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Effect of Additive Type and Concentration on the Physicochemical Stability of Aloe vera Gel-Based Edible Coating

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A B S T R A C T

Aloe vera gel has attracted considerable attention as a natural edible coating material due to its polysaccharide-rich composition and environmentally friendly characteristics. However, its application is limited by poor physicochemical stability during storage, including changes in pH, viscosity, color, brightness, and transparency. This study aimed to evaluate the effect of additive type and concentration on the physicochemical stability of Aloe vera gel-based nano-edible coatings during storage. The experiment was conducted using a completely randomized design with four additive treatments, namely citric acid, ascorbic acid, potassium sorbate, and mixed additives, each applied at concentrations of 0.15%, 0.30%, and 0.45%. The formulated gels were stored under refrigerated conditions, and changes in pH, viscosity, total color difference (ΔE), brightness (L^*), and transparency were periodically evaluated. The results showed that the type and concentration of the additive significantly affected the stability of Aloe vera gel. Citric acid and ascorbic acid were more effective in maintaining pH stability, brightness, and colour retention, while potassium sorbate mainly contributed to microbial stability but had limited effects on optical properties. Mixed additive formulations, particularly at lower concentrations, demonstrated synergistic effects by improving overall physicochemical and visual stability during storage. These findings indicate that appropriate selection and optimization of additives are essential for developing stable Aloe vera gel-based nano-edible coatings suitable for postharvest and food preservation applications.

Contribution to Sustainable Development Goals (SDGs):
SDG 2: Zero Hunger
SDG 3: Good Health and Well-being
SDG 9: Industry, Innovation and Infrastructure
SDG 12: Responsible Consumption and Production

1. INTRODUCTION

1.1. Research Background

Aloe vera gel has long been recognized as a promising natural material for edible coating applications due to its rich polysaccharide composition, particularly acemannan and glucomannan, which provide film-forming ability, moisture retention, and selective gas permeability [1]. These characteristics make aloe vera gel an attractive, environmentally friendly alternative to synthetic coatings for postharvest handling and food preservation. In addition, aloe vera gel is biodegradable, non-toxic, and generally regarded as safe, aligning with the growing demand for sustainable food packaging systems [2,3].

Despite these advantages, the practical application of aloe vera gel as an edible coating is often limited by its poor stability during storage. Native aloe vera gel is highly susceptible to physicochemical degradation, including enzymatic browning, reduction in viscosity, loss of transparency, and microbial spoilage. Oxidative reactions, enzymatic activity, and the gradual breakdown of polysaccharide structures within the gel matrix mainly drive these changes. Several studies have reported that without appropriate formulation or stabilization, aloe vera gel rapidly loses its visual clarity and functional properties, thereby reducing its effectiveness as a coating material [4,5].

To address these limitations, the incorporation of food-grade additives has been widely explored as a stabilization strategy. Acidification is one of the most effective approaches to improving the stability of aloe vera gel. Citric acid is commonly used as an acidulant and chelating agent, capable of lowering pH and inhibiting polyphenol oxidase activity, thereby helping suppress enzymatic browning and maintaining colour stability [6,7]. Acidified aloe gel systems have been shown to exhibit slower physicochemical degradation and improved storage stability [2].

Ascorbic acid is another additive frequently applied due to its strong antioxidant properties. By scavenging free radicals and reducing oxidized phenolic compounds, ascorbic acid effectively delays oxidative browning and helps preserve brightness (L*) and overall visual quality [8,9]. However, previous studies indicate that its effectiveness is highly dependent on concentration, as excessive amounts may interfere with polymer interactions and reduce gel clarity [10].

Potassium sorbate is widely used as a preservative due to its strong inhibitory effect on yeasts and moulds. While effective in enhancing microbiological safety, potassium sorbate alone has been reported to contribute less to the preservation of optical properties such as transparency and brightness [10]. Previous research emphasized that physicochemical stability of aloe vera gel is more effectively achieved when preservatives are combined with acidulants and antioxidants [11].

Recent studies therefore suggest that mixed additive formulations may provide synergistic effects by simultaneously controlling pH, oxidation, and microbial growth. Such combinations have been reported to improve the homogeneity of the matrix, visual stability, and overall functional performance of aloe vera gel-based edible coatings [3,12]. Nevertheless, additive concentration remains a critical factor, as inappropriate levels may negatively affect gel structure and quality. Based on this background, a systematic evaluation of additive type and concentration is required to identify optimal formulations for stable aloe vera gel-based nano-edible coatings.

1.2. Literature Review

Previous studies have consistently highlighted the potential of Aloe vera gel as an edible coating material, mainly due to its polysaccharide-rich matrix and bioactive properties. The primary functional components, acemannan and glucomannan, play a crucial role in forming a semipermeable barrier that regulates moisture transfer and gas exchange on food surfaces [1]. However, several authors have emphasized that the inherent instability of fresh aloe gel remains a significant limitation, as structural degradation and oxidative reactions occur rapidly during storage [2].

One of the most widely reported approaches to improve aloe gel stability is acidification. Citric acid has been extensively used in food systems as an acidulant and chelating agent capable of lowering pH and inhibiting polyphenol oxidase activity. This mechanism effectively suppresses enzymatic browning and delays color changes in polysaccharide-based matrices [6,7]. Studies on acidified aloe gel have shown improvements in visual appearance, viscosity retention, and overall physicochemical stability during storage, suggesting that pH control is a key factor in maintaining gel quality [2].

Ascorbic acid has also received considerable attention due to its strong antioxidant activity. Acting as a reducing agent, ascorbic acid interrupts oxidative pathways by scavenging free radicals and converting oxidized phenolic compounds into more stable forms. Several studies have reported its effectiveness in preserving brightness (L*) and minimising total colour difference (ΔE) in edible coatings and in fresh-cut horticultural products [8,9]. Nevertheless, the literature indicates that its stabilizing effect is highly concentration-dependent, as excessive amounts may lead to reduced transparency and undesirable interactions within the polymer network [10].

Potassium sorbate is commonly applied as a preservative to control microbial growth, particularly yeasts and molds. While its antimicrobial effectiveness is well established, previous research suggests that potassium sorbate contributes more to microbiological stability than to the preservation of physicochemical and optical properties [10]. Preservatives alone are insufficient to maintain the structural stability of aloe gel, highlighting the need for complementary mechanisms such as acidification and antioxidative protection [5].

Recent studies demonstrated that combined additives improve matrix homogeneity, slow polysaccharide degradation, and enhance visual stability of aloe gel-based edible coatings [3,11,12]. These findings confirm that both additive type and concentration play decisive roles in determining gel performance during storage.

1.3. Research Objective

Given the limitations identified in previous studies and the need to improve the storage stability of Aloe vera gel as an edible coating material, this research systematically evaluated the effects of additive type and concentration on gel stability. Although various additives have been reported to enhance aloe gel performance, comparative information on the effectiveness of individual and combined additives at different concentrations remains limited, particularly regarding their effects on physicochemical and optical properties during storage.

Therefore, the primary objective of this study was to investigate the effect of citric acid, ascorbic acid, potassium sorbate, and mixed additives incorporated at concentrations of 0.15%, 0.30%, and 0.45% on the physicochemical stability of aloe vera gel-based nano-edible coatings. The study specifically focused on evaluating changes in pH, viscosity, color parameters (ΔE), brightness (L*), and transparency throughout the storage period.

In addition, this research aimed to compare the performance of single-additive formulations with that of mixed additive systems to identify potential synergistic effects that improve gel stability. By determining the most effective additive type and concentration, this study is expected to provide practical guidance for developing stable, natural, and environmentally friendly aloe vera gel-based nano-edible coatings suitable for postharvest and food preservation applications.

2. MATERIALS AND METHODS

2.1. Materials

Fresh Aloe vera leaves were obtained from local growers in Bali, Indonesia. Only mature, healthy leaves free from mechanical damage and visible defects were selected for the experiment. Food-grade citric acid, ascorbic acid, and potassium sorbate were used as additives. All chemicals employed in this study were of analytical grade. Distilled water was used throughout the preparation and analysis processes.

2.2. Preparation of Aloe Vera Gel

The aloe vera leaves were thoroughly washed under running water to remove surface dirt and latex residues. The outer green rind was carefully removed using a sterile knife, and the inner transparent gel was collected. The gel was then homogenized using a blender until a uniform consistency was achieved. To remove fibrous materials and impurities, the homogenised gel was filtered through a fine-mesh filter. The resulting aloe vera gel served as the base material for all treatments.

2.3. Experimental Design and Treatments

The experiment was arranged using a completely randomized design (CRD), with additive type and concentration as the primary treatment factors. The aloe vera gel was formulated with different additives at three concentrations: 0.15%, 0.30%, and 0.45% (w/v). The treatments consisted of citric acid, ascorbic acid, potassium sorbate, and a mixed additive formulation. The mixed additive treatment contained citric acid, ascorbic acid, and potassium sorbate combined in equal proportions to achieve the desired final concentration. Each additive was first dissolved in a small volume of distilled water and then incorporated into the aloe vera gel. The mixtures were stirred continuously until a homogeneous gel was obtained. All formulated gels were stored at approximately 4 ± 1 °C under refrigerated conditions. Physicochemical evaluations were conducted periodically throughout storage to monitor changes in gel stability.

2.4. Physicochemical Analysis

The pH of the aloe vera gel formulations was measured using a calibrated digital pH meter. Viscosity was determined at room temperature using a rotational viscometer to assess changes in gel consistency during storage. Color characteristics were measured using a colorimeter, and the values of L*, a*, and b* were recorded. Total colour difference (ΔE) was calculated to assess overall colour changes. Brightness was expressed as L* values, while transparency was assessed by measuring light transmittance using a UV–visible spectrophotometer. All measurements were conducted in triplicate to ensure data reliability.

2.5. Statistical Analysis

The obtained data were analyzed using analysis of variance (ANOVA) to determine the effects of additive type and concentration on the physicochemical properties of aloe vera gel. When significant differences were detected, mean comparisons were performed using a post hoc test at a 95% confidence level.

3. RESULT AND DISCUSSION

3.1. Acidity

Acidity level or pH is a parameter used to determine the acidity of a substance or solution.The results show that the pH range of Ecogel is 3.00-4.86. The formulation with citric acid has the lowest value compared to the others. This is because citric acid is an acidulant compound [6]. In addition, aloe vera gel is known to be stable at low pH, and the addition of additives tends to extend the storage period by inactivating enzymes, thereby preventing the breakdown of polysaccharides into acids such as arachidonic acid, γ-linolenic acid, and other organic acids [12,13].

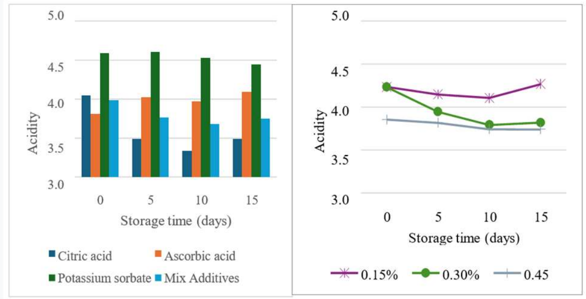

Fig 1. Acidity of aloe vera gel with the addition

3.2. Viscosity

Based on observations, the viscosity of all Ecogels treated with additives increased, which may have been influenced by particle amount and size [14]. This increase began on day 3 and was followed by a decrease after day 12. Meanwhile, additive accumulation is thought to strengthen the cross-linking of polysaccharide polymers, although proteins, minerals, sitosterols, esters, and long-chain hydrocarbons are also present [15]. Despite the presence of various other organic and inorganic components, acemannan and glucomannan are identified as the main functional components of aloe vera gel. Specifically, acemannan (acetylated glucomannan) is a polysaccharide composed of mannose units located in the protoplasm of parenchyma cells [1]. Figure 2 shows the viscosity of Ecogel with the addition of additives during storage.

Observations of the viscosity variable indicate that all additive treatments resulted in an increase in the viscosity of the aloe vera gel. The number and size of particles influences viscosity. The increase in viscosity began on day 3 and decreased again after day 12. This is because the addition of additives strengthens the cross-linking bonds connecting the polymers in the aloe vera gel, thereby increasing viscosity. The viscosity of aloe gel with additives during storage can be seen in Figure 2.

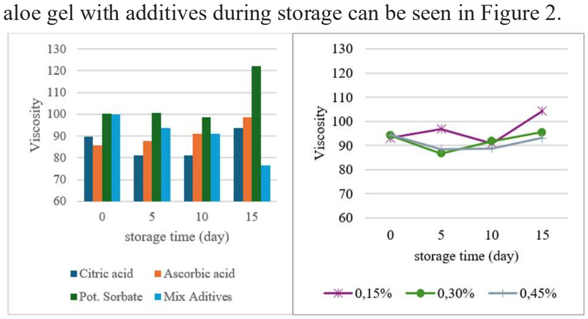

Fig 2. Viscosity of aloe vera gel with the addition

3.3. Color (ΔE)

Based on color observations using L*a*b* coordinates, formulations containing citric acid and ascorbic acid showed the lowest ΔE values, which were close to the control until day 15, while CaCl2 showed the highest values. This indicates a tendency for citric acid and ascorbic acid to suppress potential colour changes, thereby maintaining stability and effectiveness as edible coatings. In addition, a direct proportional relationship was observed between increases in ΔE values, storage length, and cloudy appearance. This manifestation results from the hydrolysis

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of the polymer gel after the enzymatic reaction, thereby promoting the turbidity of the components. Conversely, browning reactions were also observed, as the physicochemical properties are strongly influenced by air, light, and heat. Direct contact with air leads to pink and, eventually, brown pigmentation, while heat and light catalyse reactions supported by the high sugar content [7,9]. Citric acid is an agent that inhibits browning, as it forms dissulfide, which acts as a catalyst. This compound also lowers the pH, inhibiting polyphenol oxidase (PPO). Furthermore, high levels of hot water treatment (50°C) and ascorbic acid (1% v/v) have been reported to be effective in controlling enzymatic browning in fresh S15 apples, with ascorbic acid being more effective. Research on the beta of citric acid and ascorbic acid has also been conducted on S16 fruits, where 700 mg/L ascorbic acid was maintained.

Chroma refers to the degree of coloration, in relation to the brightness of the same illuminated area that appears white or highly transparent. This parameter was evaluated in Ecogel with additives during storage, and the results are shown in Figure 3.

Aloe vera gel with citric acid and ascorbic acid additives had the lowest ΔE values or were close to the control until day 15, while the highest values were observed in the gel with $CaCl_2$. This indicates that citric acid and ascorbic acid can help stabilise the colour of aloe vera gel, keeping it effective as an edible coating.

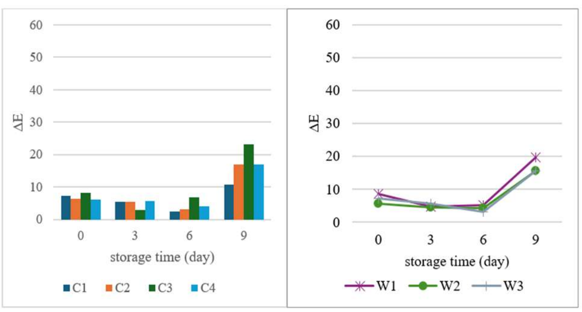

Fig 3. (ΔE) of aloe vera gel with the addition

3.4. *Brightness value (L*)*

Brightness value (L*) represents the light–dark appearance of the gel, where higher values indicate a brighter and clearer appearance. The results revealed a general decrease in L* values until day 10, followed by an increase on day 15 across all treatments. This fluctuating pattern reflects dynamic physicochemical changes occurring within the gel during storage.

The initial decrease in brightness is likely due to increased turbidity resulting from partial degradation of acemannan and glucomannan, producing smaller polymer fragments that enhance light scattering [2,9]. Potassium sorbate-treated gels exhibited the lowest L* values during mid-storage, suggesting limited effectiveness of this preservative in suppressing non-enzymatic oxidative discoloration [10]. In contrast, citric acid and ascorbic acid treatments maintained higher L* values due to their combined acidifying and antioxidant effects, which inhibited browning reactions [7,8].

The increase in brightness observed on day 15 may be attributed to structural reorganisation of the gel matrix and precipitation of dissolved components, both of which reduced light scattering. Mixed additive treatments, particularly at lower concentrations, showed more stable L* values, indicating a synergistic effect among additives in improving optical stability [3].

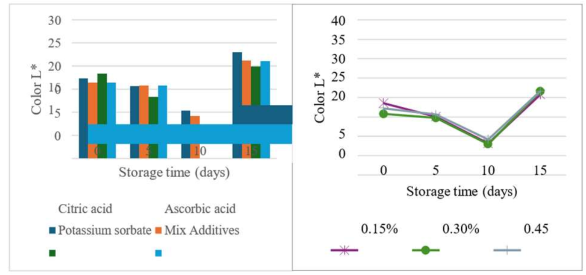

Fig 4. Color L* of aloe vera gel with the addition

3.5. *Transparency*

Transparency refers to the ability of a material to transmit light. The results show a decrease in the aloe vera gel value with various additives after a longer storage period, accompanied by an increase in turbidity. Meanwhile, storage is assumed to facilitate the breakdown of Glucomannan polymer acetyl bonds into smaller components, thereby affecting clarity, which initially increases then decreases significantly. The characteristics of the raw materials used influence this parameter. In addition, aloe vera gel contains clear, tasteless parenchyma cells in aloe vera leaves [3], which lose stability when not refrigerated immediately [5].

According to [8,10] the special characteristics applied in edible coatings are as follows: Waterproof nature, which serves as a barrier, and is permeable to moisture and solutes, melting point of over 40° C, ease of emulsion formation, non-sticky, no impact on fruit quality, low viscosity, transparent, tasteless, odorless and capable of tolerating pressure. Conversely, the formulation of edible coatings is expected to be free from harmful additivies.

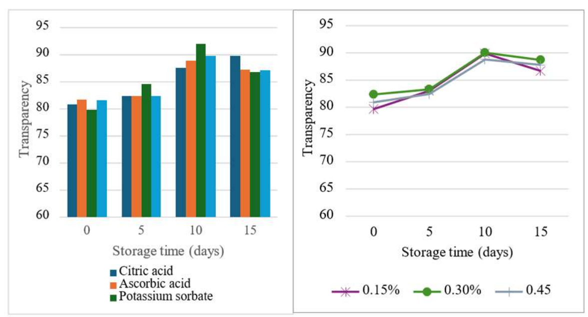

Figure 5. Transparency of aloe vera gel with the addition

4. CONCLUSION

The results of this study demonstrate that the type and concentration of the additive play a critical role in determining the physicochemical stability of Aloe vera gel-based nano-edible coatings during storage. Citric acid and ascorbic acid showed superior performance in maintaining pH stability, brightness (L*), and color retention, indicating their effectiveness in suppressing enzymatic and oxidative degradation. Potassium sorbate primarily contributed to preservative effects but exhibited limited ability to maintain optical properties when applied alone.

Mixed additive formulations exhibited synergistic effects, particularly at lower concentrations, by improving viscosity stability, reducing color changes, and maintaining transparency during storage. These findings suggest that combining acidulants, antioxidants, and preservatives can enhance the functional performance of Aloe vera gel more effectively than single additives. Overall, the optimization of additive type and concentration is essential for developing stable, natural, and environmentally friendly Aloe vera gel-based edible coatings suitable for postharvest and food preservation applications.

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