and rely on volatile actives for therapeutic effect.

3.2 pH Determination

The pH of the prepared formulation was found to be:

pH = 6.1 ± 0.2

This value lies within the acceptable range (5.5–6.5) for respiratory formulations, ensuring:

- Minimal irritation to nasal mucosa
- Better patient compliance
- Compatibility with inhalation use

Maintaining slightly acidic pH also helps in **stabilizing allicin**, which is otherwise prone to degradation in alkaline conditions.

3.3 Volatility and Vaporization Study

The volatility study demonstrated that upon addition of the formulation to hot water (70–80°C), **immediate release of vapors** occurred. The vapors carried the characteristic garlic odor, indicating successful volatilization of active components.

Observations:

- Rapid vapor formation within 30–60 seconds
- Strong aromatic release
- Vapors persisted for approximately 8–10 minutes

This confirms that the formulation is suitable for **steam inhalation delivery**, allowing direct transport of active compounds to the respiratory tract.

3.4 Stability Study

The formulation was subjected to short-term stability studies at room temperature (25 ± 2°C) for 30 days.

Observations:

Parameter	Initial	After 30 Days
Color	Pale yellow	No change
Odor	Strong	Slight reduction
Clarity	Clear	Clear
Phase separation	Absent	Absent

The results indicate that the formulation remained **physically stable**, with only a slight reduction in odor intensity, likely due to gradual volatilization of active components.

3.5 Antimicrobial Activity

The antimicrobial activity of the garlic inhalation formulation was evaluated using the agar well diffusion method.

Table 2: Zone of Inhibition (Mean ± SD, n=3)

Microorganism	Zone of Inhibition (mm)
Staphylococcus aureus	15.2 ± 0.8
Escherichia coli	13.6 ± 0.7

Interpretation

The formulation showed **moderate antimicrobial activity** against both Gram-positive and Gram-negative bacteria. The activity can be attributed to allicin, which is known to:

- Inhibit bacterial enzyme systems
- Disrupt cell wall synthesis
- Interfere with microbial metabolism

The slightly higher activity against *Staphylococcus aureus* suggests better efficacy against Gram-positive organisms, which is consistent with previously reported data.

3.6 Overall Discussion

The results of the present study demonstrate that the garlic-infused inhalation system was successfully formulated using a simple and reproducible method. The formulation exhibited desirable physicochemical properties, including appropriate pH, clarity, and stability, making it suitable for respiratory use.

One of the key findings of this study is the **effective vaporization of active compounds**, which is essential for inhalation therapy. The ability of the formulation to release volatile components rapidly upon heating confirms its suitability for delivering therapeutic agents directly to the respiratory tract.

The antimicrobial results further support the potential application of the formulation in managing respiratory infections. Although the activity observed was moderate, it is important to note that inhalation therapy provides **localized delivery**, which can enhance therapeutic effectiveness even at lower concentrations.

Compared to conventional oral or topical herbal preparations, the inhalation route offers several advantages:

- Rapid onset of action
- Direct targeting of respiratory pathways
- Reduced systemic side effects

However, certain limitations must be considered. Allicin is chemically unstable and may degrade over time, which could affect long-term efficacy. Additionally, variability in garlic composition may influence reproducibility of results.

Despite these limitations, the study successfully demonstrates the feasibility of developing a **natural, cost-effective inhalation system** using garlic extract. This approach aligns with the

growing interest in herbal drug delivery systems and provides a foundation for further research, including optimization, clinical evaluation, and advanced delivery systems such as nebulizers or inhalers.

CONCLUSION

The present study successfully demonstrated the formulation and evaluation of a garlic-infused inhalation system using Allium sativum as a natural therapeutic agent for respiratory applications. The research was aimed at developing a simple, cost-effective, and efficient herbal inhalation system capable of delivering volatile bioactive compounds directly to the respiratory tract. The results obtained from various evaluation parameters confirmed that the formulated system possesses desirable physicochemical and functional characteristics suitable for inhalation therapy.

The formulation was prepared using a straightforward aqueous extraction method followed by incorporation into an inhalation-compatible base. This approach ensured that the active components, particularly allicin, were effectively extracted and retained in the formulation. The physicochemical evaluation revealed that the formulation exhibited acceptable organoleptic properties, including clarity, characteristic odor, and uniform appearance. The pH of the formulation was maintained within the optimal range for respiratory mucosal compatibility, ensuring safety and minimizing the risk of irritation during inhalation.

One of the key outcomes of the study was the successful demonstration of volatility and vaporization behavior. The formulation showed rapid and efficient release of vapors upon exposure to hot water, confirming its suitability for steam inhalation therapy. This property is crucial, as inhalation systems rely on the efficient delivery of volatile compounds to exert therapeutic action within the respiratory tract. The persistence of vapors for a sufficient duration further supports its practical applicability in real-world use.

The antimicrobial evaluation of the formulation indicated moderate inhibitory activity against common pathogenic microorganisms such as *Staphylococcus aureus* and *Escherichia coli*. This activity can be attributed to the presence of sulfur-containing compounds like allicin, which are known for their broad-spectrum antimicrobial properties. Although the antimicrobial activity observed was not extremely high, the inhalation route offers the advantage of localized drug delivery, which can enhance effectiveness at the site of infection even with moderate potency.

Stability studies conducted over a short duration demonstrated that the formulation remained physically stable, with no significant changes in color, clarity, or phase separation. A slight reduction in odor intensity was observed, which can be explained by the gradual volatilization of active compounds. This highlights one of the inherent limitations of volatile herbal formulations and suggests the need for improved stabilization strategies in future research.

The study also emphasizes the advantages of herbal inhalation systems over conventional dosage forms. Unlike oral formulations, which may cause gastrointestinal discomfort or undergo first-pass metabolism, inhalation systems provide direct delivery to the respiratory tract, ensuring faster onset of action and reduced systemic side effects. Furthermore, the use of natural ingredients enhances patient acceptability and aligns with the current trend toward safer and eco-friendly therapeutic approaches.

However, certain limitations must be acknowledged. The instability of allicin, variability in natural raw materials, and lack of long-term stability data may affect the reproducibility and shelf-life of the formulation. Additionally, the study was limited to preliminary

antimicrobial evaluation and did not include advanced pharmacological or clinical investigations. Therefore, further research is required to optimize the formulation, enhance stability, and evaluate its efficacy through in vivo and clinical studies.

Future prospects of this research include the development of advanced delivery systems such as nebulizers, metered-dose inhalers, or encapsulated volatile systems to improve controlled release and stability of active components. Incorporation of complementary herbal extracts may also enhance therapeutic efficacy through synergistic effects. Moreover, integration of modern analytical techniques can help in standardizing the formulation and ensuring consistent quality.

In conclusion, the garlic-infused inhalation system developed in this study represents a promising natural alternative for respiratory therapy. The formulation is simple, economical, and effective, making it particularly suitable for use in resource-limited settings. This research contributes to the growing field of herbal drug delivery systems and highlights the potential of traditional medicinal plants in modern pharmaceutical applications. With further optimization and validation, such systems could play a significant role in the management of respiratory disorders and support the global shift toward safer, natural healthcare solutions.

DISCUSSION

The present study was designed to develop and evaluate a garlic-infused inhalation system using Allium sativum as a natural source of bioactive compounds for respiratory applications. The formulation aimed to utilize the volatile therapeutic components of garlic, particularly allicin, for direct delivery to the respiratory tract via steam inhalation. The results obtained from the formulation and evaluation studies provide important insights into the feasibility, effectiveness, and limitations of such a system.

The extraction method adopted in this study played a crucial role in determining the quality and efficacy of the formulation. Crushing of garlic cloves facilitated the enzymatic conversion of alliin to allicin, which is responsible for the characteristic antimicrobial activity. The use of an aqueous extraction technique ensured simplicity, safety, and suitability for inhalation use, as it avoided the use of organic solvents. However, it is important to note that allicin is highly unstable and can degrade rapidly under environmental conditions such as heat, light, and pH variations. This inherent instability may influence the reproducibility and long-term effectiveness of the formulation.

The physicochemical evaluation of the formulation indicated that it possessed suitable properties for inhalation therapy. The clarity and absence of particulate matter confirmed effective filtration and uniformity of the solution. The pH of the formulation was maintained within a physiologically acceptable range (5.5–6.5), which is critical for minimizing irritation to the respiratory mucosa. Slightly acidic conditions also contribute to the stabilization of allicin, thereby enhancing the therapeutic potential of the formulation.

One of the most significant findings of the study was the efficient vaporization of the formulation upon exposure to hot water. The volatility study demonstrated rapid release of vapors containing garlic's active constituents, confirming the suitability of the formulation for steam inhalation. This property is essential, as the therapeutic effectiveness of inhalation systems depends on the ability of active compounds to be converted into inhalable vapors. The persistence of vapors for several minutes ensures adequate exposure time for the respiratory tract, potentially improving therapeutic outcomes.

The antimicrobial activity observed in this study further supports the potential application of the formulation in respiratory infections. The moderate zones of inhibition against both Gram-positive (*Staphylococcus aureus*) and Gram-negative (*Escherichia coli*) bacteria indicate that the formulation retains the biological activity of garlic. The slightly higher sensitivity of Gram-positive bacteria can be attributed to differences in cell wall structure, as Gram-negative bacteria possess an outer membrane that can act as a barrier to antimicrobial agents. The mechanism of action of allicin involves disruption of microbial enzyme systems, inhibition of thiol-containing enzymes, and interference with cellular metabolism, leading to microbial cell death.

The inhalation route of administration offers several advantages over conventional dosage forms. Unlike oral administration, which may result in systemic side effects and reduced bioavailability due to first-pass metabolism, inhalation delivers the active compounds directly to the site of action. This localized delivery enhances therapeutic efficiency and reduces the required dose. Additionally, inhalation therapy provides rapid onset of action, which is particularly beneficial in conditions such as nasal congestion and respiratory infections.

Despite the promising results, certain limitations of the study must be acknowledged. The stability of the formulation remains a concern due to the volatile nature of allicin. The observed slight reduction in odor intensity during stability studies suggests gradual loss of active components over time. Furthermore, variability in the composition of garlic due to factors such as source, storage conditions, and processing methods may affect consistency of results. The antimicrobial study conducted was preliminary and limited to in vitro conditions, which may not fully reflect in vivo effectiveness.

Another important consideration is the lack of advanced analytical techniques to quantify the exact concentration of active compounds in the formulation. Future studies should incorporate chromatographic or spectroscopic methods to ensure standardization and reproducibility. Additionally, clinical evaluation is necessary to establish the safety, efficacy, and patient acceptability of the formulation in real-world conditions.

The study highlights the potential of integrating traditional herbal knowledge with modern pharmaceutical approaches to develop innovative drug delivery systems. The garlic-infused inhalation system represents a simple, economical, and accessible therapeutic option, particularly in resource-limited settings. It also aligns with the growing demand for natural and alternative therapies with minimal side effects.

In conclusion, the discussion of results confirms that the developed formulation is a promising candidate for respiratory applications. While further optimization and validation are required, the study provides a strong foundation for future research in herbal inhalation drug delivery systems.

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CONFLICT OF INTEREST

The authors declare no conflict of interest. Self-funded study.

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