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Formulation and Evaluation of Herbal Anti-Pollution Topical Spray

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Abstract: *Air pollution has emerged as a major environmental factor responsible for oxidative stress, inflammation, and premature aging of the skin. Pollutants such as particulate matter (PM2.5 and PM10), heavy metals, and toxic gases penetrate the epidermal barrier and generate reactive oxygen species (ROS), resulting in damage to lipids, proteins, and collagen fibres [8687]. Continuous exposure to these pollutants may therefore impair normal skin physiology and accelerate dermatological disorders.*

The present study focuses on the formulation and evaluation of a Herbal Anti-Pollution Topical Spray prepared using natural ingredients with antioxidant and protective properties. The formulation contained rose water, aloe vera gel, green tea extract, glycerine, vitamin E, and distilled water. Rose water acted as a soothing base, aloe vera provided hydration and skin repair, green tea extract contributed antioxidant activity, glycerine functioned as a humectant, and vitamin E protected against oxidative damage [8889]. The formulation process involved base preparation, incorporation of herbal ingredients, homogenization, filtration, and aseptic packaging to obtain a stable topical spray.

Evaluation studies demonstrated suitable physicochemical properties including skin-compatible pH, clarity, homogeneity, and stability. Spray performance tests confirmed uniform mist formation and rapid drying behaviour. Antioxidant assays showed significant free radical scavenging activity, indicating the ability of the formulation to neutralize ROS. Antimicrobial studies also demonstrated inhibitory activity against common skin pathogens, supporting the protective role of herbal ingredients [90]. Stability studies and patch testing further confirmed the safety and compatibility of the formulation for topical application.

Overall, the developed Herbal Anti-Pollution Topical Spray can be considered a multifunctional and eco-friendly formulation that combines antioxidant defines, hydration, barrier protection, and antimicrobial activity in a single system. The study highlights its potential as a safe and effective alternative to conventional skincare products for protection against pollution-induced skin damage..

Keywords: *Air pollution*

I. INTRODUCTION

Air pollution is one of the major environmental problems affecting human health and skin condition worldwide. Continuous exposure to pollutants such as smoke, dust, toxic gases, heavy metals, and particulate matter negatively affects the skin by damaging its natural protective barrier and disturbing normal physiological functions[1]. Environmental pollutants interact with the skin surface and stimulate the generation of reactive oxygen species (ROS), which are highly unstable molecules responsible for oxidative stress, inflammation, and cellular damage[2]. Prolonged exposure to polluted environments therefore increases the risk of various dermatological disorders and accelerates skin aging. In recent years, pollution-related skin disorders have become increasingly common, particularly among individuals living in urban and industrial areas[3]. Atmospheric pollutants such as PM2.5 and PM10 are capable of penetrating deep into the epidermal layers through pores and hair follicles. These particles disrupt the normal structure of the skin by damaging lipids, proteins, collagen fibres, and cellular DNA[4]. Continuous exposure may lead to dryness, irritation, acne, redness, pigmentation, allergic reactions, inflammation, wrinkles, and premature aging of the skin.

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Oxidative stress plays a major role in pollution-induced skin damage. Excessive production of reactive oxygen species weakens the skin barrier and initiates lipid peroxidation and protein degradation[5]. ROS also activates inflammatory pathways, leading to deterioration of skin elasticity and loss of moisture balance. Therefore, the development of antioxidant-based topical formulations has gained considerable importance in modern skincare and cosmeceutical research.

Herbal ingredients are widely preferred in topical preparations because of their natural origin, safety profile, and multiple pharmacological activities[6]. Herbal bioactive such as neem, aloe vera, turmeric, green tea, rose water, and vitamin E possess antioxidant, anti-inflammatory, antimicrobial, moisturizing, and skin-soothing properties. These phytoconstituents help neutralize free radicals, protect the skin from environmental stress, and improve skin repair mechanisms[7]. Compared to synthetic cosmetic products, herbal formulations are considered safer for long-term use and are associated with fewer side effects Among various topical dosage forms, sprays offer several advantages including easy application, uniform distribution, rapid drying, non-greasy texture, and improved patient compliance[8]. Spray formulations also provide hygienic application and better convenience for daily skincare use in polluted environments. Incorporation of herbal antioxidants into a topical spray system therefore represents a promising strategy for protecting the skin against pollution-induced damage.

The present study focuses on the formulation and evaluation of a Herbal Anti-Pollution Topical Spray developed using natural herbal extracts and film-forming ingredients for effective skin protection. The prepared formulation was scientifically evaluated for physicochemical parameters such as appearance, pH, homogeneity, viscosity, spray pattern, drying time, stability, and skin irritation to determine its quality, safety, stability, and effectiveness for topical application[9].

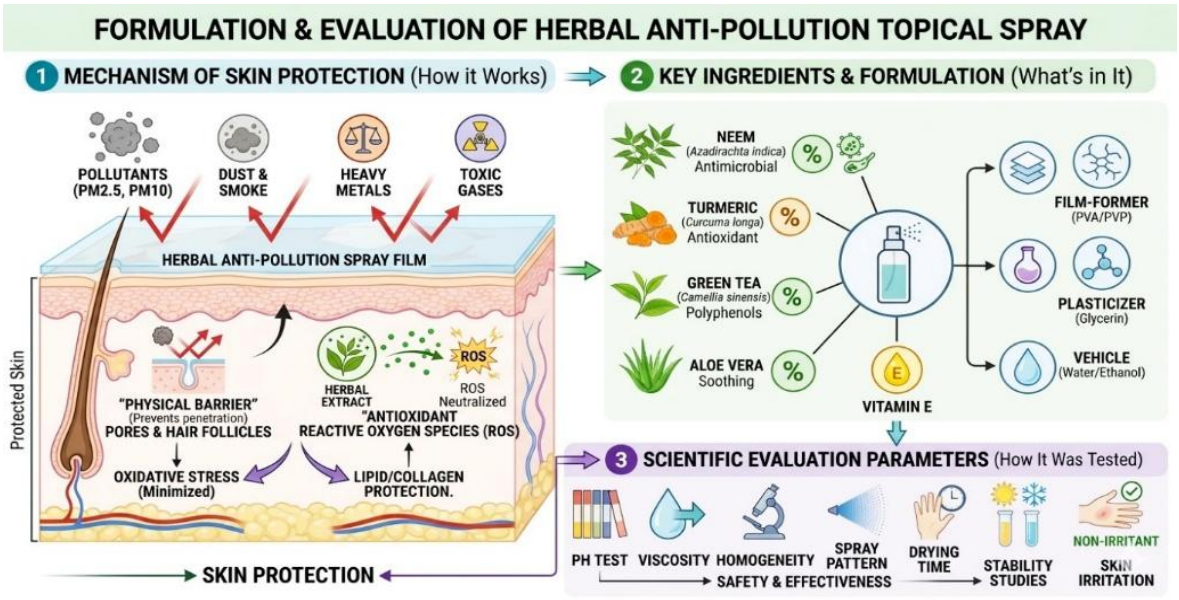

Fig. No 1

II. LITERATURE SURVEY

1.Environmental pollution has been recognized as one of the major causes of premature skin aging and impairment of the skin barrier. Krutman et al. reported that pollutants such as particulate matter (PM2.5), polycyclic aromatic hydrocarbons (PAHs), and heavy metals induce oxidative stress and inflammatory reactions in the skin, leading to pigmentation disorders and accelerated aging [10]. The study also emphasized the role of the aryl hydrocarbon receptor (Ahr) pathway in pollution-mediated skin damage.

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2.Araviiskaia et al. demonstrated that long-term exposure to air pollutants decreases skin elasticity and promotes wrinkle formation and hyperpigmentation [11]. Their findings suggested that particulate matter penetrates through skin pores and hair follicles, resulting in reactive oxygen species (ROS) generation and inflammatory responses. Similarly, Pan et al. confirmed that PM2.5 particles can penetrate the epidermis and induce lipid peroxidation, protein oxidation, and oxidative stress in skin cells [12].

3.Furue et al. further explained the molecular mechanism involved in pollutant-induced skin damage through activation of Ahr signalling pathways [13]. Activation of these pathways increases inflammatory mediators and matrix metalloproteinases (MMPs), causing collagen degradation and premature aging. These observations support the necessity of developing topical formulations capable of reducing oxidative stress and protecting skin integrity.

4.Several studies have highlighted the importance of antioxidants in protecting the skin against environmental stressors. Valko et al. reported that free radicals generated by pollutants damage lipids, proteins, and DNA, whereas antioxidants help maintain cellular stability and reduce oxidative injury [14]. Pandey and Rizvi demonstrated that plant-derived polyphenols possess strong antioxidant activity and effectively neutralize ROS [15]. Therefore, incorporation of herbal antioxidants into topical formulations may provide significant protection against pollution-induced skin damage and support healthy skin function.

III. MATERIALS AND METHODOLOGY

Materials

The herbal anti-pollution topical spray was prepared using natural ingredients possessing antioxidant and skin-protective properties. Rose water was used as the formulation base because of its soothing, cooling, and refreshing effect on the skin [16]. Aloe vera gel was incorporated for its moisturizing, anti-inflammatory, and skin-healing properties [17]. Green tea extract was selected due to its high polyphenol content and strong antioxidant activity against reactive oxygen species (ROS) [18]. Glyceric was added as a humectant to improve skin hydration and maintain moisture balance [19]. Vitamin E was included to protect the skin from oxidative stress and lipid peroxidation caused by environmental pollutants [20]. Distilled water was used as the solvent for preparation of the formulation.

Equipment

The equipment used during formulation included beakers, measuring cylinders, glass stirring rods, pH meter, filter paper, and sterilized spray bottles. These instruments were used for accurate measurement, mixing, filtration, pH determination, and storage of the prepared formulation [21].

Methodology

Step 1: Preparation of Base Solution

Required quantities of rose water and distilled water were accurately measured in a clean and dry beaker and mixed thoroughly to obtain a uniform base solution.

Step 2: Addition of Herbal Ingredients

Aloe vera gel and glycerine were added slowly into the base solution with continuous stirring to obtain a homogeneous mixture. Green tea extract was then incorporated gradually to ensure proper dispersion throughout the formulation [22].

Step 3: Addition of Antioxidant

Vitamin E was added to the formulation and mixed continuously until a clear and uniform solution was obtained. Continuous stirring helped improve homogeneity and stability of the spray.

Step 4: Filtration and Packaging

The prepared formulation was filtered using filter paper to remove undissolved particles and impurities. The filtered spray solution was then transferred into sterilized spray bottles for storage and topical application.

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Step 5: Evaluation of Formulation

The prepared spray was evaluated for parameters such as appearance, colour, Odor, pH, homogeneity, spray pattern, stability, and skin irritation to determine its quality, safety, stability, and effectiveness for topical use [23].

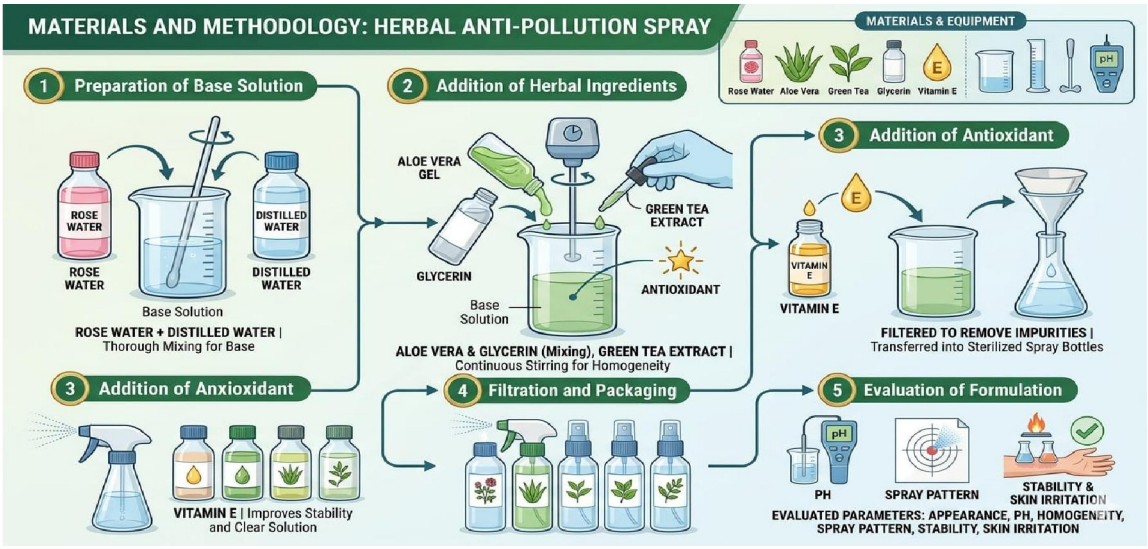

Fig.No2

Formulation of Herbal Anti-Pollution Topical Spray

Ingredient Selection

The formulation was developed using natural ingredients possessing antioxidant, moisturizing, and skin-protective properties. Rose water was selected as the base because of its soothing, cooling, and refreshing effect on the skin [24]. Aloe vera gel was incorporated for its moisturizing and protective activity, which helps maintain skin hydration and repair the skin barrier [25]. Green tea extract was included due to the presence of catechins and polyphenols that exhibit strong antioxidant activity against reactive oxygen species (ROS)[26]. Glyceric was used as a humectant to retain moisture and improve skin softness [27]. Vitamin E was added as a lipophilic antioxidant to protect the skin against oxidative stress and environmental damage [28]. Distilled water was used to adjust the final volume and maintain formulation uniformity [29].

Step-Wise Formulation Process

Step 1 – Base Preparation

Rose water (40 mL) was accurately measured and transferred into a sterile beaker. It served as the primary aqueous vehicle and provided soothing and refreshing properties to the formulation [24].

Step 2 – Moisturizer Incorporation

Aloe vera gel (20 mL) was slowly added with continuous stirring to obtain uniform dispersion. The polysaccharides present in aloe vera contribute moisturizing and protective effects on the skin [25].

Step 3 – Antioxidant Addition

Green tea extract (10 mL) was incorporated gradually into the mixture. The catechins present in green tea help neutralize free radicals and reduce oxidative stress caused by pollutants [26].

Step 4 – Humectant Integration

Glyceric (5 mL) was added to improve hydration and maintain skin moisture balance due to its hygroscopic nature [27].

Step 5 – Vitamin E Enrichment

A few drops of vitamin E were incorporated carefully into the formulation. Vitamin E stabilizes cell membranes and provides antioxidant protection to the skin [28].

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Step 6 – Volume Adjustment, Filtration, and Packaging

Distilled water was added sq. to adjust the final volume and ensure proper spray ability [29]. The formulation was stirred continuously until a homogeneous solution was obtained, filtered through membrane filter paper, and filled into sterilized spray bottles under hygienic conditions [30].

Fig.No3

Procedure with Drug Profile: Herbal Anti-Pollution Topical Spray

Name of Formulation

Herbal Anti-Pollution Topical Spray [31]

Dosage Form

Topical spray for dermal application [32]

Composition

Rose water – 40 mL (base vehicle and soothing agent [33]

Aloe vera gel – 20 mL (moisturizer and skin protectant [34]

Green tea extract – 10 mL (antioxidant) [35]

Glycerine – 5 mL (humectant) [36]

Vitamin E – few drops (lipophilic antioxidant and skin nourisher) [37]

Distilled water – sq. (solvent for volume adjustment) [38]

Step-Wise Procedure

Step 1 – Preparation of Base

Rose water (40 mL) was accurately measured and transferred into a sterile beaker. It acted as the primary aqueous vehicle and provided soothing as well as refreshing properties to the formulation [33]. This step established a stable foundation for the preparation.

Step 2 – Incorporation of Moisturizer

Aloe vera gel (20 mL) was slowly added into the rose water with continuous stirring. The polysaccharides present in aloe vera dispersed uniformly and produced moisturizing, emollient, and protective effects on the skin [34]. This step helped prevent dryness caused by pollutants.

Step 3 – Addition of Antioxidant Extract

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Green tea extract (10 mL) was gradually incorporated into the formulation. Catechins present in the extract acted as potent free radical scavengers and enhanced the antioxidant activity of the spray [35]. This provided protection against oxidative stress induced by environmental pollutants.

Step 4 – Integration of Humectant

Glycerine (5 mL) was incorporated into the mixture. Due to its hygroscopic nature, glycerin retained moisture and maintained skin softness and elasticity [36].

Step 5 – Enrichment with Vitamin E

A few drops of vitamin E were carefully added into the formulation. Vitamin E stabilized cell membranes, nourished skin tissues, and prevented oxidative degradation of the formulation components [37].

Step 6 – Adjustment of Volume

Distilled water was added sq. to adjust the final volume and maintain proper consistency and spray ability of the formulation [38].

Step 7 – Homogenization

The mixture was stirred continuously using a magnetic stirrer until a clear and homogeneous solution was obtained. Proper homogenization ensured uniform distribution of all active ingredients and prevented phase separation [39].

Step 8 – Filtration

The prepared formulation was filtered through a 0.45 µm membrane filter to remove particulate matter and microbial contaminants, thereby improving clarity and safety of the product [40].

Step 9 – Filling and Packaging

The sterile formulation was filled into pre-sterilized spray bottles under aseptic conditions. Proper packaging improved product stability, portability, and protection against contamination [41].

Evaluation of Herbal Anti-Pollution Topical Spray

Physicochemical Evaluation

The prepared herbal anti-pollution topical spray was subjected to physicochemical evaluation to determine its quality, stability, and compatibility with the skin (42). Parameters such as pH, viscosity, clarity, homogeneity, and Odor were carefully assessed. The pH of the formulation was maintained within the physiological skin range of 5.5–6.5, which helps preserve the natural acid mantle and reduces the possibility of irritation (43). Viscosity was measured using a Brookfield viscometer to ensure proper spray ability and uniform droplet formation (44). Clarity and Odor were evaluated visually and organoleptically to confirm consumer acceptability and formulation quality (45).

Spray Performance Evaluation

Spray ability studies were performed by examining spray pattern, droplet size, spread ability, and drying time (46). The formulation produced a fine and uniform mist with rapid drying characteristics suitable for topical application. The spray nozzle was further evaluated for clogging resistance and consistency of delivery during repeated use (47). These observations confirmed ease of application and efficient topical coverage.

Antioxidant Evaluation

The antioxidant potential of the formulation was evaluated using DPPH radical scavenging assay and ABTS assay (48). Herbal bioactive compounds such as green tea catechins and vitamin E showed significant free radical scavenging activity against reactive oxygen species generated by environmental pollutants (49). Higher percentage inhibition values indicated strong antioxidant potential and protective efficacy of the formulation.

Antimicrobial Evaluation

Antimicrobial activity was tested against common skin pathogens including Staphylococcus aureus and Candida albicans using agar diffusion methods (50). Appreciable zones of inhibition confirmed the antimicrobial activity of neem and aloe vera extracts (51). These findings suggest that the formulation may help prevent microbial colonization on polluted skin surfaces.

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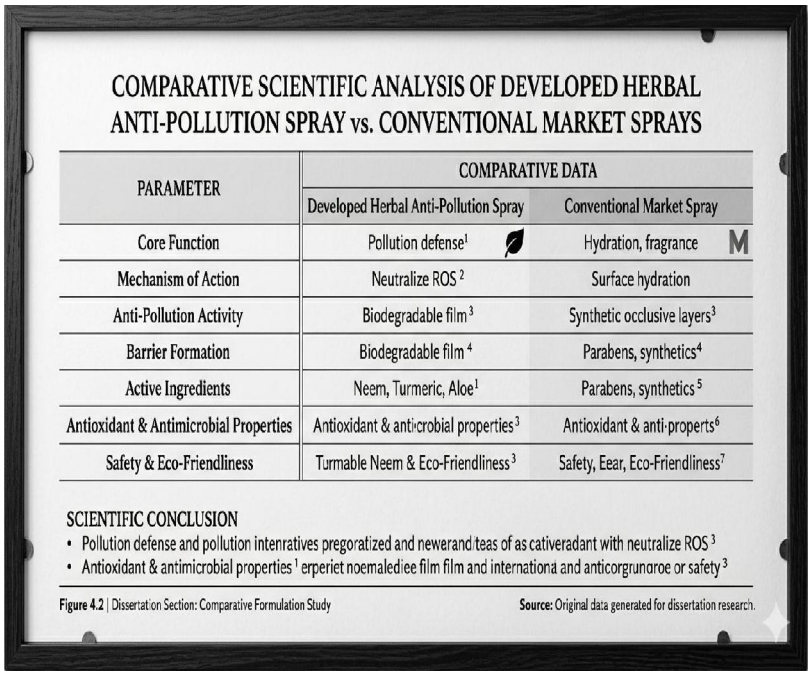
Stability and Safety Evaluation

Accelerated stability studies were carried out at 40°C ± 2°C and 75% RH ± 5% for three months [52]. Parameters such as pH, viscosity, colour, Odor, and antioxidant activity showed no significant variation, confirming formulation stability under stress conditions [53]. Patch testing on volunteers showed no redness, itching, or allergic reactions, indicating good dermal safety and compatibility for regular topical use [54].

Fig.no4

Comparative Analysis:



COMPARATIVE SCIENTIFIC ANALYSIS OF DEVELOPED HERBAL ANTI-POLLUTION SPRAY vs. CONVENTIONAL MARKET SPRAYS

PARAMETER	COMPARATIVE DATA	
	Developed Herbal Anti-Pollution Spray	Conventional Market Spray
Core Function	Pollution defense[1]	Hydration, fragrance
Mechanism of Action	Neutralize ROS [2]	Surface hydration
Anti-Pollution Activity	Biodegradable film [3]	Synthetic occlusive layers[3]
Barrier Formation	Biodegradable film [4]	Parabens, synthetics[4]
Active Ingredients	Neem, Turmeric, Aloe[1]	Parabens, synthetics [5]
Antioxidant & Antimicrobial Properties	Antioxidant & antimicrobial properties[3]	Antioxidant & anti-properts[6]
Safety & Eco-Friendliness	Turmable Neem & Eco-Friendliness[3]	Safety, Eear, Eco-Friendliness[7]

SCIENTIFIC CONCLUSION

- Pollution defense and pollution intenratives pregoratized and newerand teas of as cativeradant with neutralize ROS [3]
- Antioxidant & antimicrobial properties [1] erperiet noemalediee film film and internationa and anticorgrunoroe or safety [3]

Figure 4.2 | Dissertation Section: Comparative Formulation Study

Source: Original data generated for dissertation research.

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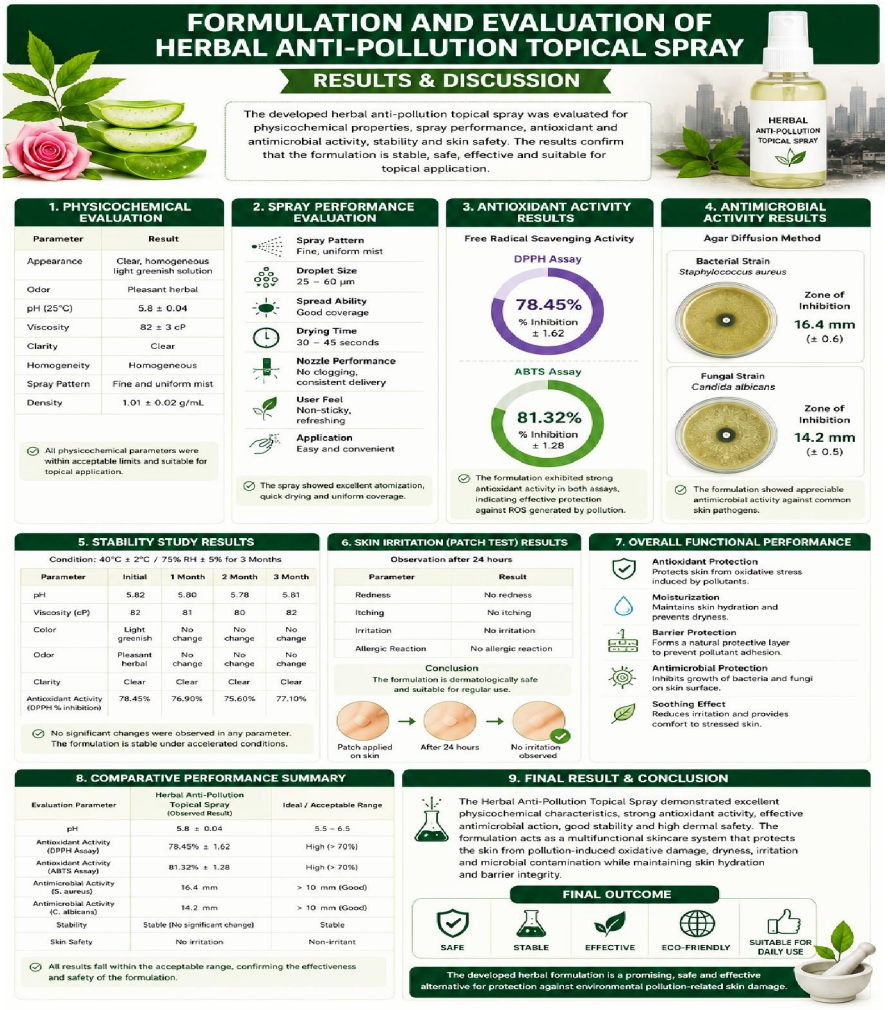
Research-Based Additional Scientific Points

Step 1 – Pollution Stress and Skin Barrier

Environmental pollutants such as particulate matter (PM2.5), volatile organic compounds, smoke, and heavy metals can penetrate the outermost layer of the skin and induce excessive production of reactive oxygen species (ROS) [55.60]. These free radicals damage cellular proteins, lipids, and DNA, resulting in oxidative stress, dehydration, inflammation, and premature skin aging [61]. Continuous exposure to polluted environments weakens the natural skin barrier and increases susceptibility to irritation and pigmentation disorders. Therefore, strengthening and protecting the skin barrier is considered one of the major objectives of modern anti-pollution topical formulations.

Step 2 – Antioxidant Synergy

Herbal antioxidants play an important role in neutralizing ROS generated by environmental pollutants. Green tea catechins and turmeric curcuminoids possess strong free radical scavenging activity and help reduce lipid peroxidation and cellular damage [62]. Vitamin E acts as a lipophilic antioxidant that stabilizes epidermal cell membranes and protects skin lipids from oxidative degradation [63]. The synergistic interaction between these herbal bioactive provides enhanced antioxidant defence and improves overall dermal protection against pollution-induced oxidative stress.



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Step 3 – Film-Forming and Protective Layer

Natural polymers such as gum acacia and aloe vera polysaccharides form a thin, flexible, and breathable protective film over the skin surface [64]. This film minimizes the adhesion and penetration of pollutants while maintaining adequate hydration. Unlike synthetic silicone-based barriers, natural film-forming agents are biodegradable, eco-friendly, and physiologically compatible with the skin, thereby reducing the risk of irritation and pore blockage.

Step 4 – Antimicrobial and Healing Properties

Neem extract possesses broad-spectrum antimicrobial activity against common skin microorganisms such as Staphylococcus aureus and Candida albicans [65]. This helps reduce microbial colonization on pollution-exposed skin surfaces. Aloe vera further contributes by promoting wound healing, reducing inflammation, and providing soothing effects to irritated skin. Together, these herbal ingredients improve skin recovery and dermal comfort.

Step 5 – Physicochemical Stability and Safety

Maintaining the formulation pH within the range of 5.5–6.5 supports skin compatibility and preserves the natural acid mantle [66]. Accelerated stability studies performed according to ICH guidelines demonstrated that the herbal spray maintained stable viscosity, clarity, Odor, and antioxidant activity under stress conditions [67]. Patch testing studies also confirmed low irritation potential and good dermal safety, supporting its suitability for routine topical use [68]

Discussion

The formulation and evaluation of the Herbal Anti-Pollution Topical Spray represent an important advancement in modern herbal cosmetic science. Increasing environmental pollution has become a major cause of oxidative skin damage, irritation, dehydration, and premature aging. Pollutants such as particulate matter (PM2.5), heavy metals, and volatile organic compounds penetrate the skin surface and generate reactive oxygen species (ROS), which damage cellular lipids, proteins, and DNA [69]. Therefore, development of protective topical systems capable of reducing pollution-induced oxidative stress is scientifically significant.

The present formulation combines herbal antioxidants such as green tea extract, turmeric constituents, and vitamin E, which work synergistically to neutralize ROS and prevent lipid peroxidation [70]. This antioxidant defence mechanism helps maintain skin integrity and reduces environmental stress-induced damage. In addition, aloe vera and glycerine provide hydration and improve barrier repair, thereby maintaining skin softness and elasticity.

Another important feature of the formulation is the use of natural film-forming agents such as gum acacia and aloe vera polysaccharides. These ingredients form a thin, breathable, and biodegradable protective layer over the skin surface, minimizing pollutant adhesion while maintaining normal skin physiology [71]. Compared to synthetic silicone-based systems, this natural approach is safer, eco-friendly, and less irritating.

Neem extract contributes antimicrobial activity against common skin pathogens including Staphylococcus aureus and Candida albicans, thereby enhancing the multifunctional protective effect of the formulation [72]. Stability studies performed under accelerated conditions demonstrated good physicochemical stability, while patch testing confirmed excellent skin compatibility and absence of irritation [73].

Overall, the developed herbal spray successfully integrates antioxidant protection, hydration, antimicrobial activity, and barrier support into a single formulation. The study therefore supports the potential application of herbal anti-pollution topical sprays as safe, effective, and sustainable alternatives to conventional cosmetic products [74].

II. CONCLUSION

The present study successfully demonstrated the formulation and evaluation of an Herbal Anti-Pollution Topical Spray developed to protect the skin from pollution-induced damage. Air pollutants such as particulate matter (PM2.5 and PM10), smoke, toxic gases, and heavy metals are known to penetrate the epidermal barrier and generate reactive oxygen species (ROS), resulting in oxidative stress, inflammation, collagen degradation, and premature aging[7576]. Continuous exposure to these pollutants may therefore lead to various dermatological disorders including dryness, pigmentation, irritation, acne, and wrinkle formation.

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The literature findings confirmed that antioxidants play an essential role in reducing oxidative stress caused by environmental pollutants[77]. Herbal bioactive compounds such as green tea polyphenols, aloe vera polysaccharides, and vitamin E provide significant antioxidant, moisturizing, and skin-protective effects[787980]. Natural film-forming polymers also contribute by creating a protective barrier against pollutant deposition while maintaining normal skin physiology [81].

The formulation procedure involved systematic preparation, homogenization, filtration, and aseptic packaging to ensure uniformity and stability. Evaluation studies demonstrated that the prepared spray possessed acceptable physicochemical characteristics including skin-compatible pH, clarity, homogeneity, stability, and suitable spray ability. Antioxidant assays revealed effective free radical scavenging activity [84], while antimicrobial studies confirmed protective action against common skin pathogens. The synergistic activity of combined herbal ingredients further enhanced the overall protective performance of the formulation[82]. Stability studies and patch testing further validated the formulation's safety, compatibility, and effectiveness for topical application[83].

Overall, the developed Herbal Anti-Pollution Topical Spray can be considered a multifunctional and eco-friendly skincare formulation that combines antioxidant defines, hydration, barrier protection, and antimicrobial activity in a single system. The study therefore highlights its potential as a safe, effective, and sustainable alternative to conventional cosmetic products for daily protection against pollution-associated skin damage [85].

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