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A Natural Sheild: Enhancing Immune Protection and Supportive Therapy for Tuberculosis Patient and Families

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ABSTRACT:

Tuberculosis (TB) remains a major global public health challenge due to the increasing prevalence of multidrug-resistant strains, prolonged chemotherapy, severe adverse drug reactions, and associated systemic inflammation. Chronic pulmonary tuberculosis is frequently accompanied by neuroinflammatory complications, anxiety, depression, and compromised mucosal immunity, which collectively reduce patient quality of life and treatment adherence. The present study focuses on the formulation and evaluation of a botanical mucoadhesive oromucosal spray containing *Curcuma longa* (curcumin), *Azadirachta indica* (neem), *Zingiber officinale* (ginger), and honey as a supportive host-directed therapeutic approach for tuberculosis management. The formulation was designed to enhance local mucosal immunity, prolong retention time within the oral cavity, and provide sustained release of phytoconstituents through the use of mucoadhesive polymers. Curcumin was incorporated for its potent anti-inflammatory, antioxidant, immunomodulatory, and macrophage-activating properties, while neem and ginger contributed antimicrobial and immunoprotected activities. Honey acted as a natural co-adhesive, soothing agent, and antimicrobial component. The formulation was evaluated for physicochemical characteristics including pH, viscosity, spray pattern, wash-off time, and phytochemical screening. Results confirmed the presence of major bioactive constituents such as flavonoids, alkaloids, terpenoids, tannins, phenols, saponins, and reducing sugars. The optimized spray demonstrated suitable rheological behavior, acceptable organoleptic properties, and enhanced mucoadhesive retention, indicating its potential for localized delivery and improved patient compliance. The synergistic botanical combination may enhance macrophage autophagy, reduce inflammatory cytokine expression, protect the oral mucosa, and support mucosal immune defense against Mycobacterium tuberculosis. Thus, the developed mucoadhesive spray represents a promising adjunctive and non-invasive supportive therapy for tuberculosis patients, warranting further in-vivo and clinical investigations.

Keywords: Immunomodulatory Therapy, Curcumin, Azadirachta indica, Zingiber officinale, Host-Directed Therapy (HDT), Tuberculosis, Mucoadhesive Oromucosal Spray.

INTRODUCTION:

Tuberculosis (TB) remains one of the most devastating infectious diseases worldwide and continues to pose a major burden on global public health systems. The disease is primarily caused by Tuberculosis infection with Mycobacterium tuberculosis and mainly affects the lungs, although extrapulmonary manifestations are also common. Despite the availability of anti-tubercular chemotherapy for several decades, TB continues to rank among the leading causes of death from infectious diseases due to poor treatment adherence, prolonged drug regimens, severe adverse effects, and the alarming rise of multidrug-resistant tuberculosis (MDR-TB). According to global estimates, nearly one-fourth of the world's population is infected latently with Mycobacterium tuberculosis, and a significant proportion eventually develops active disease under conditions of weakened immunity.

Conventional anti-tubercular therapy primarily relies on prolonged multidrug regimens that frequently produce hepatotoxicity, neurotoxicity, gastrointestinal disturbances, and systemic inflammatory complications. In addition to pulmonary damage, chronic TB infection is strongly associated with excessive inflammatory responses that may extend beyond the lungs and contribute to neuroinflammation, anxiety, depression, fatigue, and reduced quality of life. Such complications negatively influence patient compliance and increase the likelihood of therapeutic failure and drug resistance. Consequently, there is an urgent need for safer adjunctive therapies capable of enhancing host immunity, reducing inflammation, improving patient comfort, and supporting conventional treatment strategies.

In recent years, Host-Directed Therapy (HDT) has emerged as a promising therapeutic strategy for tuberculosis management. Unlike traditional antibiotics that directly target the pathogen, HDT aims to strengthen the host immune system and improve the body's

natural ability to eliminate intracellular pathogens. Natural phytoconstituents possessing immunomodulatory, anti-inflammatory, antioxidant, and antimicrobial activities have gained substantial scientific attention as potential HDT candidates. Among these, curcumin derived from Turmeric (*Curcuma longa*) has demonstrated remarkable therapeutic potential due to its ability to activate macrophage autophagy, promote phagosome-lysosome fusion, suppress NF-κB signaling, and reduce inflammatory cytokine production. Curcumin also exhibits neuroprotective properties that may help alleviate TB-associated neuroinflammation and behavioral complications.

Similarly, Neem (*Azadirachta indica*) possesses broad-spectrum antimicrobial, anti-inflammatory, antioxidant, and immunomodulatory activities attributed to bioactive compounds such as azadirachtin, nimbin, and nimbolide. Neem extracts have shown promising activity against pathogenic microorganisms and contribute to immune enhancement and tissue protection. Ginger (*Zingiber officinale*) is another important medicinal plant widely recognized for its antioxidant, anti-inflammatory, antimicrobial, and respiratory protective properties. The major bioactive compounds of ginger, including gingerols and shogaols, contribute to free radical scavenging and inhibition of inflammatory mediators, thereby supporting immune defense mechanisms and respiratory health. Honey further complements these botanical ingredients through its soothing, antimicrobial, wound-healing, and mucoadhesive properties.

The oral and oropharyngeal mucosa play a critical role as the first line of defense against inhaled pathogens. However, conventional oral or systemic formulations often fail to maintain prolonged contact with the mucosal surface due to rapid salivary clearance and poor retention. Mucoadhesive drug delivery systems offer a promising solution by increasing residence time, enhancing local absorption, and enabling sustained release of active phytoconstituents at the target site. Oromucosal sprays, in particular, provide a non-invasive, patient-friendly, and effective approach for localized immunomodulation and supportive therapy. By delivering active ingredients directly to the mucosal-associated lymphoid tissues (MALT), such systems can strengthen mucosal immunity, improve oral hygiene, reduce opportunistic infections, and support respiratory defense mechanisms.

The present research focuses on the development and evaluation of a botanical mucoadhesive oromucosal spray containing *Curcuma longa, Azadirachta indica, Zingiber officinale*, and honey as a supportive host-directed therapeutic formulation for tuberculosis patients. The formulation aims to enhance mucosal immunity, provide sustained release of phytoconstituents, reduce localized inflammation, and offer adjunctive antimicrobial support against Mycobacterium tuberculosis. The study also emphasizes physicochemical characterization, phytochemical screening, rheological evaluation, and mucoadhesive performance of the developed formulation. This innovative polyherbal approach may provide a safe, stable, non-invasive, and patient-compliant supportive therapy capable of complementing conventional anti-tubercular treatment while improving the overall health and quality of life of TB patients.

Aim & Objectives:

Aim:

To develop and evaluate a polyherbal mucoadhesive oromucosal spray containing curcumin, neem, and ginger for stimulating mucosal immunity and enhancing host defense mechanisms against Tuberculosis through sustained localized delivery of natural bioactive compounds.

Objectives:

i. **Formulation Development:** To successfully design and formulate a localized mouth spray incorporating the active botanical constituents of *Curcuma longa* (curcumin), *Azadirachta indica* (neem), *Zingiber officinale* (ginger), and honey.

ii. **Targeted Delivery & Retention**: To achieve prolonged contact time and sustained release of these botanical extracts within the oral cavity by utilizing effective mucoadhesive polymers.

iii. **Immunomodulation:** To enhance local mucosal immunity in the oropharyngeal region, specifically functioning as a targeted immunity booster against Tuberculosis, rather than a curative treatment for an active infection.

iv. **Synergistic Action:** To harness the combined immunomodulatory, anti-inflammatory, and antimicrobial properties of the selected natural ingredients for maximum therapeutic benefit.

v. **Physicochemical Evaluation:** To systematically assess the quality and stability of the final formulation through standard evaluation parameters, such as pH, viscosity, spray pattern, mucoadhesive strength, and in-vitro drug release.

Method:

❖ ***Curcuma Longa*/ Turmeric:**

- **Botanical Name:** *Curcuma longa*
- **Common Name:** Turmeric
- **Family*:*** *Zingiberaceae* (Ginger family)
- **Plant Type:** Perennial herbaceous plant

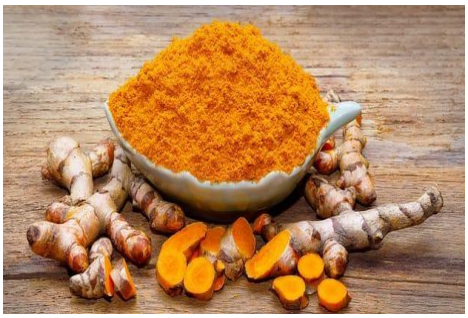


Fig. Turmeric

● **Collection of *Curcuma Longa*/ Turmeric:**

The goal here is to maximize curcuminoid yield and prevent the degradation of these light-sensitive compounds.

Collection:

Harvest the rhizomes when the plant's lower leaves turn yellow and start drying. Carefully dig up the primary and secondary rhizomes, ensuring they are not bruised or cut, as this can lead to fungal infections.

Preservation & Processing:

Boiling:

Clean the dirt off and boil or steam the fresh rhizomes for 30–45 minutes. This destroys the vitality of the fresh rhizome, removes the raw odor, gelatinizes the starch, and helps distribute the curcumin uniformly throughout the tissue.

Drying:

Dry the cured rhizomes immediately, either in the sun or using artificial dryers (at around 60°C), until the moisture content drops to 5–10%.

Storage:

Curcumin is highly photosensitive. Store the dried, polished rhizomes (or the extracted powder) in strictly airtight, light-resistant containers in a cool, dry place.

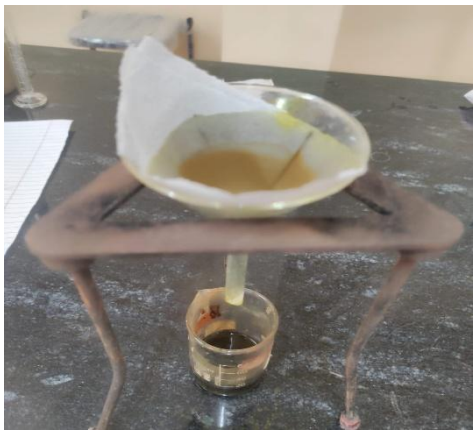


Fig. Turmeric Extraction

❖ ***Azadirachta indica*/ Neem:**

- **Botanical Name:** *Azadirachta indica* A. Juss.
- **Common Names:** Neem, Indian Lilac, Margosa Tree
- **Family:** *Meliaceae* (Mahogany family)
- **Plant Type:** Evergreen tree

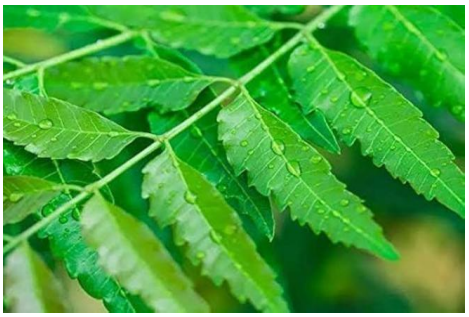


Fig. Neem Leaves

● **Collection of *Azadirachta indica*/ Neem**

For formulations, neem leaves are most commonly used, and the primary concern is protecting the volatile compounds and terpenoids like azadirachtin.

Collection:

Harvest mature, healthy green leaves. The best time for collection is early morning after the dew has evaporated, during the vegetative stage before flowering, as this is when the active secondary metabolites are highly concentrated.

Preservation & Processing:

Drying:

Strictly shade-dry the leaves. Direct sunlight rapidly degrades azadirachtin and other active principles. Spread them in a thin layer in a well-ventilated, shaded area.

Storage:

Once they are crisp and easily crumble (less than 10% moisture), store them whole or powdered in airtight, moisture-proof containers in a cool, dark environment to prevent mold and loss of potency.

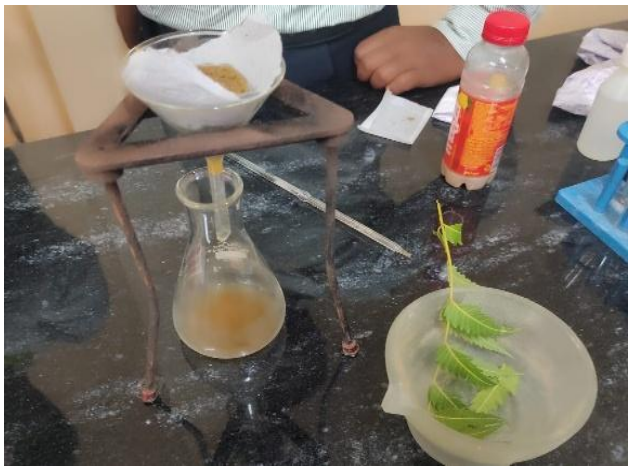


Fig. Neem Extraction

❖ ***Zingiber officinale*/ Ginger:**

- **Botanical Name:** *Zingiber officinale*
- **Common Name:** Ginger
- **Family:** *Zingiberaceae* (the same family as turmeric)
- **Plant Type:** Perennial herbaceous plant

Fig. Ginger

● **Collection of *Zingiber officinale*/ Ginger:**

The preservation of ginger focuses on retaining gingerols and preventing moisture-induced fungal growth

Collection:

Harvest the rhizomes when the aerial stems turn yellow and wither (about 8 to 9 months after planting). Carefully lift the rhizome clumps from the soil, taking care not to break them.

Preservation & Processing:

Preparation:

Wash the rhizomes thoroughly to remove all soil. For long-term preservation as dried ginger, scrape off the outer skin (epidermis) using a bamboo or wooden knife (avoid iron tools, which can cause oxidation and discoloration).

Drying:

Slice the peeled rhizomes to accelerate drying and dry them in the sun or in a hot-air oven at 50°C to 60°C.

Storage:

Store the dried rhizomes (or powder) in tightly closed containers in a cool, dry place. Ginger is highly susceptible to moisture, so controlling the humidity during storage is critical to prevent mold.

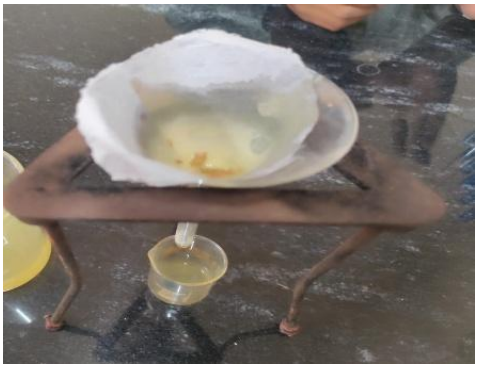


Fig. Ginger Extraction

- **INGREDIENTS:**

Ingredient	Role	Concentration (% w/v) Amount for 100mL
Turmeric Extract	Antioxidant/Anti-inflammatory	0.5% 0.5 g
Ginger Extract	Antimicrobial	1.0% 1.0 g
Neem Extract	Antiseptic	0.5% 0.5 g
Honey	Sweetener / Co-adhesive	10.0% 10.0 g
Methylcellulose	Mucoadhesive Polymer	1.5% 1.5 g
Castor oil	Solubilizer (for Curcumin)	2.0% 2.0 mL
Propylene Glycol	Co-solvent / Humectant	5.0% 5.0 mL
Methylparaben	Preservative	0.18% 0.18 g
Menthol	Flavor / Permeation enhancer	0.1% 0.1 g
Peppermint oil	Flavor	0.1% 0.1g
Distilled Water	Vehicle	q.s. to 100% up to 100 mL

- **EXPERIMENTAL WORK:**

Formulation of Mucoadhesive Spray:

1. Preparation of the Aqueous Polymeric Phase:

- Distilled water is heated to approximately 60°C to lower its viscosity. methylcellulose is introduced sequentially into the vortex of a continuous high-shear homogenizer.

- This intense mechanical shear prevents premature agglomeration, clumping, or "fish-eye" formation of the hydrophilic polymers.

- The pH is carefully monitored and adjusted using mild organic acids to maintain a slightly acidic environment (pH 5.5–6.5), ensuring the complete protonation and solubilization of methylcellulose while maintaining the structural stability of methylcellulose.

2. Preparation of the Micellar Active Organic Phase:

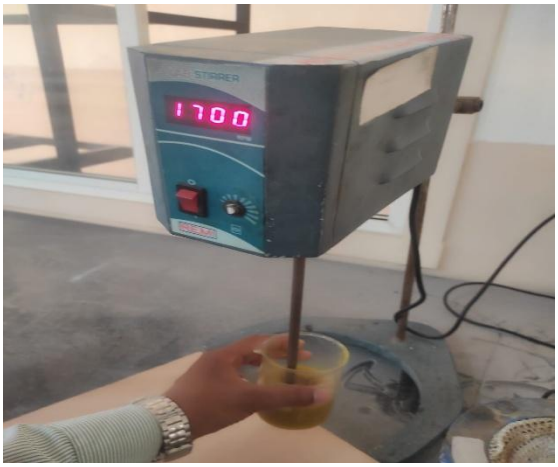
- In a separate, temperature-controlled vessel, the lipophilic components are processed.
- Standardized turmeric extract (yielding 95% pure curcuminoids), ginger extract, and neem extract are accurately weighed.
- Trace amounts of edible ethanol are introduced as a primary volatile solubilizer. Propylene glycol and Castor oil are subsequently added to this mixture.
- The lipid phase is subjected to mild, controlled heating (50°C–70°C) and continuous, vigorous stirring (800–1200 rpm) under atmospheric pressure to initiate the spontaneous, thermodynamically driven formation of functionalized drug-loaded micelles.
- Menthol crystals are dissolved into this organic-surfactant phase only once the temperature begins to decrease, thereby preventing the unwanted volatilization of the active terpene.

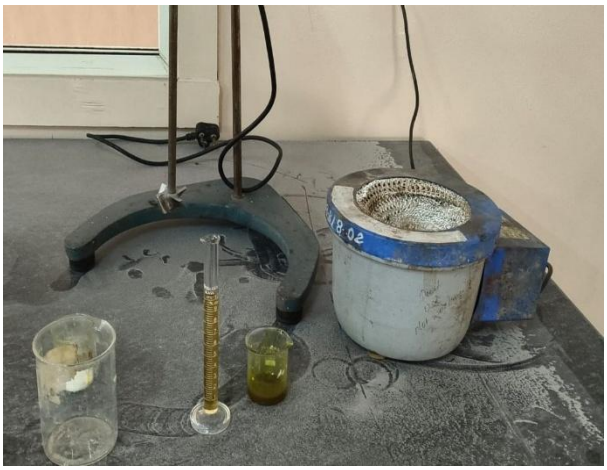
3. Phase Integration and Active Incorporation:

- The micellar active organic phase is slowly titrated into the continuously mixing aqueous polymeric phase.
- The integration is performed slowly to ensure that the micelles remain stable and do not crash out of solution upon contacting the water.
- The inclusion of the medical-grade honey is executed exclusively during the final cooling phase (below 40°C).

4. Final Homogenization and Degassing:

- The combined dispersion is subjected to a final stage of high-pressure homogenization to ensure an ultra-fine, monodisperse micellar droplet distribution and absolute phase uniformity.
- The uniform, dark-amber liquid is then vacuum-degassed to remove all trapped air bubbles (which could otherwise compromise dose uniformity and polymer stability) and transferred into specialized metered-dose pump spray containers equipped with precise actuators.





- **RESULT:**

The present study successfully developed a stable polyherbal mucoadhesive oromucosal spray containing curcumin, neem, and ginger intended for mucosal immunity stimulation and supportive respiratory health management.

The synergistic combination of curcumin, neem, and ginger showed promising immunomodulatory, antioxidant, anti-inflammatory, and antimicrobial properties that may contribute to strengthening mucosal immune defense mechanisms against respiratory pathogens, including Mycobacterium tuberculosis. Overall, the developed formulation demonstrated satisfactory stability, compatibility, and functional performance, suggesting its potential as a natural immunity-enhancing oromucosal spray for supportive healthcare applications.

Phytochemical screening confirmed the presence of important bioactive constituents such as alkaloids, flavonoids, phenols, tannins, terpenoids, and saponins, indicating the therapeutic potential of the selected herbal extracts.

Phytochemical Constituent	**Botanical Extract**	**Test Performed**	**Observation**	**Inference**
Alkaloids	*A. indica, C. longa*	Dragendorff's Test	Formation of a reddish-brown precipitate.	Presence confirmed
Flavonoids	*Z. officinale, A. indica*, Honey	Shinoda Test	Emergence of a deep pink/magenta color	Presence confirmed
Phenols & Tannins	All extracts, Honey	Ferric Chloride (FeCl) Test	Development of a dark green or bluish-black color.	Presence confirmed
Terpenoids	*Z. officinale*	Salkowski's Test	Reddish-brow n coloration at the solvent interface.	Presence confirmed.
Saponins	*A. indica*	Froth Test	Persistent foaming upon vigorous shaking.	Presence confirmed.
Reducing Sugars	Honey	Benedict's Test	Formation of a brick-red precipitate upon heating.	Presence confirmed.

The mucoadhesive characteristics of the formulation demonstrated enhanced retention time on the mucosal surface, supporting sustained localized delivery of phytoconstituents.

Spray pattern analysis revealed uniform atomization and effective distribution over the oral mucosal surface.

Physicochemical evaluation demonstrated that the formulation possessed a suitable pH range compatible with the oral mucosa, thereby minimizing the possibility of irritation or discomfort. The rheological analysis confirmed desirable pseudoplastic flow behavior, enabling efficient sprayability and prolonged mucosal retention.

- **RIGOROUS EVALUATION:**

1. Organoleptic and Visual Inspection

The formulations were evaluated qualitatively for color, odor, taste, and clarity

Taste	Mint
Odor	Menthol
Color	Olive green
Texture	Smooth, slightly hazy

2. Determination of pH

The pH of the oral mucosa normally ranges from 6.2 to 7.4. Extreme acidic or alkaline variations can cause severe tissue irritation, inflammation, or damage the tooth enamel. The pH of the formulations was meticulously determined using a calibrated digital glass electrode pH meter at an ambient temperature of 25^0C.

$$pH = 6.5^{+}/-0.5$$

3. Viscosity and Rheological Behavior

Viscosity profoundly influences both the mechanical spray ability of the liquid from the actuator nozzle and the subsequent retention time of the formed film on the mucosa. Viscosity was measured using a Brookfield Rotational Viscometer equipped with appropriate spindle configurations. Measurements were systematically recorded at varying shear rates (e.g., 12 rpm to 100 rpm) to observe whether the fluid exhibited shear-thinning (pseudoplastic) behavior. Pseudoplasticity is the ideal rheological state for a spray—allowing it to fluidize under the high shear of actuation and rapidly thicken upon low-shear mucosal impact.

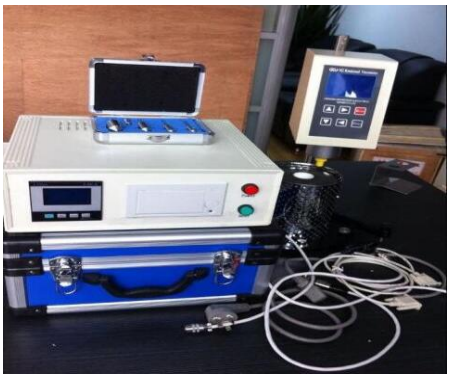


Fig. Brookfield Rotational Viscometer

4. Spray Pattern and Spray Angle Measurement

Atomization efficiency determines the exact surface area covered by the active ingredients, directly correlating to absorption kinetics.

- **Spray Pattern Ovality:** The formulation was actuated from a fixed distance of 5cm onto a vertically mounted piece of pH-sensitive indicator paper. The dimensions of the resulting droplet impact zone were precisely measured to determine the maximum D_{max} and minimum D_{min} diameters, yielding the ovality ratio.

Fig. 6.4 Spray Pattern

5.Wash-off Test:

Apply the spray to a piece of mucosa mounted on a glass slide at an angle. Continuously flow simulated salivary fluid over the slide at a set rate and record how long it takes for the formulation to completely wash away.

- **PHYTOCHEMICAL SCREENING PROTOCOLS**

i. **Test for Alkaloids (Drage Dorff's Test):** A minor quantity (50mg) of the extract was dissolved in dilute hydrochloric acid and filtered. The filtrate was treated with Drage Dorff's reagent (solution of potassium bismuth iodide). The formation of a prominent reddish-brown precipitate indicated a positive result for alkaloids.

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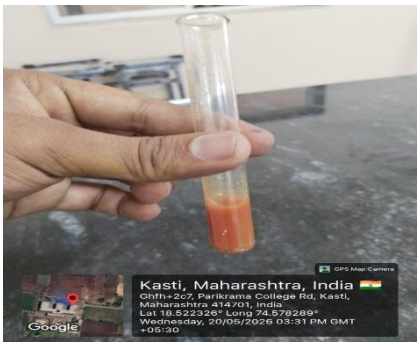

Fig. Drage Dorff's Test

ii. **Test for Flavonoids (Shinoda Test):** To 2mL of the extract solution, a few fragments of magnesium ribbon were added, followed by the dropwise addition of concentrated sulfuric acid (H_2SO_4). The emergence of a deep pink, scarlet, or magenta coloration confirmed the presence of flavonoid compounds.

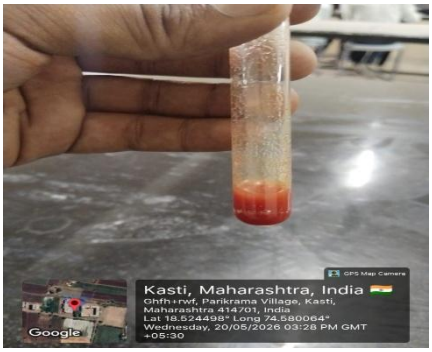

Fig. Shinoda Test

iii. **Test for Phenols and Tannins (Ferric Chloride Test):** The extracts were treated with a few drops of a 5% neutral ferric chloride ($FeCl_3$) solution. The rapid development of a dark green or bluish-black color indicated the presence of phenolic hydroxyl groups.

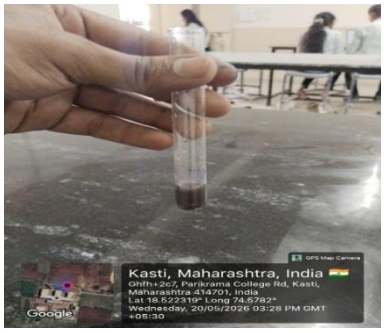

Fig. Ferric Chloride Test

iv. **Test for Terpenoids (Salkowski's Test):** The extract (5mL) was mixed with 2mL of chloroform, and 3mL of concentrated sulfuric acid was carefully added along the sides of the test tube to form a distinct lower layer. A reddish-brown coloration at the interface confirmed the presence of terpenoids.

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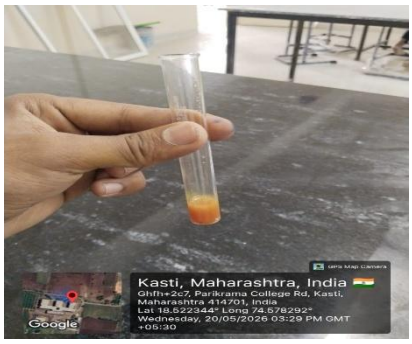

Fig. Salkowski's Test

v. **Test for Saponins (Froth Test):** Approximately 0.2g of the extract was shaken vigorously with 5mL of distilled water in a graduated cylinder and heated slightly. The formation of a persistent, stable honeycomb froth indicated the presence of saponin glycosides.

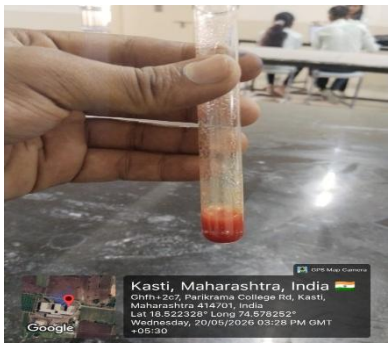

Fig. Froth Test

vi. **Test for Reducing Sugars (Benedict's Test):** Honey samples were diluted and treated with Benedict's reagent, followed by gentle heating in a water bath. The formation of a brick-red cuprous oxide precipitate confirmed the high concentration of reducing monosaccharides (glucose and fructose).

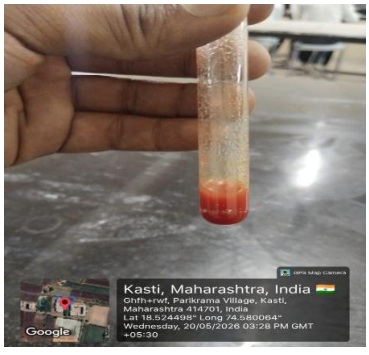

Fig. Benedict's Test

- **DISCUSSION:**

The present research successfully demonstrated the formulation and evaluation of a polyherbal mucoadhesive oromucosal spray containing curcumin, neem, and ginger intended for mucosal immunity stimulation and supportive respiratory healthcare applications. The study was designed on the principle that strengthening local immune defense at the oral and oropharyngeal mucosa may contribute to enhanced protection against respiratory pathogens, including Mycobacterium tuberculosis. Unlike conventional anti-tubercular therapies that directly target bacterial eradication, the developed formulation primarily focuses on immunomodulation, mucosal protection, and supportive host defense enhancement.

The selection of curcumin, neem, and ginger was based on their well-documented pharmacological properties. Curcumin possesses strong antioxidant, anti-inflammatory, and immunomodulatory activities and has been reported to stimulate macrophage activation, autophagy, and cytokine regulation. Neem contributes broad-spectrum antimicrobial and immunostimulatory effects due to the presence of bioactive compounds such as azadirachtin, nimbin, and nimbolide. Ginger provides additional antioxidant and anti-inflammatory support through active constituents such as gingerols and shogaols, which are known to reduce oxidative stress and inflammatory responses. The synergistic incorporation of these herbal ingredients may therefore provide a multifactorial supportive effect on mucosal immunity and respiratory wellness.

The developed formulation exhibited satisfactory physicochemical characteristics, indicating the successful preparation of a stable mucoadhesive spray system. The pH of the formulation remained within the acceptable physiological range for oral administration, thereby reducing the possibility of mucosal irritation and improving patient acceptability. Rheological analysis revealed pseudoplastic behavior, which is considered ideal for spray formulations because it facilitates easy atomization during administration while enhancing retention after contact with the mucosal surface. The observed mucoadhesive properties may prolong the residence time of active phytoconstituents within the oral cavity and improve localized delivery efficiency.

Phytochemical screening confirmed the presence of essential secondary metabolites including alkaloids, flavonoids, phenols, tannins, terpenoids, and saponins. These phytoconstituents are strongly associated with antioxidant, antimicrobial, and immunomodulatory activities. The presence of flavonoids and phenolic compounds may contribute significantly to free radical scavenging and reduction of oxidative stress, while terpenoids and alkaloids may enhance antimicrobial defense mechanisms. Such combined biological activities support the rationale behind using a polyherbal combination for immunity stimulation purposes.

The mucoadhesive oromucosal delivery system also provides several advantages over conventional oral dosage forms. Direct application to the oral mucosa allows localized delivery of bioactive compounds and may bypass partial first-pass metabolism, potentially improving the availability of phytoconstituents at the site of action. Sustained retention of the spray on the mucosal surface may further support prolonged interaction between the active compounds and mucosal-associated lymphoid tissues (MALT), thereby enhancing local immune responsiveness. In addition, the formulation may help maintain oral hygiene, soothe mucosal irritation, and provide protective support to the upper respiratory tract.

Although the present study demonstrated encouraging formulation and evaluation outcomes, certain limitations remain. The investigation was primarily limited to physicochemical and phytochemical characterization, and therefore detailed in-vivo immunological studies and clinical evaluations are still required to establish therapeutic efficacy, long-term safety, and immunostimulatory performance in human subjects. Future research should also focus on microbial challenge studies, stability optimization, pharmacokinetic assessment, and advanced clinical validation to further confirm the practical utility of the developed spray as a supportive immunity-enhancing formulation.

Overall, the findings of the study suggest that the developed polyherbal mucoadhesive oromucosal spray possesses promising characteristics as a natural mucosal immunity stimulator and supportive healthcare formulation. The synergistic integration of curcumin, neem, and ginger within a mucoadhesive delivery platform represents an innovative and patient-friendly approach for promoting localized immune defense and respiratory health support.

- **CONCLUSION:**

The present study successfully developed and evaluated a polyherbal mucoadhesive oromucosal spray containing curcumin, neem, and ginger for mucosal immunity stimulation and supportive respiratory health applications. The formulation demonstrated satisfactory physicochemical properties, appropriate pH, desirable rheological behavior, effective sprayability, and enhanced mucoadhesive retention, indicating its suitability for localized oral delivery. Phytochemical screening confirmed the presence of important bioactive constituents such as flavonoids, alkaloids, terpenoids, phenols, and tannins, which contribute to antioxidant, antimicrobial, anti-inflammatory, and immunomodulatory activities.

The synergistic combination of herbal extracts may help strengthen mucosal immune defense mechanisms and provide supportive protection against respiratory pathogens, including Mycobacterium tuberculosis. Furthermore, the mucoadhesive delivery system offers prolonged retention and sustained localized action within the oral cavity. Overall, the developed formulation represents a promising, natural, patient-friendly, and non-invasive approach for immunity enhancement and supportive healthcare, warranting further in-vivo and clinical investigations for future therapeutic applications.

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