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Mechanistic Investigation of Borax Concentration on the Stability and Physicochemical Properties of Cold Cream Emulsions

Uditi Handa

uditipharmacist@gmail.com

Guru Gobind Singh College of Pharmacy

Anuj Malik

M.M. College of Pharmacy, M.M. (DU)

Anil Kumar

Geeta Institute of Pharmacy, Geeta University

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Abstract

Objective

The aim of this investigation was to analyze the mechanistic impact of borax content on cold cream formulations' physicochemical characteristics, and statistically assessed skin tolerability.

Methods

Cold cream formulations with different amounts of borax (0.16 g, 0.21 g, and 0.4 g) were developed while maintaining the same levels of other excipients. The formulations were assessed using established physicochemical and dermatological screening techniques for morphological features, spreadibility, pH, and skin irritation. To quantify irritation responses, statistical analysis was conducted using a one-sample t-test.

Results

The study revealed that via in situ soap foaming, interfacial film fortification, and morphological wax–soap network growth, borax content serves a crucial mechanistic role in stabilized cold cream emulsions. While greater borax levels elevated formulation pH and decreased spreadibility, indicating its mechanistic impact upon emulsion stability, the ideal borax content (0.16 g) resulted in durable, smooth, and skin-compatible cold cream. All formulations displayed significantly high irritation scores (mean difference range: 1.75–2.75, $p < 0.05$), according to one-sample t-test analysis, suggesting that they were appropriate for non-irritating skin responses. While V9 had the lowest mean score (1.75), it was still within the acceptable tolerance range. Formulation V8 had the highest mean score (2.75), suggesting greater dermatological safety. These results demonstrate that optimal borax content improves stability, performance, and skin compatibility.

Conclusion

This study finds that the borax concentration critically controls the stability and performance of cold cream emulsions. The results offer mechanistic guidance for improving conventional water-in-oil topical formulations for improved skin tolerability and stability.

INTRODUCTION

The cold creams have been a staple in skin care for centuries; primality used for their moisturizing cleansing and soothing properties. A typically cold cream consists of two phases an oil phase and a water phase - emulsified together to form a smooth. Creamy texture. The main ingredients include emulsifier oils [like-mineral oil, lanolin, or vegetable oil] water, thickness [such as-carbomer], preservative and perfume [1]. Cold cream is the water in oil emulsion and it gives the prolonged contact time in the site of application as compared to the other semisolid dosage form or formulation. They give elegancy to the skin and it is not that much greasy. Due to the oil phase, it gives an emollience to the skin. The function of the cold cream is for restoring moisture to dry skin, it allows to eliminate the waste materials from the pores and cools the body .it

is easy watered washable and easy to wash away. They are non-irritation when applied on the skin. The water phase provides the skin with additional protection. At body temperature, it becomes liquefiable. It enters the skin through the pores of the skin's epidermis. Galen, a Greek physician who created the cold cream formulation in the second century, is created with developing [2].

Topical delivery is the application of a drug-containing formulating to the skin to treat a cutaneous disorder or the cutaneous manifestations of a general disease directly the goal of containing the pharmacological effect of drug to the surface of the skin. Semisolid formulation in all their variety dominates the system for topical delivery, but foams, spray, medicated lotion, and other forms of topical administration are also used [3]. As cold creams contain enough amount of water and oil, they keep skin safe from the rough environments. They also keep skin moisturized and safe. Cold creams are designed to remove makeup and smooth the skin. To provide an emollient effect and oily protective layer on the skin. It prevents ageing and dehydration of skin [4].

Mechanistic role of excipients in cold cream

The formulation of the cold cream comprised beeswax, borax, rose water, methyl paraben, liquid paraffin, and purified water as the principal constituents. In the formation of cold cream, beeswax is an essential component that largely contributes to the product's emulsification, structural integrity, and sensory qualities. Chemically, beeswax is made up of hydrocarbons, free fatty acids, and long-chain fatty acid esters, which provide the formulation consistency and a semi-solid matrix. Beeswax thickens and structures the water-in-oil (w/o) emulsion in traditional cold cream systems, enhancing its viscosity and stability [1]. The production of soap in situ is one of beeswax's prime mechanistic aspects. In the aqueous phase, the free fatty acids in beeswax interact to the alkali borax to produce sodium salts of fatty acids, which serve as emulsifiers. These soaps improve emulsion stability and inhibit phase separation by stabilizing the scattered watery droplets within the oil phase. Furthermore, beeswax improves skin hydration and reduces transepidermal water loss through forming a protective lipid layer on the skin's surface, which helps cold cream's occlusive qualities. In addition, the rheological characteristics and texture of the formulation are improved by beeswax, giving it a smooth, spreadable consistency and enhancing the product's appearance and acceptability among consumers [5], [6].

Traditionally borax (sodium tetraborate) is an essential mechanistic component in cold cream that mainly functions as an alkaline agent and in situ emulsifier generator [1]. Borax dissolves in the aqueous phase of cold cream systems and subsequently dissociates to form borate ions, which results in a slightly alkaline condition. This alkalinity promotes the interaction between borax and the free fatty acids found in beeswax, which produces sodium salts of fatty acids (soap). By decreasing interfacial tension and encouraging uniform dispersion of the aqueous phase within the oil phase, these soaps serve as the main emulsifying agents, stabilizing the water-in-oil (w/o) emulsion [7]. Borax mechanism helps to stabilize emulsions by promoting the development of a structured interfacial layer around water droplets, which inhibits phase separation and coalescence. Furthermore, borax improves the cream's consistency and viscosity, which affects the formulation's rheological characteristics. Moreover, because of its buffering ability, the formulation's pH is kept within a range that is appropriate for topical use, which promotes product reliability and skin compliance [8], [9].

Methyl paraben (methyl p-hydroxybenzoate) serves as an important preservative in cold cream formulations, providing protection against microbial contamination. Mechanistically, methyl paraben exhibits antimicrobial activity by disrupting microbial cell membranes and inhibiting essential enzymatic processes within bacteria and fungi. Its efficacy is attributed to its ability to penetrate microbial cell walls and interfere with cellular metabolism, thereby preventing microbial growth and product spoilage. In cold cream formulations, which contain both aqueous and lipid phases, methyl paraben primarily acts in the aqueous phase, where microbial proliferation is more likely to occur [6], [7]. The inclusion of methyl paraben enhances the microbiological stability and shelf life of the formulation by preventing contamination during storage and repeated consumer use. Additionally, methyl paraben is chemically stable over a wide pH range and exhibits good compatibility with other formulation ingredients, making it a widely used preservative in topical pharmaceutical and cosmetic products [8].

Liquid paraffin (also known as mineral oil or paraffin oil) is a key lipid-phase component in classical cold cream formulations and functions primarily as an emollient, occlusive agent, and oil-phase vehicle. Mechanistically, liquid paraffin forms a hydrophobic film on the skin surface, which reduces transepidermal water loss (TEWL) by creating a semi-occlusive barrier [10]. This barrier effect helps to retain moisture within the stratum corneum, thereby improving skin hydration and preventing dryness. From a formulation perspective, liquid paraffin acts as the continuous oil phase in water-in-oil (w/o) emulsions, providing solubilization of lipophilic components and contributing to the stability and rheological properties of the cream. It also imparts smoothness, lubricity, and spreadibility to the formulation, enhancing sensory characteristics and patient compliance [11], [12]. Recent in vivo studies have demonstrated that paraffin oil penetrates only the superficial layers of the stratum corneum but significantly decreases TEWL through semi-occlusive effects, confirming its mechanism as a surface-protective emollient rather than a penetrative active ingredient. Additionally, liquid paraffin and white petrolatum are recognized as common occlusive excipients that physically block water evaporation from the skin, which is beneficial in dermatological conditions associated with barrier dysfunction, such as xerosis and atopic dermatitis [13].

Rose water, an aqueous distillate of Rosa damascena flowers, is commonly used in cold cream formulations as a fragrance, soothing agent, and mild bioactive component. Mechanistically, rose water contains trace amounts of volatile oils, phenolic compounds, and flavonoids that exhibit antioxidant, anti-inflammatory, and antimicrobial properties, which contribute to skin soothing and product acceptability. In cold cream formulations, rose water primarily functions in the aqueous phase, imparting a pleasant sensory profile and enhancing consumer compliance. Additionally, its mild antimicrobial and antioxidant properties may synergistically support preservative systems by reducing microbial load and oxidative degradation. Rose water also improves the sensorial characteristics of topical formulations by providing a cooling effect and enhancing spreadability due to its aqueous nature [6], [14].

Purified water serves as the dispersed aqueous phase in classical water-in-oil (w/o) cold cream emulsions and plays a critical mechanistic role in emulsion formation and stability. Water acts as the solvent for hydrophilic ingredients such as borax and preservatives and facilitates in situ soap formation between borax and free fatty acids from beeswax, which is essential for emulsification. Mechanistically, water droplets dispersed within the oil phase contribute to the cream’s cooling sensation upon application due to evaporation and enhance skin hydration by increasing water content in the stratum corneum. Water also

influences the rheological and physicochemical properties of the formulation, including viscosity, spreadability, and pH, thereby affecting product stability and performance [11], [12].

Cold cream is a classical water-in-oil (w/o) emulsion in which formulation stability is predominantly governed by in situ soap formation. Beeswax, a key structural component of the formulation, contains free fatty acids that react with borax (sodium borate) present in the aqueous phase. Upon dissolution, borax dissociates to generate borate ions, which subsequently interact with the free fatty acids of beeswax to form sodium salts of fatty acids (soap). This soap is formed at the oil–water interface, where it acts as the primary emulsifying agent [15], [16]. The resulting interfacial soap film effectively lowers interfacial tension, enhances the cohesion of dispersed aqueous droplets within the continuous oil phase, and contributes to improved emulsion stability, viscosity, and overall consistency of the cold cream formulation as illustrated in Fig. 1.

Cold cream stability is governed by in situ soap formation between beeswax fatty acids and borax; however, borax is a critical functional ingredient in cold cream formulations, and its concentration significantly influences emulsion stability, pH, texture, and skin compatibility. Understanding its mechanistic role is essential for optimizing formulation design, ensuring product stability, and minimizing potential skin irritation in cosmetic and pharmaceutical applications. Previous studies have largely focused on formulation development without systematically evaluating the concentration-dependent effects of borax. Therefore, this study provides novel mechanistic insights into optimizing borax concentration for stable, safe, and effective cold cream emulsions, contributing to the scientific understanding and modernization of traditional topical emulsion systems.

MATERIALS AND METHODS

Cold cream formulations were prepared using beeswax, liquid paraffin, borax (sodium borate), filtered water, and fragrance. All compounds were of analytical quality and utilized without additional purification.

Preparation of Coldcream

All chemicals were precisely measured in accordance with the composition outlined for formulations F1–F4 as detailed in Table I. Beeswax was placed in a china dish and combined with liquid paraffin to formulated the oil phase, which was warmed on a hot plate to 70°C until fully melted. Borax was independently dissolved in the requisite volume of water to formulate the aqueous phase and heated concurrently with continuous agitation until a transparent solution was achieved. The heated aqueous phase was thereafter introduced dropwise into the oil phase while maintaining continuous agitation to promote emulsion formation. Stirring persisted until a homogeneous and smooth consistency was attained. The mixture was permitted to cool, then rose water was added at around 40°C. Methyl paraben was incorporated as a preservative, and the final amount was calibrated with water to get the appropriate consistency, as illustrated in Fig. 2. The produced mixtures were stored in appropriate containers for subsequent examination [16].

Table I: Composition of cold cream.

Sr.no.	Ingredient	F1	F2	F3	F4	Role of ingredient
1.	Beeswax (gm)	3.2	3.2	3.2	2	Moisturizer base
2.	Borax (gm)	0.16	0.21	0.4	0.16	Emulsifying agent
3.	Liquid paraffin (gm)	10	10	10	10	Lubricating agent
4.	Rose water (ml)	Q.s	Q.s	Q.s	Q.s	Perfuming agent
5.	Methyl paraben (gm)	Q.s	Q.s	Q.s	Q.s	Preservative
6.	Water (ml)	Q.s	Q.s	Q.s	Q.s	Diluent

Mechanistic Evaluation of Borax Concentration in Cold Cream Formulations:

1. pH Determination: The pH of the cream compositions was assessed utilizing a digital pH meter. Before measurement, the pH meter was calibrated with standard buffer solutions of established pH values. A 0.5 g sample of cream was precisely measured and dispersed in 50 mL of distilled water to achieve a homogeneous mixture. The pH meter's electrode was submerged in the dispersion, and the pH value was documented upon achieving a steady reading [17].

2. Spreadibility Test: The spreadability of the cream was assessed utilizing the glass slide method. A predetermined amount of cream was positioned between two glass slides and subjected to compression to achieved a uniform thickness through applied a specified weight on the upper slide for five minutes. Subsequent to compaction, an extra weight was placed on the weighing pan, and the duration for the upper slide to traverse the lower slide was documented. Spreadability was determined using the Eq. (1), where M represents the weight applied in grams, L denotes the length of the glass slide in centimeters, and T indicates the time taken for the upper slide to move in seconds. The mean spreadability was determined from triple measurements [18].

$$Spreadability\ (S) = \frac{\mathrm{M{*}L}}{\mathrm{T}} \ldots\ldots\ldots\ldots (1)$$

3. Morphological Evaluation: The morphological attributes of the cream compositions were evaluated using manual visual and sensory analysis. Parameters such as colour, odour (fragrance), and texture were assessed to ascertain the physical appearance and cosmetic acceptability of the formulations. The cream was assessed for homogeneity, grittiness, phase separation, and general consistency [19].

Irritancy Test and Ethical Consideration

A 1 cm² region was delineated on the left dorsal surface of the skin, and a little amount of cold cream was administered to the specified location. The exposure duration was documented, and the treated region was observed at consistent intervals for a maximum of 10 minutes for any indications of irritation, such as erythema, redness, swelling, or, itching. Ten healthy adult participants aged 21 to 30 years engaged in the study [20]. Before participation, the participants were apprised of the study aims and procedures, and written informed consent was secured. The research was executed in compliance with the Declaration of Helsinki

and received approval from the Institutional Ethics Committee (Ref. No. GGSCOP/2025/2024). Participants were apprised of potential dangers and their entitlement to withdraw at any moment. Observations reported by the volunteers were recorded and summarized in Table II. The data were analyzed using SPSS software, and employed a one-sample t-test for statistical assessment.

Table II: Irritability Test of Cold Cream Formulations in Human Volunteers

Formulation batch	Skin irritation evaluation									
	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10
F1	++	+++	++	+++	+++	+++	+++	+++	++	+++
F2	+++	++	++	++	++	+++	++	+++	++	++
F3	++	+	+	+	++	+	+	++	+	++
F4	+++	++	+++	++	+++	+++	++	+++	++	++
Slightly (+), Acceptable (++), No (+++)										

RESULTS AND DISCUSSION

A mechanistic evaluation was conducted by correlating borax concentration with pH, spreadability, morphological stability, and irritancy data. The fundamental mechanism for emulsion stabilization was identified as the formation of sodium fatty acid soaps by the reaction of borax with free fatty acids in beeswax. Formulation F1 exhibited optimal pH, and balanced spreadibility while, increasing borax concentration in F2 and F3 resulted in higher pH and reduced spreadibility due to increased consistency and rigidity (Table III). Decreasing the proportion of beeswax in F4 enhanced spreadability but slightly reduced formulation consistency and stability. The results affirm that both borax and beeswax substantially affect the physicochemical and morphological characteristics of cold cream compositions. F3 exhibited the lowest spreadability owing to increased viscosity resulting from excessive borax, whilst F4 demonstrated the highest spreadability due to reduced beeswax concentration. Therefore, the reported data also confirm that the sodium fatty acid soaps formed at the oil–water interface reduce interfacial tension and create a rigid protective film around dispersed aqueous droplets. The interfacial film inhibits droplet coalescence and phase separation, enhancing the stability of the emulsion system. Thus, borax concentration directly governs droplet stabilization and the overall physical stability of the formulation [21], [22]. In addition to emulsification, borax contributes to the development of a semi-crystalline wax–soap structural network within the continuous oil phase. This network enhances the mechanical strength and consistency of the cream. Optimal borax levels resulted in improved spreadibility without compromising emulsion integrity, indicating its structural reinforcement effect in the formulation matrix [6].

Table III: Physicochemical and Morphological Evaluation of Cold Cream Formulations (F1–F4).

Formulation	Colour	Fragrance	Texture	Homogeneity	Phase Separation	pH (Mean ± SD)	Average Spreadibility (g·cm/s)
F1	Creamy White	Pleasant rose fragrance	Smooth, creamy	Uniform	Absent	6.4 ± 0.05	5.5
F2	Off-white	Pleasant rose fragrance	Slightly stiff, creamy	Uniform	Absent	6.8 ± 0.04	4.8
F3	White	Mild soap-like odour	Thick, slightly gritty	Slightly non-uniform	Absent	7.4 ± 0.06	1.2
F4	Pale Yellow	Pleasant rose fragrance	Soft, less viscous	Uniform	Slight tendency observed	6.3 ± 0.03	6.4

Morphological evaluation revealed that F1 exhibited smooth texture, uniform appearance, and acceptable fragrance. The uniform texture of F1 results from the optimal concentration of beeswax and borax, which promotes the formation of sodium fatty acid soaps at the oil–water interface and contributes to a stable water-in-oil (w/o) emulsion system. These soaps serve as principal emulsifying agents, diminishing interfacial tension and creating a cohesive interfacial film surrounding scattered water droplets, thus improving emulsion uniformity and sensory characteristics [21], [22]. Formulation F2 showed slightly increased stiffness compared to F1, which might be attributed to the higher borax concentration, leading to enhanced soap formation and a more structured wax–soap network in the continuous oil phase. Increased borax levels can facilitate the formation of a semi-crystalline structure, improving rigidity and consistency of the cream. However, excessive structuring can negatively affect spreadibility and consumer sensory perception, as observed in F2 [23], [24]. While, Formulation F3 demonstrated a thicker and slightly gritty texture, attributable to an excess of borax leading to the over-neutralization of free fatty acids in beeswax and the resultant creation of excessive soap aggregates. Such aggregates may disrupt the uniformity of the emulsion and impart a gritty or coarse texture. Additionally, high alkalinity associated with excess borax can induce partial destabilization of the wax matrix and alter rheological behavior, leading to a less desirable sensory profile [25], [26]. F4 exhibited a more pliable consistency with a little propensity for phase separation, attributable to the reduced concentration of beeswax, as illustrated in Fig. 3. Beeswax serves as a vital structural ingredient and consistency enhancer in cold cream formulations by establishing a crystalline lipid network that stabilizes the dispersed phase. A decrease in beeswax content compromises this structural network, leading to reduced viscosity and heightened vulnerability to phase separation. This observation aligns with prior reports emphasizing the significance of wax concentration in preserving emulsion stability and averting creaming or coalescence [27].

Overall, the morphological assessment indicates that the quantities of borax and beeswax significantly affect the texture, consistency, and stability of cold cream formulations. A precise equilibrium between emulsifier

production (borax–fatty acid soaps) and wax structure is crucial for attaining a stable, visually appealing, and pharmaceutically robust topical cream system.

Irritancy Test Interpretation

The irritancy study revealed that formulations F1, F2, and F4 exhibited no significant sign of irritation, edema, redness, or swelling, demonstrating favorable dermatological compatibility. Formulation F3 exhibited minor redness and acceptable irritation responses in certain volunteers, which might be attributed to the higher borax concentration and increased alkalinity of the formulation, as the responses for F1–F4 as detailed in Table IV. Overall, F1 exhibited the most favorable safety profile with negligible discomfort, affirming its appropriateness as the optimal formulation for topical use.

Table IV. Skin irritancy evaluation of cold cream formulations (F1–F4) based on irritation, edema, redness, and swelling parameters.

Irritancy test	F1	F2	F3	F4
Irritation	No	No	Acceptable	No
Edema	No	No	No	No
Redness	No	No	Slightly	No
Swelling	No	No	No	No

The mild irritation observed in F3 might be due to excessive borax concentration, which raises the formulation pH and perhaps compromises the skin barrier. The absence of irritation in F1 and F4 suggests that optimized borax concentration and beeswax content provide a protective occlusive effect, improving skin tolerability. The irritancy test findings demonstrated that the formulated creams did not produce any significant signs of skin irritation. No erythema, edema, itching, or redness was noted at the application site throughout the 10-minute observation period. This suggests that the formulations were dermatologically safe and suitable for topical application. Increased borax concentration did not show visible irritation at optimized levels; however, higher concentrations may potentially raise skin alkalinity, perhaps resulting in irritation. The optimized formulation (F1) exhibited no adverse reactions, confirming its safety and suitability for cosmetic use. The reduced beeswax formulation (F4) also showed no irritation but demonstrated lower consistency, suggesting that beeswax predominantly influences formulation stability rather than skin compatibility.

Borax additionally affects the pH of the formulation, serving as a mild buffering agent. Controlled concentrations of borax (F1) maintained the pH within a dermatologically acceptable range, evidenced by the absence of significant irritation, edema, or redness in human volunteers. This illustrates that borax aids in both emulsion stabilization and formulation safety, as well as skin compatibility.

Interpretation of One-Sample t-Test outputs

A one-sample t-test was performed to evaluate the irritability scores of cold cream formulations (V1–V10) in human volunteers, with a test value of 0. The average scores of all formulations found to be more than zero ($p < 0.05$), indicated that the formulations were non-irritant and well tolerated. All volunteer (V1–V10) showed statistically significant results for formulations ($p < 0.05$), confirmed that the observed irritability scores were not due to random variation as mentioned in Table V. The graphical representation shows (Fig. 4) that all formulations exhibited mean irritability scores above 1.75, indicated acceptable to non-irritant responses. Formulation V8 showed the highest mean score, suggesting superior dermatological safety, while V9 showed comparatively lower but still acceptable tolerability.

Statistical analysis using the one-sample t-test revealed significant deviations from the null hypothesis ($p < 0.05$), confirmed that borax concentration significantly affected key formulation parameters such as stability, pH, and spreadability. These results statistically validated the mechanistic role of borax in enhancing the physicochemical and functional performance of cold cream formulations.

Table V. One-sample t-test results of irritability scores of cold cream formulations in human volunteers.

One-Sample Test						
	Test Value = 0					
	T	Df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
V1	8.660	3	.003	2.500	1.58	3.42
V2	4.899	3	.016	2.000	.70	3.30
V3	4.899	3	.016	2.000	.70	3.30
V4	4.899	3	.016	2.000	.70	3.30
V5	8.660	3	.003	2.500	1.58	3.42
V6	5.000	3	.015	2.500	.91	4.09
V7	4.899	3	.016	2.000	.70	3.30
V8	11.000	3	.002	2.750	1.95	3.55
V9	7.000	3	.006	1.750	.95	2.55
V10	9.000	3	.003	2.250	1.45	3.05

All the formulations had shown statistically significant mean scores ($p < 0.05$) according to results found, this showed that observed responses were not incidental. The average scores were in range of 1.75 to 2.75, this suggested that all formulations were either non-irritant or acceptable. Volunteers V1, V5, V6, V8 and V10 indicated higher mean scores and in the “no irritation” category this also showed superior dermatological

tolerance. Volunteers V2, V3, V4, V7, and V9 exhibited mean scores around 2 (++), corresponding to an acceptable irritation profile with no adverse skin reactions.

For all the formulations 95% confidence intervals were positive and did not consisting of zero this proved the relailblity and consistency of the volunteer responses. Overall, the findings indicate that the developed cold cream formulations are safe for topical application and do not induce significant skin irritation.

The stability and physicochemical properties of cold cream were impacted by the variation in borax concentration. Formulation F1 (0.16 g borax, 3.2 g beeswax) exhibited optimal characteristics with pH 6.4 ± 0.05, good spreadibility (5.5 g·cm/s), smooth texture, uniform homogeneity, and no phase separation. Increasing borax concentration in F3 (0.40 g) increased pH (7.4 ± 0.06), reduced spreadibility (1.2 g·cm/s), and produced a thick, slightly gritty texture, indicated excessive soap formation. F4 (reduced beeswax) showed higher spreadibility (6.4 g·cm/s) but slight phase separation, highlighted the role of wax–soap network strength. Overall, optimized borax concentration (0.16 g) provided the best balance of stability, texture, and skin compatibility.

Furthermore, a concentration-dependent dual effect of borax was observed. Low borax concentrations resulted in insufficient soap formation, leading to weaker emulsification and potential instability. An optimal concentration produced maximum stability and acceptable skin tolerability. Although excessive borax levels can theoretically increase alkalinity and irritation risk, such adverse effects were not observed in the optimized formulations investigated in this study.

CONCLUSION

This study demonstrated that borax concentration plays a critical mechanistic role in stabilizing cold cream emulsions through in situ soap formation, interfacial film strengthening, and structural network development. Optimal borax concentration (0.16 g) produced stable, smooth, and skin-compatible cold cream, whereas higher borax levels increased pH and reduced spreadability, confirming its mechanistic role in emulsion stability. One-sample t-test analysis showed that all formulations exhibited significantly high irritability scores (mean difference range: 1.75–2.75, $p < 0.05$), indicating acceptable to non-irritant skin responses. Formulation V8 showed the highest mean score (2.75), indicating superior dermatological safety, while V9 showed the lowest (1.75), yet remained within the acceptable tolerance range. These findings confirm that optimized borax concentration improves emulsion stability, physicochemical performance, and skin compatibility.

However, the study was limited by a small sample size (n = 4 per formulation), short-term stability evaluation, and the absence of advanced microstructural characterization techniques. Future studies should focus on long-term accelerated stability testing, droplet size and microstructure analysis (e.g., microscopy or particle size analysis), detailed rheological modeling, and large-scale in vivo dermatological studies to further validate the mechanistic role of borax and optimize its concentration for pharmaceutical and cosmetic applications.

Declarations

Author Contribution

U.H. wrote the original manuscript, A.M. supervised the research and A.K. edited the manuscript. All authors reviewed the manuscript.

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Figures

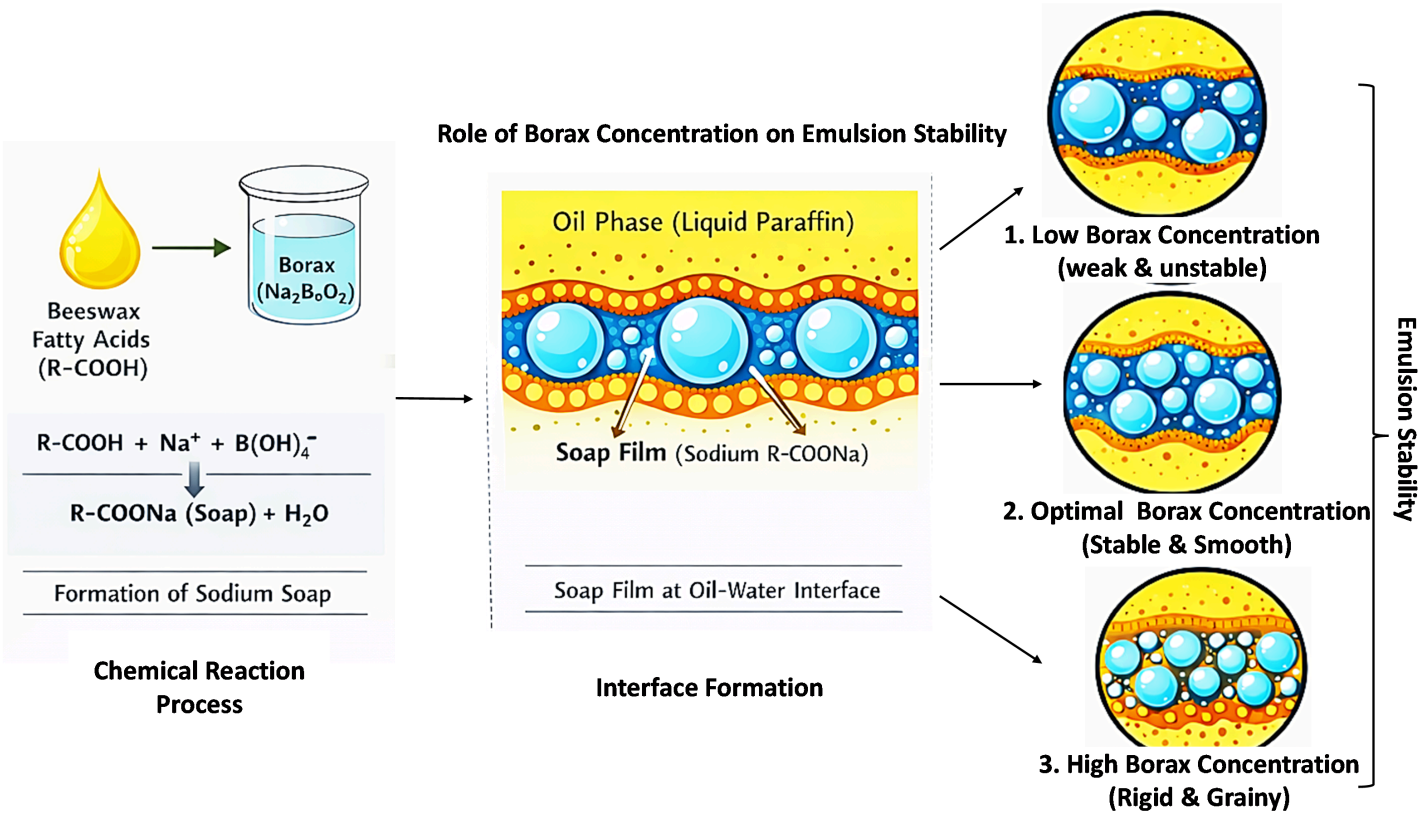


Figure 1

Mechanistic pathway depicting the influence of borax concentration on emulsion stabilization and skin compatibility in cold cream formulations.

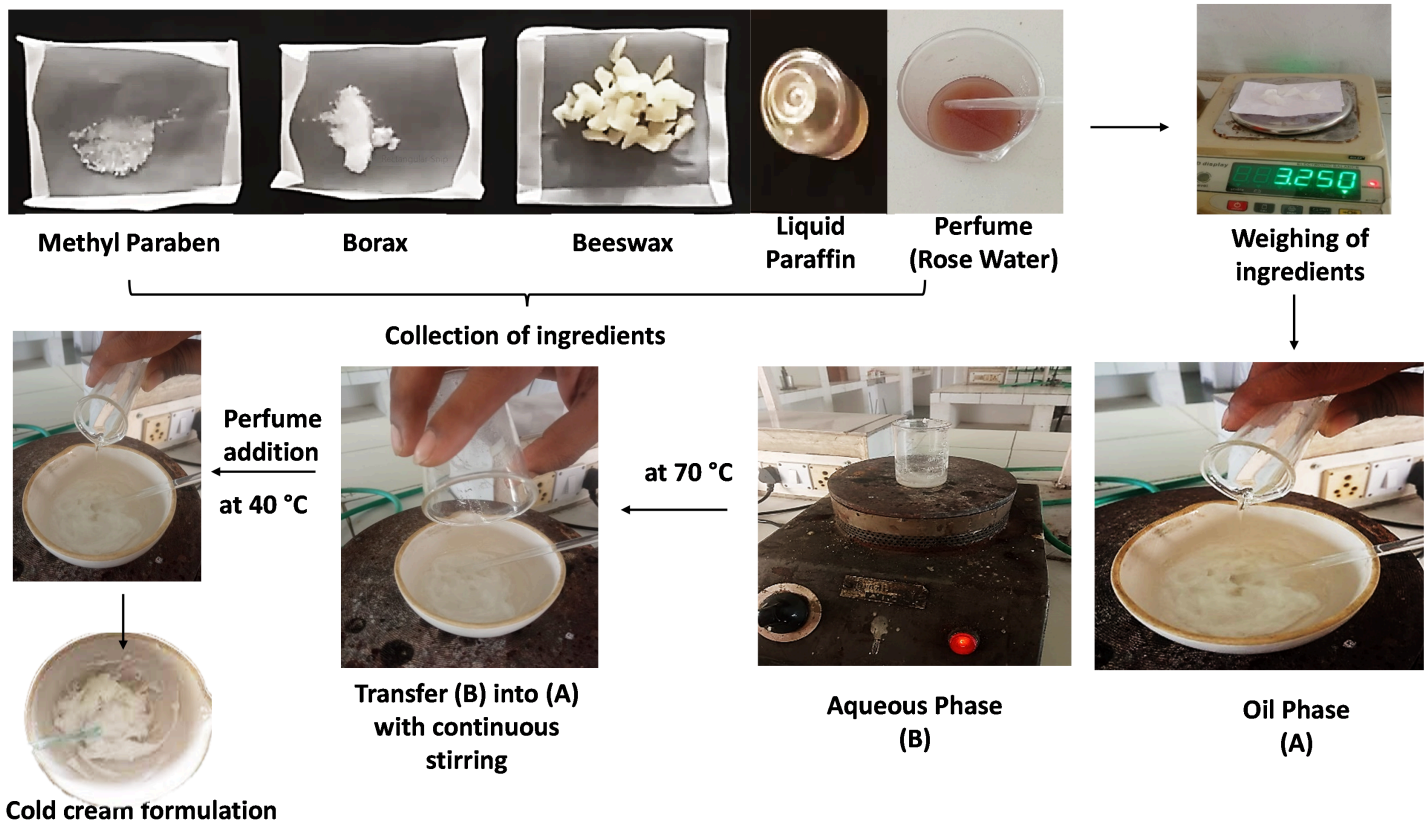


Figure 2

Schematic representation of the preparation process of cold cream by the water-in-oil emulsification method.

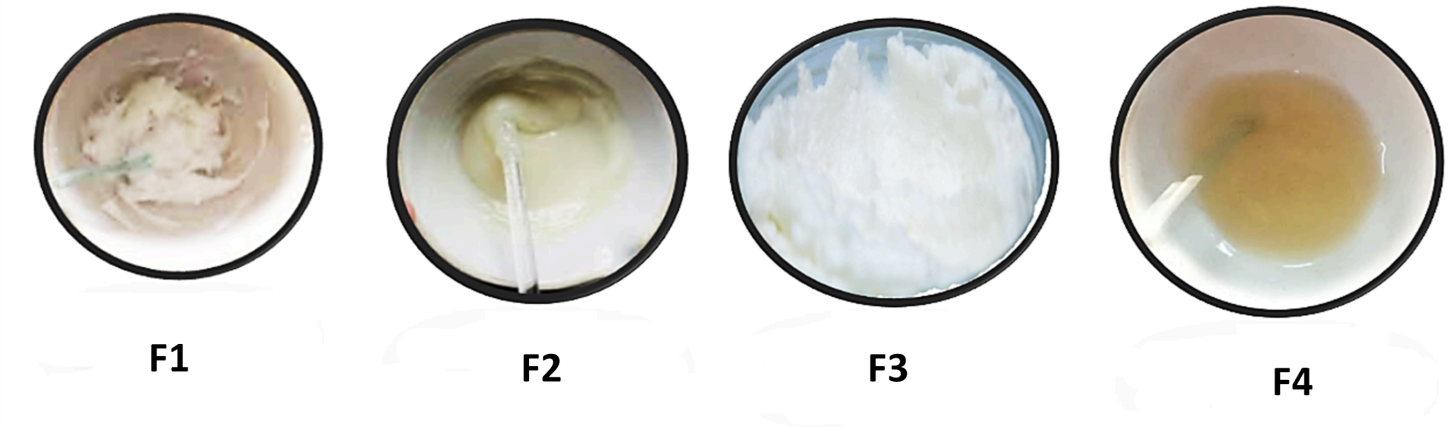


Figure 3

Photographic representation of cold cream formulations F1–F4 illustrating differences in consistency and texture due to variation in borax and beeswax concentrations.

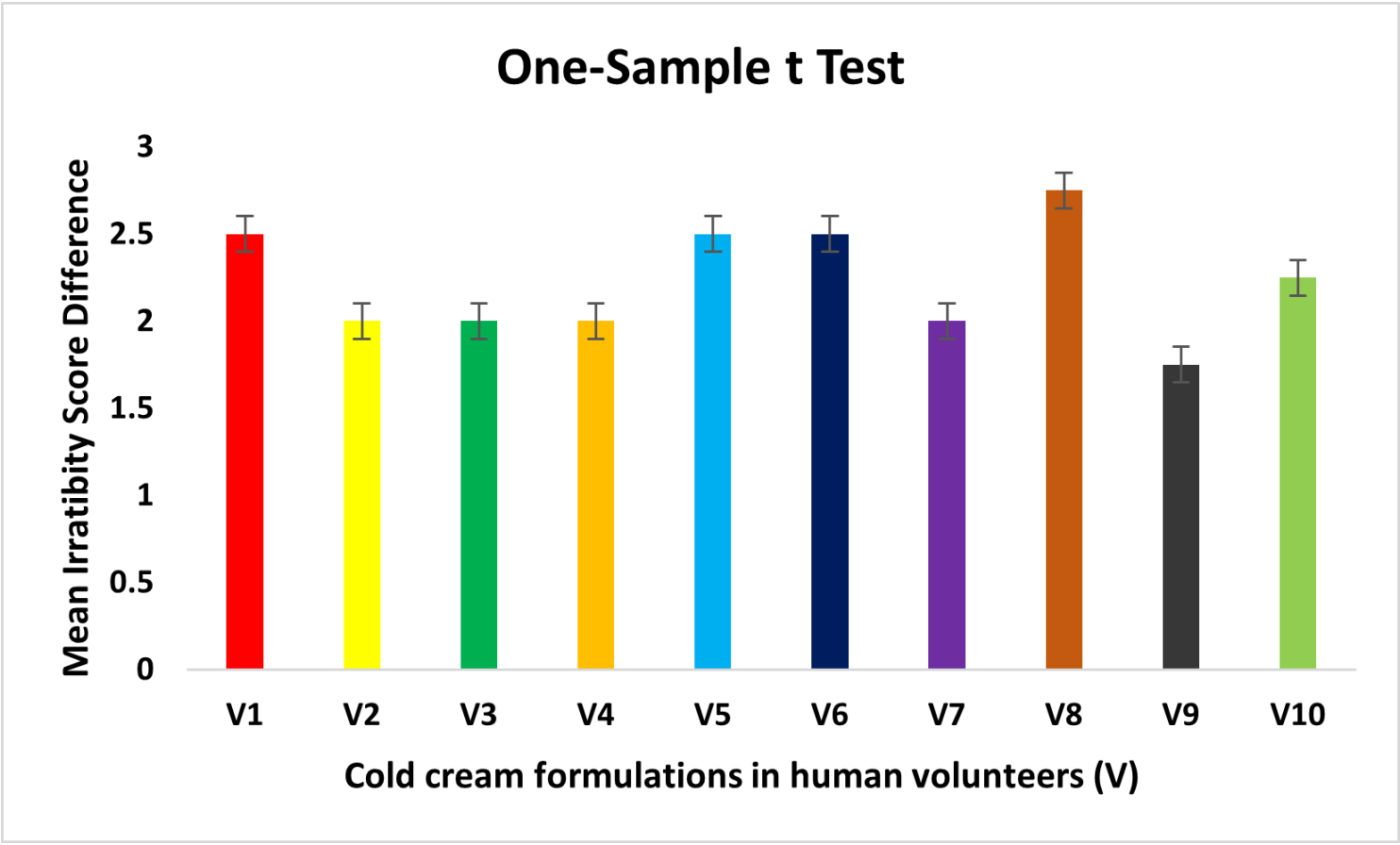


Figure 4

Mean irritability scores of cold cream formulations obtained from one-sample t-test analysis, indicating acceptable to non-irritant skin responses among volunteers.

Supplementary Files

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