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Evaluation of Physical Stability of Carbopol Gel Containing Curcumin under Temperature Variations

Najwa Athifah Tsamarah Umar[1*], Mohamad Aprianto Paneo[2] Nurain Thomas[3], Fika Nuzul Ramadhani[4], Lisa Efriani Puluhulawa[5]

[1,2,3,4,5] *Department of Pharmacy, Faculty of Sports and Health, Universitas Negeri Gorontalo, Jl. Jenderal Sudirman No. 06 Kota Gorontalo 96128, Indonesia*
** Penulis Korespondensi. Email: najwathifah@gmail.com*

ABSTRAK

Inflamasi merupakan respon biologis tubuh terhadap kerusakan jaringan yang ditandai dengan pembengkakan, kemerahan, nyeri, dan peningkatan suhu lokal. Kurkumin diketahui memiliki aktivitas antiinflamasi melalui penghambatan mediator inflamasi seperti tumor necrosis factor-alpha (TNF-α). Penelitian ini bertujuan untuk mengembangkan formulasi sediaan gel kurkumin berbasis Carbopol serta mengevaluasi karakteristik fisik dan stabilitasnya pada berbagai kondisi suhu. Penelitian dilakukan menggunakan metode eksperimental laboratorium yang meliputi optimasi basis gel, formulasi gel kurkumin dengan variasi konsentrasi (1%, 2%, dan 3%), evaluasi sifat fisik, serta uji stabilitas menggunakan metode temperature stress test pada suhu rendah dan tinggi. Hasil penelitian menunjukkan bahwa basis gel Carbopol 0,5% merupakan formula optimal. Seluruh formula gel kurkumin memenuhi persyaratan sifat fisik meliputi homogenitas, pH, viskositas, daya sebar, dan daya lekat. Uji stabilitas menunjukkan bahwa sediaan stabil secara organoleptik dan relatif stabil secara kimia, meskipun terjadi penurunan viskositas pada suhu tinggi. Dengan demikian, gel kurkumin berbasis Carbopol memiliki potensi sebagai sediaan topikal yang stabil dan efektif.

Kata Kunci: *kurkumin; gel carbopol; stabilitas fisik; suhu; antiinflamasi*

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ABSTRACT

Inflammation is a biological response to tissue damage characterized by swelling, redness, pain, and increased local temperature. Curcumin is known to possess anti-inflammatory activity by inhibiting inflammatory mediators such as tumor necrosis factor-alpha (TNF-α). This study aimed to develop a Carbopol-based curcumin gel formulation and evaluate its physical characteristics and stability under various temperature conditions. This research employed a laboratory experimental method including gel base optimization, formulation of curcumin gel with concentration variations (1%, 2%, and 3%), physical evaluation, and stability testing using a temperature stress test at low and high temperatures. The results showed that Carbopol 0.5% was the optimal gel base. All formulations met the required physical characteristics, including homogeneity, pH, viscosity, spreadability, and adhesiveness. Stability testing indicated that the formulations were organoleptically stable and relatively stable chemically, although viscosity decreased at higher temperatures. Therefore, Carbopol-based curcumin gel has potential as a stable and effective topical preparation.

Keywords: *curcumin; carbopol gel; physical stability; temperature; anti-inflammatory*

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1. Introduction

Inflammation is a physiological protective response of the body that occurs as a result of tissue injury or damage, which may be triggered by mechanical trauma, exposure to harmful chemical substances, or infection by microorganisms. This process is generally characterized by the appearance of typical clinical signs, including erythema, increased local temperature, edema formation, pain, and a reduction or impairment of function in the affected tissue [1]. The inflammatory response is initiated by the migration of polymorphonuclear cells, such as basophils, eosinophils, and neutrophils, along with a small number of monocytes, which subsequently become predominant. Local inflammation involves mediators such as bradykinin and prostaglandins that induce vasodilation and increase vascular permeability, and it may progress to systemic inflammation. Macrophages then release proinflammatory cytokines, including IL-1, IL-6, and TNF-α, which trigger local and systemic changes, macrophage activation, neutrophil recruitment, and enhanced phagocytosis. An increase in the synthesis of acute-phase proteins serves as an indicator of systemic inflammation [2].

Therapies commonly used in the management of inflammation include nonsteroidal anti-inflammatory drugs (NSAIDs) and corticosteroids, which function to reduce swelling and alleviate pain associated with inflammatory processes. Despite their effectiveness, long-term use of NSAIDs may lead to various adverse effects, such as gastric ulcers, cardiovascular toxicity, and other complications. Therefore, the development of safer alternative therapies is essential, one of which involves topical formulations that act locally, thereby minimizing systemic side effects and improving patient comfort.

Curcumin is a natural bioactive compound known to have potential in supporting the wound healing process. Its effectiveness in wound therapy is attributed to its pharmacological properties, including anti-inflammatory, antibacterial, anti-infective, and antioxidant activities. Curcumin is a polyphenolic compound that exhibits anti-inflammatory effects by inhibiting the activity of COX-2 and LOX enzymes, thereby suppressing the formation of inflammatory mediators such as prostaglandins and leukotrienes. It also inhibits the activation of NF-κB and reduces the levels of proinflammatory cytokines, including TNF-α, IL-1β, and IL-6, thereby contributing to the attenuation of the inflammatory response [3].

Gel is a semisolid dosage form consisting of small inorganic particles or large organic molecules uniformly dispersed within a liquid phase, forming a system with a viscous consistency and a three-dimensional structure. Gel formulations offer several advantages, including ease of application on the skin surface, a cooling sensation, good absorption, non-greasy characteristics, and convenience in use. To obtain a gel formulation with optimal stability and compatibility, it is necessary to employ a base with low toxicity that can enhance the contact time with the skin [4]. Carbopol 940 is one of the gelling agents widely used in the cosmetic industry due to its good compatibility and high stability. This material is safe for topical use as it is non-toxic and allows ease of application and spreading. Physically, Carbopol 940 appears as a fine powder and is commonly formulated as a gel base in cosmetic and personal care products. It is typically used within a concentration range of 0.5–2.0%, where an increase in concentration is directly proportional to the viscosity and structural strength of the resulting gel [5].

However, most previous studies have primarily focused on the initial physical evaluation of gel formulations, while investigations on their physical stability—particularly under extreme storage temperature conditions (low and high temperatures)—remain limited. In fact, temperature is a critical parameter that can influence the physical stability of gels, including changes in viscosity, pH, homogeneity, and spreadability during storage. Instability of the formulation may reduce the effectiveness and safety of the product during use.

Based on these considerations, this study aims to evaluate the physical characteristics and assess the physical stability of Carbopol-based gel formulations containing curcumin under various storage temperature conditions. This research is expected to provide scientific information regarding the stability of curcumin gel formulations and to serve as a basis for the development of stable, effective, and safe topical anti-inflammatory products.

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2. Methods

This study was an experimental laboratory investigation aimed at optimizing the gel base, formulating Carbopol-based gel preparations containing curcumin, and evaluating their physical characteristics and stability.

Materials

70% ethanol, 96% ethanol, aluminum foil, distilled water (H_2O), Carbopol, glycerin, curcumin, chloroform, methanol, methyl paraben, and propylene glycol.

Instruments

Glass stirring rod, beakers (Pyrex®), porcelain dish, Erlenmeyer flask (Pyrex®), measuring cylinder (Pyrex®), caliper, glass slides, mortar and pestle, object glass, universal pH indicator, pipettes, volumetric pipettes, analytical balance (Osuka, Japan), and a Brookfield viscometer.

Thin Layer Chromatography (TLC)

Curcumin was spotted onto a TLC plate and eluted using a mobile phase of chloroform:methanol (9.5:0.5), with modifications. The resulting spots were then detected under UV light to observe the presence of the compound [6]. The stationary phase used was a silica gel TLC plate, while the mobile phase consisted of chloroform:methanol (9.5:0.5). The TLC plate was placed into a chamber, then removed and air-dried. Observation was carried out at a wavelength of 366 nm, followed by the calculation of the Rf value [7].

Gel Base Optimization

The gel base was formulated using Carbopol as the gelling agent, triethanolamine (TEA) as the neutralizing agent, and distilled water as the solvent. The gel base was prepared in three formulation variations with Carbopol concentrations of 0.5%, 1%, and 2%, respectively. Other components, including TEA (2%), methyl paraben (0.4%), propylene glycol (15%), and glycerin (10%), were used at fixed concentrations in each formulation. Distilled water was added to achieve a final volume of 100 mL.

The preparation process was initiated by dispersing Carbopol into heated distilled water, followed by stirring until the polymer swelled and formed a gel mass. Subsequently, methyl paraben, propylene glycol, and glycerin were added and mixed until homogeneous. TEA was then added gradually to adjust the pH and to optimize the formation of a clear and viscous gel structure. The resulting gel base did not contain any active ingredient and was used as the base formulation for the subsequent formulation stage.

Table 1. Curcumin Gel Formulation

Ingredients	Concentration			Function
	FI	FII	FIII	
Curcumin	1	2	3	Active ingredient
Carbopol	0.5	0.5	0.5	Base (gelling agent)
TEA	2	2	2	Alkalizing agent
Propylene glycol	15	15	15	Humectant
Glycerin	10	10	10	Emollient
Methyl paraben	0.4	0.4	0.4	Preservative
Distilled water	ad 100	ad 100	ad 100	Solvent

Data source: primary data processed, 2026

All materials were prepared prior to the formulation process. The weighed Carbopol was placed into a mortar containing warm distilled water and stirred until it was uniformly dispersed and allowed to swell, forming a gel mass. Subsequently, methyl paraben, glycerin, and propylene glycol were added to the dispersion and mixed until homogeneous. Triethanolamine (TEA) and the remaining distilled water were then added, followed by further homogenization until a uniform gel preparation was obtained. Curcumin was first dissolved in 96% ethanol, then gradually incorporated into the Carbopol dispersion with continuous stirring to ensure uniform mixing.

Evaluation of Gel Preparations

1. Organoleptic Test

Organoleptic evaluation was conducted through sensory observation, primarily visual inspection. This assessment included the evaluation of color, odor, and the consistency or texture of the formulated gel preparation [8].

2. pH Test

The pH test was performed to ensure that the formulation had an acidity level compatible with the physiological pH of the skin, which ranges from 4.6 to 6.5. Prior to measurement, the pH meter was calibrated using distilled water, and the electrode was dried with tissue paper. The electrode was then immersed into the sample and allowed to stand until a stable pH value was displayed. The recorded value represented the pH of the tested preparation once the reading became stable and constant [9].

3. Spreadability Test

The spreadability test was carried out by placing 0.5 g of the sample at the center of a circular glass plate with a diameter of 15 cm. A cover glass was then placed over the sample and left for approximately one minute before observation. The diameter of spread was measured after the gradual application of loads of 50 g and 100 g until a stable result was obtained. The formulation was considered acceptable if it exhibited a spread diameter within the range of 3–5 cm, in accordance with established standards [9].

4. Adhesion Test

The adhesion test aimed to determine the ability of the preparation to adhere to the skin surface. The procedure began by weighing 0.5 g of the sample and placing it on a petri dish, then covering it with an inverted lid. A load of 150 g was applied for 5 minutes. After removing the load, the time required for the two surfaces to separate was recorded. The formulation was considered to have good adhesion if the adhesion time exceeded 4 seconds [10].

5. Viscosity Test

Viscosity testing was performed using a Brookfield viscometer with spindle number 7 to evaluate the consistency of the preparation, which influences ease of topical application. According to SNI 16-4399-1996, a gel preparation meets the standard if it has a viscosity ranging from 6,000 to 50,000 cP (or 6–50 Pa·s) [5].

Pengujian Suhu Tinggi

(*Temperature Stress Test*)

1. High Temperature

The high-temperature stress test was conducted to evaluate the physical stability of the gel formulation under elevated temperature conditions that may accelerate formulation changes. A number of gel samples were placed in closed containers representing actual storage conditions. The climatic chamber was turned on and allowed to reach a stable condition. The test temperatures were set at 40°C, 50°C, 60°C, 70°C, and 80°C, with observations carried out at 1-hour intervals. The samples were then placed in the climatic chamber and maintained for the specified duration according to the predetermined parameters. After the testing period, the samples were removed and evaluated for physical parameters, including pH, viscosity, and organoleptic properties.

2. Low Temperature

The low-temperature stress test was performed to determine the physical stability of the gel formulation under low-temperature conditions. Gel samples were placed in closed containers representing actual storage conditions. The climatic chamber was activated and allowed to reach a stable state. The temperature was set according to the test variations, namely 2°C, 4°C, 6°C, 8°C, and 10°C, with observations conducted at 1-hour intervals. The samples were placed in the climatic chamber and maintained for the specified testing duration. After completion of the test, the samples were removed and evaluated for physical parameters, including pH and viscosity.

3. Results and Discussion

Thin Layer Chromatography (TLC)

The results of Thin Layer Chromatography (TLC) analysis of curcumin using a chloroform:methanol (9.5:0.5) mobile phase showed the presence of a yellowish-orange spot

when observed under UV light at 366 nm, with an Rf value of 0.84. The analysis was performed in triplicate and demonstrated consistent Rf values across all repetitions.

Table 2. Thin Layer Chromatography (TLC) Results of Curcumin Compound

Eluent (mL)	Spot Color	Rf
Chloroform : Methanol (9.5 : 0.5)	Yellowish-orange	0.84
	Yellowish-orange	0.84
	Yellowish-orange	0.84

Data source: primary data processed, 2026

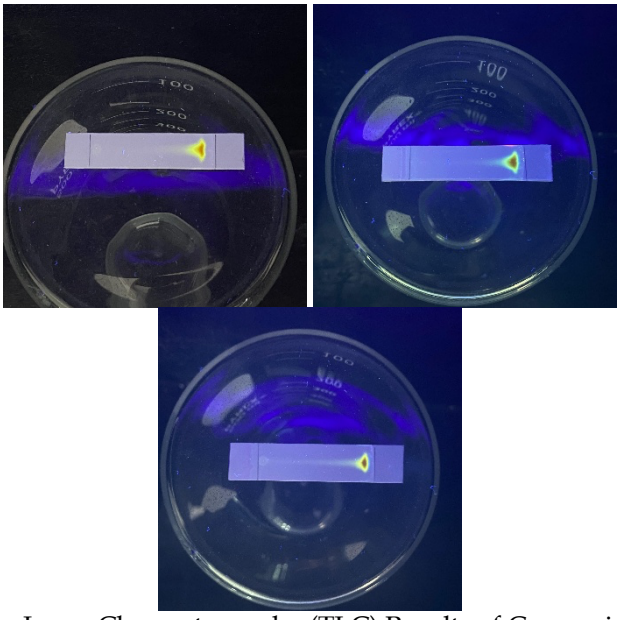


Figure 1. Thin Layer Chromatography (TLC) Results of Curcumin Compound

Based on Table 1, the spot observed on the TLC plate appeared yellowish-orange under UV light at 366 nm, with an Rf value of 0.84. A study by Santana & Meireles (2016) reported that spots on TLC plates exhibit a yellow-orange color under UV 366 nm, consistent with the characteristics of curcuminoid spots separated on a silica gel stationary phase. These spots have been described as "dark-yellow to orange spots" observed in curcuminoid chromatograms when visualized under UV 366 nm, confirming that the analyzed component corresponds to curcuminoid compounds such as curcumin [11],[12]. The Retention Factor (Rf) is defined as the ratio of the distance traveled by the compound on the stationary phase to the distance traveled by the solvent as the mobile phase [12]. Based on the study by Suharsanti et al. (2020), after elution with a chloroform:methanol (9.5:0.5) mobile phase, curcumin was identified at an Rf value of 0.84, demethoxycurcumin at 0.69, and bisdemethoxycurcumin at 0.57. According to Munthe et al. (2020), the movement of spots and the number of sample spots on the TLC plate are influenced by polarity. The analyte must be soluble in the eluent, and its migration depends on its polarity [6],[12].

Overall, the TLC results indicate that the chloroform:methanol (9.5:0.5) solvent system is effective for the identification of curcumin. This is evidenced by the appearance of yellowish-orange spots under UV light at 366 nm and the consistent Rf values obtained across all repetitions. Therefore, it can be concluded that the compound identified in this analysis exhibits characteristics consistent with curcumin.

Gel Base Optimization

Table 3. Results of Gel Base Optimization

No.	Evaluation	FI	FII	FIII
1	Color	Clear	Clear	Clear
2	Odor	Characteristic of Carbopol	Characteristic of Carbopol	Characteristic of Carbopol
3	Texture	Viscous	Viscous	Very viscous
4	Homogeneity	Homogeneous	Homogeneous	Homogeneous
5	pH	6	7	7
6	Viscosity (cP)	11,680	31,040	52,240
7	Spreadability (cm)	6.03	4.46	3.76
8	Adhesion (seconds)	8	9	8

Data source: primary data processed, 2026

Gel base optimization was carried out to obtain a formulation with stable physical characteristics that meets the requirements for topical preparations. Carbopol 940 was selected as the gelling agent due to its ability to produce clear, stable gels with good viscosity even at low concentrations, as well as its compatibility with other ingredients [5],[13]. Variations in Carbopol concentration (0.5%, 1%, and 2%) were applied to evaluate their effects on the physical properties of the gel, including organoleptic characteristics, homogeneity, pH, viscosity, spreadability, and adhesion.

The evaluation results presented in Table 2 show that all gel bases exhibited a clear appearance, a characteristic Carbopol odor, and good homogeneity, indicating that the polymer dispersion and hydration processes occurred optimally. The pH values ranged from 6 to 7, which are within the acceptable range for skin pH. The increase in pH at higher concentrations is attributed to the addition of triethanolamine as a neutralizing agent, which reacts with the acidic Carbopol and consequently increases the pH of the formulation [14],[15].

An increase in Carbopol concentration significantly affected the viscosity of the gel, rising from 11,680 mPa·s at 0.5% to 31,040 mPa·s at 1% and 52,240 mPa·s at 2%. This is due to the formation of a denser polymer network, resulting in higher gel consistency. The increase in viscosity correspondingly led to a decrease in spreadability, where the spreadability values decreased from 6.03 cm at 0.5% to 4.46 cm at 1% and 3.76 cm at 2%. This relationship indicates that higher viscosity reduces the ability of the gel to spread on the skin surface [16].

In terms of adhesion, the 0.5% and 2% concentrations showed values of 8 seconds, while the 1% concentration showed 9 seconds. These results suggest that increasing Carbopol concentration does not necessarily enhance adhesion, as excessively high viscosity may reduce the gel's ability to interact optimally with the skin surface. This finding is consistent with reports stating that increasing Carbopol concentration decreases spreadability while increasing gel consistency [17].

Overall, each Carbopol concentration demonstrated different characteristics. The 2% concentration produced a gel with very high viscosity but low spreadability, making it less comfortable for application. The 1% concentration showed relatively balanced characteristics but was not yet optimal. The 0.5% concentration provided the most suitable combination of physical properties, including a pH close to that of the skin, adequate viscosity, good spreadability, and satisfactory adhesion. Therefore, the 0.5% Carbopol concentration was selected as the optimal gel base for further formulation.

Formulation of Curcumin Gel Preparation

The curcumin gel in this study was formulated using curcumin as the active ingredient at concentrations of 1% (F1), 2% (F2), and 3% (F3). Curcumin is a polyphenolic compound with anti-inflammatory activity through mechanisms such as inhibition of cyclooxygenase (COX-2) and lipoxygenase (LOX) enzymes, reduction of prostaglandin and leukotriene production, and suppression of NF-κB activation and proinflammatory cytokine expression, including TNF-α, IL-1β, and IL-6 [3]. The gel base utilized 0.5% Carbopol as the gelling agent due to its high stability, non-toxic nature, and ability to produce gels with good spreadability [5]. Triethanolamine was used as a neutralizing agent to increase pH and facilitate the formation of

a clear and viscous gel structure [18]. while propylene glycol functioned as a humectant to maintain moisture and stability of the formulation [19]. Additional components such as emollients and parabens were included to enhance user comfort and prevent microbial growth [20],[21].

Table 4. Results of Physical Evaluation of Curcumin Gel

Evaluation	FI	FII	FIII
Color	Orange	Orange	Orange
Odor	Characteristic of Carbopol	Characteristic of Carbopol	Characteristic of Carbopol
Texture	Viscous	Viscous	Very viscous
Homogeneity	Homogeneous	Homogeneous	Homogeneous
pH	8	8	8
Viscosity (cP)	10,240	10,880	10,960
Spreadability (cm)	4.64	5.42	5.21
Adhesion (seconds)	27.55	24.72	23.89

Data source: primary data processed, 2026

The results of organoleptic and homogeneity evaluations indicate that all formulations exhibited good and stable physical characteristics. Increasing the concentration of curcumin resulted in a more intense orange color without affecting the homogeneity of the preparations. This suggests that curcumin was well dispersed within the gel matrix. Considering that curcumin is poorly soluble in water, the use of a solvent such as ethanol plays an important role in enhancing the solubility and distribution of the active compound within the gel system [22]. This finding is consistent with previous research [23], which reported that dissolving curcumin in ethanol prior to incorporation into the gel base produces a more homogeneous and stable formulation.

The pH measurements showed that all formulations had an average pH value of 8, indicating a slightly alkaline nature. The relatively similar pH values across all formulations suggest that variations in curcumin concentration did not significantly affect the pH of the preparations. This condition may be influenced by the use of ethanol as a solvent, which can modify hydrogen ion activity in the water–ethanol system, resulting in higher measured pH values compared to purely aqueous systems [24].

In terms of spreadability, F2 exhibited the highest value (5.42 cm), followed by F3 (5.21 cm) and F1 (4.64 cm), all of which fall within the acceptable range of 3–5 cm [9]. Increased spreadability indicates a greater ability of the gel to distribute over the skin surface, potentially enhancing the delivery of the active compound. In contrast, adhesion values showed a decreasing trend with increasing curcumin concentration, where F1 demonstrated the highest adhesion (27.55 seconds), followed by F2 (24.72 seconds) and F3 (23.89 seconds). All formulations met the requirement for good adhesion (>4 seconds) [10]. These differences indicate a relationship between viscosity and adhesive properties, where changes in composition can influence the interaction between the gel and the skin surface [25].

The viscosity results showed that all formulations had relatively similar values, namely 10,240 cP (F1), 10,880 cP (F2), and 10,960 cP (F3), which fall within the standard range for gel preparations according to SNI 16-4399-1996 (6,000–50,000 cP) [5]. The absence of significant differences in viscosity suggests that variations in curcumin concentration did not substantially affect the gel matrix structure, indicating that rheological properties are more strongly influenced by the Carbopol base than by the active ingredient.

Stability Test *(Temperature Stress Test)*

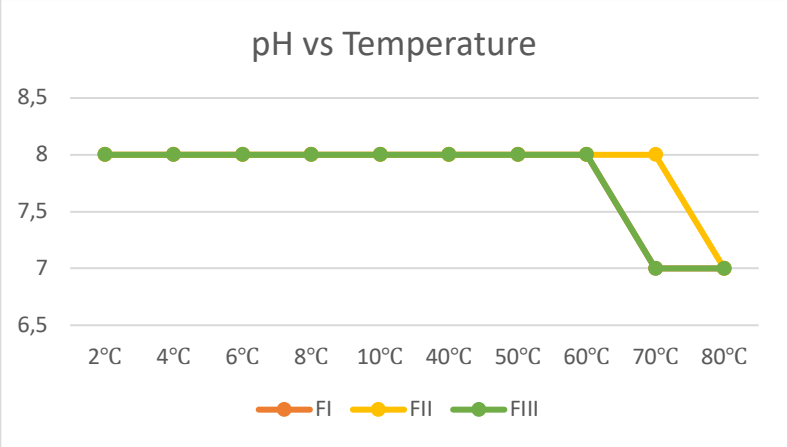
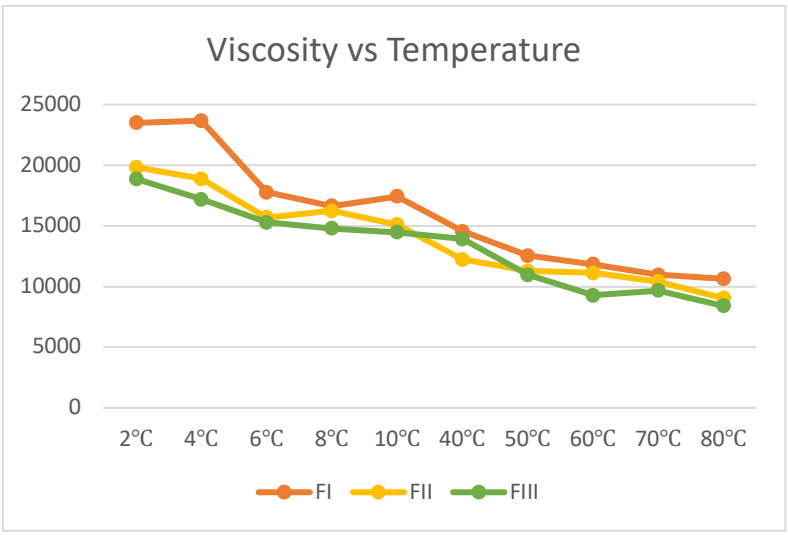


Figure 1. Graph of pH Stability Test Results (Temperature Stress Test) as a Function of Temperature



Gambar 2. Grafik Hasil Uji Stabilitas (*Temperature Stress Test*) Viskositas Terhadap Suhu

Stability testing was conducted to evaluate changes in the quality of curcumin gel formulations during storage under the influence of environmental factors, particularly temperature [26]. In this study, stability testing was performed under extreme temperature variations to assess changes in physical parameters, including organoleptic properties, pH, and viscosity. The physical stability of a formulation is indicated by the absence of changes in color, odor, texture, and consistency, whereas any alteration in these parameters may indicate instability [27]. The results of the stability test showed that all formulations (FI, FII, and FIII) remained organoleptically stable during storage within the temperature range of 2°C to 80°C. No changes in color, odor, or texture were observed, as all preparations remained orange in color with a characteristic Carbopol odor. This indicates that temperature variations did not cause visual degradation or significant changes in consistency, suggesting that the gel system was able to maintain its physical integrity under extreme storage conditions.

The pH parameter demonstrated relatively good stability at low to moderate temperatures (4–60°C), with a constant value around pH 8. However, at higher temperatures (70°C and 80°C), a slight decrease in pH to 7 was observed in some formulations. This decrease is likely due to changes in the polymer structure upon heating, which affect the degree of ionization of the carboxylate groups in Carbopol. Nevertheless, the observed changes were not significant and remained within an acceptable range, indicating that the formulations were relatively stable from a chemical standpoint.

The most notable changes due to temperature variation were observed in the viscosity parameter. All three formulations exhibited a decreasing trend in viscosity with increasing temperature. FI showed a decrease from 23,500 cP (2°C) to 10,640 cP (80°C), FII from 19,840 cP to 9,040 cP, and FIII from 18,880 cP to 8,400 cP. This reduction is attributed to increased thermal energy, which enhances molecular mobility and weakens intermolecular interactions within the polymer network of the gel matrix. As a result, the gel structure becomes less rigid, leading to reduced resistance to flow. This phenomenon is consistent with the findings of Mehdi-Sefiani et al. (2024), which reported that increasing temperature affects the rheological properties of gels by altering polymer chain mobility within the network, ultimately reducing system viscosity [28].

Overall, the stability test results indicate that all three formulations exhibit good organoleptic stability and are relatively stable chemically under various temperature conditions. Although a decrease in viscosity was observed at higher temperatures, the changes remained within acceptable limits and represent a common characteristic of polymer-based gel systems under thermal stress. These findings suggest that the formulated curcumin gel possesses adequate physical stability against extreme temperature variations during storage.

4. Conclusion

Based on the results of this study, it can be concluded that the Carbopol gel base at a concentration of 0.5% represents the optimal formulation, providing the best physical characteristics. Curcumin gel preparations with concentration variations of 1%, 2%, and 3% exhibited physical properties that met the requirements for topical formulations, including homogeneity, pH, viscosity, spreadability, and adhesion. Variations in curcumin concentration did not significantly affect the pH and viscosity, but they did influence the spreadability and adhesion of the formulations. The stability test results demonstrated that all formulations were organoleptically stable and relatively stable chemically under various temperature conditions, although a decrease in viscosity was observed at higher temperatures. Carbopol-based curcumin gel preparations therefore show potential for further development as stable and effective topical anti-inflammatory products. Future studies are recommended to include biological activity testing and long-term stability studies to further support product development.

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