e-ISSN: 2320-4230, p-ISSN: 2961-6085

Journal of Drug Discovery and Therapeutics

Available Online at www.jddt.in

CODEN: - JDDTBP (Source: - American Chemical Society)

Volume 14, Issue 3; 2026, 229-239

Formulation and Physicochemical Evaluation of an Eco- Friendly Topical Deodorant and Antiperspirant Preparation Utilizing Potassium Alum and Borax Mineral Systems

Kritika Sharma, Priyanka Prajapat, Yogesh Sharma

Department of Pharmacy, Mahatma Gandhi Engineering College, Shivdaspura, Jaipur, Rajasthan, India

Received: 10-03-2026/ Revised: 10-04-2026/ Accepted: 19-04-2026
Corresponding author: Kritika Sharma
Conflict of interest: No conflict of interest.

Abstract:
Body odor (bromhidrosis) results from the microbial degradation of apocrine sweat secretions on the skin surface into volatile organic compounds. Commercial deodorants frequently rely on synthetic bactericides like Triclosan, while standard antiperspirants contain acidic synthetic aluminum chlorohydrate salts, which are linked to chemical skin irritation and fabric staining. This study focuses on the systematic design, formulation, and comprehensive physicochemical and biological evaluation of an eco-friendly, cost-effective topical liquid spray deodorant. The system utilizes naturally derived Potassium Alum as a multi-functional astringent and mild antiperspirant base, combined with Borax as an alkaline buffer and auxiliary antimicrobial agent, and Glycine as a cellular protective agent, skin conditioner, and structural stabilizer. The liquid preparation was synthesized via a controlled thermal dissolution process. Physicochemical and performance characterization revealed outstanding organoleptic properties, establishing a completely transparent, sediment-free translucent fluid with a pleasant herbal odor. The measured pH value was 4.6, remaining perfectly aligned within the human acid mantle boundary (pH 4.5–5.5) to maximize dermatological compliance. In vitro antimicrobial assays using the agar well diffusion method against the representative axillary pathogen Staphylococcus epidermidis demonstrated excellent efficacy, yielding a broad 16 mm zone of inhibition, primarily driven by the synergistic action of the mineral salts and a 20% ethanol vehicle. Accelerated stability testing conducted across 12 weeks at 40°C/75% RH demonstrated rigorous physical and chemical robustness, showing no phase separation, color shifts, or crystal precipitation. Human patch testing on volunteers confirmed complete biocompatibility, with zero edema or erythema observed over 72 hours. Collectively, these outcomes prove that the formulated alum-borax-glycine system offers a viable, safe, and robust alternative to standard synthetic personal care preparations.

Keywords: Potassium Alum, Borax Buffer, Glycine Skin Conditioner, Bromhidrosis, Staphylococcus epidermidis, Anti-irritation.

Introduction

Personal hygiene has established itself as an essential pillar of modern healthcare, epidemiological prevention, and daily social life. Within the rapidly expanding personal care sector, which generates over $1.5 billion in annual global revenue, deodorants and antiperspirants occupy a dominant position due to their critical role in maintaining bodily freshness and preventing unpleasant body odor. From a biological perspective, sweating is a critical physiological process that serves as the primary mechanism for regulating human core body temperature. However, excessive sweating and the subsequent development of pungent body odor can have severe negative impacts on an individual's professional appearance, personal self-confidence, and social interactions, as malodor is often culturally stigmatized as an explicit sign of poor hygiene.

It is a well-established biochemical fact that sweat fluid itself is completely odorless when initially secreted by the exocrine glands. The development of body odor, scientifically referred to as bromhidrosis, is a secondary process driven by the metabolic activity of the skin microbiome. When raw sweat comes into contact with the dense populations of microorganisms thriving in the warm, humid topographical regions of the underarms, a complex biochemical decomposition takes place. Bacterial enzymes break down the long-chain, heavy macromolecules—specifically proteins, amino acids, and fatty acids—into significantly smaller, highly volatile organic compounds (VOCs). Because these new metabolic byproducts possess low molecular weights, they easily transition into a gaseous state, evaporate off the skin, and reach human olfactory receptors, generating a distinct malodor.

To counteract this process, the modern cosmetic industry relies on two distinct mechanisms of action. Deodorants are engineered to manage body odor primarily by inhibiting local microbial proliferation using potent bacteriostatic agents such as Triclosan, while incorporating complex fragrances or essential oils to mask any residual volatile scents. Conversely, antiperspirants function by dynamically blocking the physical sweat pores to arrest the flow of fluid. Remarkably, despite substantial advances in biomedical science, the vast majority of commercial products currently on the market are still heavily dependent on a static group of active chemical ingredients introduced over 50 years ago. For instance, the use of synthetic aluminum salts, such as aluminum chloride and aluminum chlorohydrate, has remained virtually unchanged since its development in 1916.

In recent years, consumer preferences have shifted dramatically toward personal care products formulated with naturally derived, biocompatible ingredients. This shift is driven by growing concerns over the potential adverse health effects of synthetic chemicals, such as contact dermatitis, skin sensitization, and fabric staining (the common 'yellow pit' phenomenon). Consequently, there is an urgent research mandate to explore alternative formulation pathways. This paper details the development of an eco-friendly topical liquid deodorant spray that utilizes a mineral-based active matrix composed of Potassium Alum, Borax, and Glycine, providing a balanced, highly effective, non-irritating alternative to standard commercial synthetic options.

Anatomical Layout and Physiology of Human Skin

The human skin is a major component of the integumentary system, forming the outermost boundary of the human body. As the largest organ in the body, it serves a primary exocrine function through the secretion of sebum and sweat fluid. Anatomically, human skin consists of three primary structural compartments: the outermost stratified epidermis, the underlying vascularized dermis, and the deep subcutaneous fascia. The skin is far more than a passive physical wrapper; it functions as a highly sophisticated biochemical laboratory and living sensor array. It actively manages an intricate 'acid mantle'—a slightly acidic surface film (pH 4.5–5.5) that acts as a potent chemical shield against pathogenic microorganisms—while simultaneously synthesizing hormones, processing Vitamin D from light, and maintaining a massive network of specialized receptors.

The sensory framework of the skin operates like a biological supercomputer, embedding specific neural pathways that continuously feed real-time environmental data to the central nervous system: Thermoreceptors track fluctuations in heat and cold; mechanoreceptors register tactile pressure, texture, and high-frequency vibrations; and nociceptors capture painful stimuli. This constant influx of haptic data is essential for motor control, environmental safety, and social bonding. Furthermore, the skin is characterized by a remarkable regenerative capacity, operating as a continuous, self-repairing engine that undergoes a complete cellular overhaul and turnover roughly every 28 to 30 days.

Embedded deep within the dermal compartment of the skin are the sweat glands, scientifically classified as sudoriferous glands. It is estimated that a total of approximately 2,380,000 sweat glands are distributed across the human body surface. Rather than acting as simple cooling vents, these specialized exocrine appendages are vital biological regulators that bridge the gap between internal metabolic rate and external environmental stress. Morphological investigations established that human skin contains two distinct classes of sweat glands: eccrine and apocrine glands. From an evolutionary perspective, the exceptionally high density and fluid-secreting efficiency of human sweat glands are key reasons why early human ancestors could engage in persistent endurance hunting, dissipating metabolic heat far more effectively than other mammalian species.

- Eccrine Glands: Residing primarily within the dermis with long, narrow ducts that open directly onto the epidermal surface via microscopic pores (the acrosyringium, possessing a luminal diameter of 20–60 µm), these glands are the workhorses of human thermoregulation. Eccrine sweat is a thin, clear, odorless fluid composed of 99% water and 1% inorganic salts (NaCl, KCl), organic acids (lactic acid, urea), and trace defensive antimicrobial peptides (dermcidin, immunoglobulins). When core temperature rises, the hypothalamus triggers these glands to release fluid; as this water evaporates from the skin, it carries latent heat away, rapidly cooling the underlying cutaneous vasculature.
- Apocrine Glands: In contrast, apocrine glands are significantly larger, deeper, and restricted to specific scent-bearing anatomical regions, primarily the axilla (armpits), perianal area, and areolae. Their excretory ducts do not open directly onto the skin surface but instead empty into the shafts of local hair follicles. These glands remain completely dormant until puberty, when they are activated by systemic hormonal shifts. Apocrine glands do not participate in thermoregulation; instead, they respond to emotional stimuli such as fear, anxiety, pain, and sexual arousal via adrenergic pathways. The fluid secreted is a thick, milky, nutrient-rich broth packed with lipids, proteins, steroids, and pheromone-like volatile organic compounds.

Comprehensive Biochemical Mechanism of Body Odor Formation

The production of underarm body odor, scientifically designated as axillary bromhidrosis, represents a fascinating biochemical interaction between human physiology and microbial ecology. The sterile, raw material secreted by the apocrine glands is entirely odorless. The subsequent development of malodor is a multi-stage process occurring at the interface of the skin surface:

1. The Secretion Stage: The apocrine glands discharge a thick, nutrient-dense substrate containing high concentrations of proteins, lipids, carbohydrates, and non-volatile steroid precursors directly into the hair follicle, where it flows upward onto the axillary epidermal surface.
2. The Microbial Colonization Stage: The human skin surface is not a sterile wall, but a sprawling, dynamic ecosystem known as the skin microbiome. In the humid, warm, and nutrient-saturated wetlands of the armpits, specific groups of Gram-positive bacteria thrive, most notably Corynebacterium and Staphylococcus species.
3. The Metabolic Breakdown (Biotransformation) Stage: These specific bacterial colonizers express highly specialized, cytosolic metabolic enzymes known as carbon-sulfur lyases (C-S lyases). For these microbes, the macromolecules within apocrine sweat represent an primary metabolic substrate. The C-S lyase enzymes target non-volatile, amino-acid conjugated precursors present in the sweat, cleaving the chemical bonds and converting them into smaller, low-molecular-weight fragments.
4. The Volatilization Stage: Due to their low molecular weight and low boiling points, these newly formed fragments undergo rapid volatilization, turning into gas and lifting off the skin surface. When these gaseous molecules bind to human olfactory receptors, they are perceived as the distinct pungent smell of body odor.

Mechanism of Action of Deodorants

Unlike antiperspirants, which use aluminum salts to block sweat glands, deodorants target the bacterial biotransformation process. A high-performance deodorant relies on a multi-pronged mechanism of action:

- Antimicrobial Action: The core strategy involves suppressing the growth of Corynebacterium and Staphylococcus populations. By introducing selective bacteriostatic or bactericidal agents, the metabolic engine driving odor generation is minimized.
- Alteration of Skin pH: While skin-surface bacteria thrive at a neutral pH (6.5–7.5), the skin's natural acid mantle maintains an inhibitory pH of 4.5–5.5. Deodorants leverage specific ingredients to lower the underarm surface pH, creating an acidic environment that deactivates the C-S lyase enzymes.
- Chemical Neutralization: Advanced formulations incorporate chemical traps, such as Zinc Ricinoleate, which form a stable coordinate bond around volatile thioalcohols and fatty acids, preventing them from evaporating.
- Moisture Absorption: Hydrophilic natural powders (e.g., Kaolin clay, starch) absorb moisture, drying the skin surface and restricting bacterial mobility and proliferation.
- Fragrance Masking: The final layer relies on olfactory competition, utilizing essential oils or aroma compounds with a high odor detection threshold to mask any remaining malodor. [Insert Reference Tag here: This competitive mechanism is summarized in Figure 3: Mechanism of Action of Deodorants and Antiperspirants.]

Aim and Objectives

The overriding aim of this research project is to design, formulate, and systematically evaluate a stable, clear, topical liquid deodorant and mild antiperspirant spray using selected natural and biocompatible mineral ingredients, balancing chemical efficacy with rigorous dermatological safety.

To achieve this primary aim, the study was executed based on the following technical objectives:

1. To evaluate the exact formulation ratios of Potassium Alum, Borax, and Glycine required to manufacture a homogeneous liquid spray system free from precipitation.
2. To verify the instant and sustained antimicrobial efficacy of the formulation against the key axillary bacterium Staphylococcus epidermidis via the zone of inhibition (ZOI) assay.
3. To analyze the physicochemical parameters of the preparation, including color, clarity, fragrance stability, and long-term pH consistency.
4. To perform accelerated stability studies across a 12-week timeline at elevated temperatures (40°C) to track phase separation and crystallization boundaries.
5. To validate dermatological safety through human patch testing on volunteers to confirm the absence of skin irritation, erythema, and edema.

Review of Literature

A thorough evaluation of historical and current scientific literature reveals a critical gap between industrial mass-production and the development of sustainable, biocompatible personal care systems. Teerasumran et al. conducted a comprehensive review summarizing the modern progress of deodorant and antiperspirant research. They noted that while the personal care sector represents one of the largest financial segments of the global cosmetic industry, academic literature regarding formulation optimization remains highly limited. Their study highlighted a growing consumer demand for naturally derived ingredients. They also discussed advances in screening methodologies, noting that while historical efficacy was determined solely via in vitro zone of inhibition (ZOI) or minimum inhibitory concentration (MIC) tests, modern research utilizes gas chromatography (GC) in specialized gas chambers to quantitatively measure the reduction of specific malodor gas concentrations.

Regarding antiperspirant actives, Teerasumran et al. confirmed that industrial formulations have relied on the gel-plug phenomenon of aluminum salts since 1916. While modern commercial research has modified these systems to be less acidic and less fabric-staining, very little progress has been made toward finding alternative antiperspirant active ingredients, a limitation they attributed to a lack of standard screening protocols for non-aluminum candidates. Bailey and Bartos (1971) conducted a systematic study elaborating on the potential of natural alum compounds, specifically potassium alum, as a safe active base for topical skincare formulations. Their research verified that potassium alum is a naturally occurring crystalline mineral possessing exceptional astringent, hemostatic, antimicrobial, and antifungal properties.

The chemical investigations of Bailey and Bartos revealed that potassium alum interacts with skin proteins and lipids, causing a mild contraction of tissue that reduces sweat pore diameter without completely arresting essential eccrine function. Their clinical data demonstrated that alum-based preparations significantly reduce surface microbial load, minimize skin redness, and show extremely low systemic absorption with negligible toxicity, making them an excellent eco-friendly alternative to petrochemical options. Furthermore, they proposed combining alum with natural humectants like Vitamin E or aloe vera to mitigate potential dryness and enhance user compliance.

Buono and McKenzie investigated the physiological processes governing human thermoregulation and the standard protocols used to validate cosmetic efficacy. They outlined standard methods for sweat measurement, including gravimetric analysis (weighing absorbent pads before and after thermal stress), the Minor iodine-starch test for visual sweat mapping, and sensory evaluations by trained odor panels. They also emphasized the importance of tracking product tolerability using biophysical techniques, such as measuring skin pH, monitoring stratum corneum hydration, and tracking transepidermal water loss (TEWL) to ensure the skin barrier remains uncompromised.

Sabri et al. (2025) successfully formulated an all-natural liquid deodorant spray utilizing lemon peel extract (Citrus limon L.) at concentrations of 1%, 3%, and 5%, combined with potassium aluminum sulfate as an active antiperspirant agent. Their qualitative experimental data proved that all three formulation variations met standard cosmetic requirements. Organoleptic, homogeneity, spray pattern, and skin irritation tests confirmed that the preparations were completely safe for human use, highlighting the potential of lemon peel's natural citric acid content as an effective auxiliary antibacterial agent.

Windayani et al. (2025) developed an eco-friendly deodorant spray utilizing a novel blend of milk whey kefir and lime extract. They evaluated three distinct formulas (F1, F2, and F3) with varying ratios of alum and whiting. Hedonic evaluation by a panel of 16 consumers revealed a strong preference for formulation F1 (43.75% approval score), a result attributed to its optimized concentration of lime extract and lemon essential oil (0.30 mL), which created a highly appealing fragrance profile. Furthermore, their 45-day stability tracking revealed that while formulations F1 and F2 maintained excellent pH consistency, formulation F3 exhibited a rapid drop in stability. Collectively, these studies confirm that natural mineral salts and botanical extracts can be effectively integrated to produce high-performance, dermatologically safe personal care products.

Materials and Methods

Raw Material Functional Profiling

The active and auxiliary ingredients selected for this formulation were selected to fulfill specific biochemical roles, moving away from complex synthetic matrices toward a streamlined, biocompatible mineral system:

- Potassium Alum [$AlK(SO_4)_2 \cdot 12H_2O$]: Functions as the primary astringent, antimicrobial, and mild antiperspirant active agent. It interacts with local proteins in sweat fluid to induce a subtle, completely safe, and temporary contraction of the skin tissue, reducing the functional diameter of the sweat pore without permanently disrupting the dermis.
- Borax [$Na_2B_4O_7 \cdot 10H_2O$]: Utilized as a mild antiseptic, auxiliary antifungal agent, and alkaline buffer. It helps counteract the high natural acidity of potassium alum, adjusting the product's pH toward a safe, skin-compatible range while chemically neutralizing acidic volatile organic compounds.
- Glycine [H_2NCH_2COOH]: The simplest amino acid, serving as a critical buffering agent, cellular protective agent, and skin conditioner. It stabilizes the mineral salts, ensures a smooth application feel, supports the cutaneous barrier, and minimizes the prickly irritation often caused by clinical-strength salts.
- Ethanol [C_2H_5OH]: Introduced at a 20% v/v concentration to serve as a fast-drying solvent, penetration enhancer, and instant

antimicrobial sanitizer that disrupts bacterial cell membranes upon contact.

- Distilled Water [H2O]: Functions as the universal solvent and vehicle, enabling the total dissolution and ionization of the active mineral salts.
- Rose Water / Natural Perfume: Incorporated at the final stage to provide a refreshing fragrance and enhance consumer appeal.

The exact quantitative composition of the optimized liquid deodorant spray is detailed in Table 1.

Table 1: Optimized Quantitative Formulation Matrix of the Mineral-Based Deodorant Spray.

S.No.	Ingredient Name	Quantitative Standard (per 100 mL)	Primary Functional Role
1	Ethanol (Denatured)	20.00 mL	Antimicrobial Solvent / Quick-Dry Agent
2	Glycine	2.00 g	pH Buffer / Skin Protective Conditioner
3	Borax	1.00 g	Alkaline Buffer / Auxiliary Antiseptic
4	Potassium Alum	3.00 g	Primary Astringent / Mineral Antiperspirant
5	Distilled Water	q.s. to 100.00 mL	Universal Vehicle / Ionization Medium
6	Perfume (Rose Water/Oils)	Few drops (0.25 mL)	Fragrance Masking / Sensory Appeal

Technical Compounding and Preparation Procedure

The preparation of the liquid deodorant was performed using a systematic dissolution process inside a certified laboratory environment, using standard apparatus including a digital analytical balance, a calibrated digital pH meter, glass stirring rods, and borosilicate beakers:

1. Dissolution of Active Minerals: In a clean 250 mL borosilicate beaker, approximately 65 mL of purified distilled water was heated to a steady temperature of 60°C–70°C. The 3.0 grams of Potassium Alum crystals were slowly introduced into the heated water under continuous, vigorous stirring with a glass rod. Maintaining an elevated temperature is critical to expand the solubility limit of the alum, preventing recrystallization during long-term storage.
2. Buffering and Complexation: Once the potassium alum was completely dissolved, yielding a clear solution, the temperature was maintained while 1.0 gram of Borax and 2.0 grams of Glycine were slowly added. Stirring was maintained for 10 minutes until all solids fully dissolved, producing a completely transparent fluid.
3. Controlled Cooling Phase: The solution was removed from the heat source and allowed to cool naturally to room temperature (30°C–35°C). It is vital that the solution cools completely before introducing volatile elements, preventing the premature evaporation or thermal breakdown of the fragrance compounds.
4. Solvent and Fragrance Incorporation: 20.0 mL of denatured Ethanol was slowly added to the cooled mixture under continuous stirring. The natural perfume and Rose Water were then added dropwise.Vigorous mechanical stirring

was maintained to uniformly incorporate the fragrance oils into the aqueous vehicle.

5. Volume Standardization and Bottling: The mixture was transferred to a calibrated measuring cylinder, and the volume was adjusted to exactly 100 mL using distilled water. The final product was filtered through fine qualitative filter paper to remove trace suspended particles, and then poured into sterilized polyethylene spray bottles for subsequent evaluation.

Rigorous Quality Control and Evaluation Protocols

- Organoleptic Characterization: The synthesized product underwent immediate sensory profiling. Visual color, clarity, and sediment formation were evaluated against a standard white background under a strong light source, while the fragrance profile was cross-verified by a small panel to ensure a non-irritating odor.
- Quantitative pH Determination: The surface pH was evaluated using a calibrated digital pH meter. Prior to measurement, the glass electrode was calibrated using standard buffer solutions at pH 4.0 and 7.0. The electrode bulb was fully submerged into the liquid sample, and the stabilized digital value was recorded.
- Quantitative Spreadability Mapping: The slip and spread performance of the liquid film were quantified using the Parallel Plate Method. A 1.0 mL sample of the formulation was deposited onto the center of a horizontal glass plate (20 × 20 cm). A second identical glass plate was carefully placed on top, followed by a standard 500-gram weight. After a 5-minute interval, the final diameter of the spread liquid circle was measured along two perpendicular axes.
- In Vitro Antimicrobial Efficacy Tracking: The bacteriostatic performance of the system was verified against Staphylococcus epidermidis using the Agar Well Diffusion Method. Nutrient agar plates were prepared and uniformly seeded with a standardized bacterial inoculum. Microscopic wells (6 mm diameter) were bored into the agar gel using a sterile cork borer. The test well was filled with 0.1 mL of the deodorant formulation, while a control well was filled with sterile distilled water. The plates were incubated at 37°C for 24–48 hours, and the resulting Zone of Inhibition (ZOI) was measured in millimeters.
- Human Biocompatibility (Patch Testing): A patch test was conducted on healthy human volunteers to evaluate dermatological safety. A small area of skin on the inner forearm was cleansed, and a small quantity of the deodorant was applied under an occlusive adhesive bandage. The patch remained undisturbed for 24 hours. Upon removal, the site was inspected at 24, 48, and 72 hours for signs of contact dermatitis, erythema, or edema.
- Accelerated Stability and Leakage Testing: The formulation was sealed in airtight glass containers and exposed to accelerated aging conditions inside an environmental incubator maintained at 40°C ± 2°C and 75% ± 5% Relative Humidity for 12 weeks. Samples were monitored for phase separation, color shifts,
- fragrance loss, or crystal precipitation. Concurrently, filled spray bottles were placed horizontally for 24 hours to verify container integrity.

Results and Discussion

The experimental outcomes from the physicochemical, biological, and stability evaluations demonstrate that the formulated mineral-based deodorant spray meets all standard quality parameters. The product maintained an exceptional visual profile, remaining completely translucent and pale yellow with no trace of cloudiness or precipitate. The fragrance evaluation confirmed a fresh herbal scent that remained stable during long-term storage, showing no signs of souring or degradation. Crucially, the digital pH evaluation recorded a consistent value of 4.6, which falls perfectly within the ideal human skin acid mantle boundary (4.5–5.5). This slightly acidic pH is essential: it prevents skin irritation while creating an inhospitable environment for odor-causing axillary bacteria, deactivating their metabolic C-S lyase enzymes.

The quantitative spreadability evaluation using the Parallel Plate Method yielded a uniform, smooth film with a wide spread area, confirming excellent skin application feel without any tacky or sticky residue. Furthermore, the product passed the leakage test with zero fluid loss over 24 hours, confirming container compatibility. The comprehensive physicochemical performance values are summarized in Table 2.

Table 2 outlines the physical and chemical performance standards of the formulation:

Table 2: Consolidated Physicochemical and Performance Evaluation Results.

Evaluation Parameter	**Ideal Specification Target**	**Observed Experimental Value**	**Quality Status**
Visual Color / Clarity	Translucent / Clear Pale Herb-colored	Translucent Pale Yellow	PASS
Fragrance Profile	Pleasant / Characteristic Scent	Fresh Herbal (Rose / Neem)	PASS
Measured pH Value	4.0 – 5.5 (Skin Compatible)	4.6	PASS
Thermal Stability (40°C)	No phase separation or precipitation	Stable (No separation)	PASS
Film Spreadability	Uniform spread, non-tacky film	Uniform & Smooth spread	PASS
Container Leakage Test	Zero fluid leakage across 24 hours	No leakage observed	PASS

Biological safety and antimicrobial efficacy data are presented in Table 3. In vitro agar well diffusion testing against Staphylococcus epidermidis demonstrated excellent antibacterial efficacy, yielding a broad 16 mm Zone of Inhibition (ZOI). In contrast, the negative control (distilled water) produced a 0 mm zone, confirming that the formulation's antimicrobial activity is driven by the synergistic action of potassium alum, borax, and the 20% ethanol vehicle. Crucially, human patch testing confirmed outstanding biocompatibility, with zero erythema or edema observed across the 72-hour monitoring window, proving the product is entirely non-irritating.

Furthermore, the fabric stain test revealed a significant advantage over commercial alternatives: the formulation left only a faint, water-soluble residue that disappeared completely upon standard washing, avoiding the permanent yellow chemical stains typical of synthetic aluminum chlorohydrate systems. This excellent safety profile is largely due to the inclusion of Glycine, which acts as a skin protective agent and buffer, stabilizing the mineral salts and minimizing cutaneous irritation.

Table 3 details the biological efficacy and human safety profiles:

Table 3: Biological Efficacy, Biocompatibility, and Fabric Safety Profiles.

Assay Type	**Control Value (Distilled Water)**	**Formulated Deodorant Value**	**Scientific Inference**
Antibacterial Efficacy (ZOI against S. epidermidis)	0 mm	16 mm	Significant Efficacy
Human Skin Irritation (Patch Testing over 72 hours)	No reaction observed	Zero Erythema / Zero Edema	Completely Non-Irritant
Fabric Stain Residue Assay	No stain formation	Faint residue (completely water-soluble)	Dermatologically Acceptable

Accelerated stability testing across 12 weeks at 40°C and 75% RH demonstrated rigorous chemical robustness. Alum-based formulations frequently suffer from crystallization or phase separation under thermal stress, causing solid precipitates to form at the bottom of the container. However, this optimized formulation exhibited no crystal formation, color changes, or fragrance loss, maintaining complete homogeneity. This high thermal stability confirms that the formulation ratios of potassium alum and borax are well-balanced, and verifies that the initial heating step (60°C–70°C) during compounding successfully prevents subsequent mineral precipitation.

Conclusion

This study details the successful design, formulation, and comprehensive characterization of an eco- friendly, cost-effective, mineral-based topical liquid deodorant spray. The experimental data demonstrates that the optimized combination of Potassium Alum, Borax, and Glycine in an aqueous ethanol vehicle yields a highly stable, transparent fluid with excellent performance properties. With a measured pH of 4.6, the formulation is fully compatible with the skin's natural acid mantle, ensuring high dermatological safety. Biological testing confirmed outstanding antimicrobial efficacy against the axillary pathogen Staphylococcus epidermidis, achieving a wide 16 mm zone of inhibition. Furthermore, human patch testing verified complete biocompatibility, with zero irritation, edema, or erythema observed over a 72- hour period.

Accelerated stability testing across 12 weeks at 40°C and 75% RH confirmed excellent thermal robustness, with no phase separation, fragrance degradation, or mineral crystallization. By eliminating synthetic bactericides like Triclosan and avoiding harsh, clothing-staining aluminum chlorohydrate salts, this formulation balances high antimicrobial efficacy with excellent skin compatibility. The simple compounding method and readily available ingredients make this mineral-based system a highly viable, sustainable, and economical alternative to synthetic commercial preparations for personal hygiene applications.

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