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Application of Edible Coating Water Soluble Based Chitosan Nanoparticles and Polyvinyl Alcohol in Strawberry (*Fragaria Ananassa*) Storage

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Abstract

Strawberries (*Fragaria ananassa*) are highly sought after for their vibrant color and unique flavor. However, their high perishability and rapid quality degradation lead to significant post-harvest losses and a decrease in market value. This study aimed to evaluate the effect of an edible coating based on WSC nanoparticles and PVA on the quality characteristics of strawberries during storage. The research methodology included the synthesis of WSC nanoparticles, preparation of the coating solution, application to strawberries, and subsequent storage. A Completely Randomized Design (CRD) with a single-factor arrangement was utilized, comprising five PVA concentrations (0%, 2%, 3%, 4%, and 5%) with three replications. The results demonstrated that the application of the nanoparticle WSC-PVA-based edible coating effectively reduced weight loss and delayed physical deterioration. Increasing PVA concentrations led to a more effective preservation of total soluble solids (°Brix), a lower weight loss percentage, and a slower decline in vitamin C content. Higher PVA concentrations were found to reduce the rate of quality degradation and moisture loss. The coating formulation containing 4% PVA (P3) exhibited the best performance, maintaining a water content of 92.24%, total soluble solids of 2 °Brix, a pH of 4.3, a weight loss of 30%, and a vitamin C retention rate of 9.02%. The findings of this study offer a valuable solution for farmers to mitigate strawberry quality decline and provide new insights for future research on food preservation.

Keywords: edible coating; nanoparticles; PVA; water soluble chitosan; strawberry.

INTRODUCTION

Strawberries are non-climacteric fruits rich in essential nutrients, including provitamin A, vitamin C, calcium, phosphorus, iron, sodium, potassium, and magnesium. A 100-gram serving provides 140 kJ of energy, 0.8 g of protein, 0.5 g of fat, 7.6 g of carbohydrates, 53 mg of vitamin C, and 1.7 g of fiber (Wadhani et al., 2021). The annual strawberry harvest is substantial, reaching 27,721 tons per year (BPS, 2023), reflecting strong demand in both local and global markets. Oktarina et al. (2017) reported local market demand exceeding 5,000 tons per year, while global demand, primarily from South Korea, the USA, and Australia, reaches 150 tons per year. However, this high market demand is not met with adequate post-harvest handling, leading to significant premature spoilage. Strawberry spoilage is primarily caused by high humidity and rapid respiration, which create an ideal environment for the growth of fungi and bacteria, resulting in considerable post-harvest losses (Kementan, 2023).

Under normal room temperature, strawberries can deteriorate in as little as two days, with a maximum shelf life of seven days after harvest (Herawati et al., 2019). The economic impact of this spoilage is significant. Sukasih and Setyadjit (2019) noted a sharp decline in the value of damaged fruit; fresh strawberries selling for IDR 80,000–100,000 per kg can see their price plummet to IDR 35,000–45,000 per kg when they become withered or defective. While cold storage is a common method for maintaining freshness, prolonged exposure to low temperatures can lead to chilling injury, resulting in a softened texture and altered nutritional content (Tetelepta et al., 2019). Therefore, to preserve fruit quality and enhance food sustainability, an alternative approach such as edible coating is needed.

Edible coatings are thin, consumable layers applied to food products to reduce weight loss, prevent flavor changes (Tetelepta et al., 2019), and provide a protective barrier against mechanical damage. They are particularly beneficial for fragile foods, offering an environmentally friendly solution (Kusuma & Fitriani, 2021). These coatings act as semi-permeable barriers, controlling the migration of gases and water-soluble components (Aji et al., 2024). This makes them an effective method for reducing the respiration rate and maintaining moisture within the fruit tissue.

Edible coatings can be formulated from various materials, including carboxymethyl cellulose (CMC), gelatin, and chitosan. While CMC and gelatin can form stable films, they have limited mechanical durability, creating a thick layer (Putri et al., 2019) and lacking inherent antimicrobial properties. To overcome these limitations, chitosan presents a superior alternative due to its natural antimicrobial characteristics. Derived from the deacetylation of chitin in the exoskeletons of crustaceans (like prawns and crabs), chitosan's polymer structure contains positively charged amino groups that disrupt the cell membrane metabolism of microorganisms (Nabila et al., 2018). Guge et al. (2024) has demonstrated the effectiveness of chitosan in inhibiting microbial activity, thereby preserving the freshness of agricultural products. A significant drawback of chitosan, however, is its poor solubility in water, requiring an acidic solvent that can adversely affect the aroma and taste of the fruit, potentially reducing consumer acceptance. This issue can be resolved by modifying chitosan into water-soluble chitosan (WSC).

WSC is created through a depolymerization process involving the substitution of amine groups, which increases its interaction with water molecules and enhances its solubility (Chamidah et al., 2019). Jebali et al. (2024) reported that this technology significantly increases the surface contact area by up to 50%, improving both solubility and film stability. To further enhance its activity, WSC can be processed into nanoparticles, which have been shown to increase resistance to oxidation (Novita & Astuti, 2023). While an edible coating based on WSC nanoparticles offers excellent antimicrobial and antioxidant properties, its mechanical characteristics, such as flexibility, elasticity, and crack resistance, need improvement. Reinforcing materials are essential to reduce the stiffness of the polymer chains, allowing the coating to adjust to the fruit's surface movement during storage (Erdem et al., 2022).

PVA is a water-soluble, easily processed, non-toxic, and biodegradable biopolymer. Pamela et al. (2016) found that using PVA as a filler in bio-nanocomposite films enhances surface reactivity, thermal stability, and heat resistance, resulting in packaging that is flexible enough to conform to the product's shape. Furthermore, PVA is considered safe by the Food and Drug Administration (Gomez-Aldapa et al., 2020), ensuring that its use as a reinforcing agent does not raise food safety concerns. Previous research by Putri and Nugroho (2023) demonstrated PVA's effectiveness in maintaining the quality and nutritional content of apples and tomatoes under various environmental conditions. However, there is a lack of specific research on the combined application of WSC nanoparticles and PVA as an edible coating for strawberries. Therefore, this study aims to evaluate the effect of an edible coating based on WSC nanoparticles and PVA on the quality characteristics of strawberries during storage.

MATERIALS AND METHOD

Materials and Equipments

Fresh strawberries ($\pm$ 7 g) without physical defect were purchased from Way Halim Permai Market, Bandar Lampung. Another material used include water soluble chitosan powder (deacetylation degree 94%, moisture regaint 7-10%, CV ChiMultiguna), PVA powder (Merck, 88% hydrolized), sodium tripolyphosphate food grade (Aditya Birla), aquades, dan iodine. The tools used in this research included an analytical balance (Shimadzu AY220), Whatman paper, blender, hot magnetic stirrer (Cimarec + Thermo Fisher), beaker glass, Erlenmeyer flask, set of burettes, volumetric flask, refractometer, oven (Memmert), pH meter (Lutron pH 222), plastic storage container, and spatula.

Methods

This research was conducted in several key stages: synthesis of water-soluble chitosan (WSC) nanoparticles, preparation of the polyvinyl alcohol (PVA) solution, formulation and application of the edible coating, storage of the coated strawberries, and subsequent quality characterization. The experiment was designed as a Completely Randomized Design (CRD) with a single factor at five treatment levels of PVA concentration (0%, 2%, 3%, 4%, and 5%), and was performed with three replications.

Synthesis of Water-Soluble Chitosan Nanoparticles

Water-soluble chitosan nanoparticles were synthesized using the ionic gelation method, as described by Guge et al. (2024). Initially, 2 g of chitosan powder (2% concentration) was dissolved in 100 mL of deionized water until a homogeneous solution was achieved. Simultaneously, sodium tripolyphosphate (STTP) was dissolved in deionized water at a ratio of 1:1000 (0.1 g STTP in 100 mL deionized water) with continuous stirring at 800 rpm for 20 minutes. Subsequently, 50 mL of the chitosan solution was added to 10 mL of the STTP solution and homogenized using a hot magnetic stirrer for one hour.

Preparation and Application of the Edible Coating Solution

The edible coating solution was prepared following the method of Kaynarca et al. (2023). PVA powder was weighed according to the specific formulation and placed in a beaker containing 100 mL of deionized water. The mixture was homogenized using a hot magnetic stirrer at a constant temperature of 80°C for two hours at a rotation speed of 1500 rpm. The resulting solution was then cooled to an ambient temperature of 50°C. The final edible coating solution was prepared by mixing the chitosan nanoparticle solution with the PVA solution at a ratio of 1:10 (10 mL of chitosan nanoparticles to 100 mL of PVA solution). This mixture was homogenized again using a hot magnetic stirrer for two hours, yielding a total volume of 110 mL of edible coating solution. The specific formulations are detailed in Table 1.

Table 1. Edible coating solution treatment formulation.

Sample	WSC Nanopartickes (g)	PVA Powder (g)	Aquades (ml)
Control	0	0	0
P1	2	2	100
P2	2	3	100
P3	2	4	100
P4	2	5	100

For the application, strawberries were first washed under running water to remove dirt and then dried with a paper towel. The edible coating was applied using a dipping method, where each strawberry was submerged in the solution for five minutes to ensure the surface was evenly coated. The coated fruits were then air-dried for three minutes to allow a protective layer to form. The treated strawberries were placed in an open 500 mL polypropylene (PP) container, with each container holding 7–8 strawberries. These containers were then stored at ambient temperature (25°C) for a period of seven days. Strawberry quality was evaluated on days 0, 3, 5, and 7 of storage to assess the coating's effectiveness. The measured parameters included appearance, weight loss, water content, total soluble solids (°Brix), acidity (pH), and vitamin C content.

Water Content

Water content was determined using the gravimetric method, as described by Safitri and Hakiki (2024). The initial weight of the strawberry samples was recorded, followed by drying in an oven at 105°C for three hours. After drying, the samples were reweighed to calculate the percentage of water mass loss using the provided formula:

$$\text{Water content (\%)} = \frac{\text{Wet weight} - \text{Dry weight}}{\text{Wet weight}} \text{X } 100\%$$

Weight Loss

Weight loss was measured following the procedure by Yoga et al. (2022) using an analytical balance (Shimadzu AY220, accuracy 0.0001 g). The mass of each strawberry was recorded throughout the storage period, and the percentage of weight loss was calculated using the provided formula:

$$\text{Weight loss(\%)} = \frac{W_0 - W_t}{W_0} \text{X } 100\%$$

Description:
W_0 = sample initial weight
W_t = sample final weight

Total Dissolved Solid

Total soluble solids were measured using a digital hand refractometer, following Zulaikhah's (2021) method. A few drops of crushed strawberry sample were placed on the prism surface of the refractometer. Readings were taken at an ambient temperature of approximately 25°C to determine the concentration of dissolved solids, which indicates the level of sweetness. The value was expressed in °Brix.

Acidity (pH)

The pH was measured using a digital pH meter. A 1:100 dilution was prepared by crushing 1 g of strawberry sample and adding 100 mL of deionized water. The pH meter was calibrated with deionized water before measurement. The electrode was submerged in the sample solution until a stable reading was obtained. A single pH measurement was performed for each sample in each treatment, ensuring the pH meter was properly calibrated.

Appearance

Visual observations were made to assess changes in the color and the growth of mold on the strawberries throughout the storage period. The physical appearance of each sample was meticulously noted.

Vitamin C

Vitamin C content was quantified using the iodometric titration method, as outlined by Fitriana and Ardhista (2020). The strawberries with the best appearance (fresh red color, no wrinkling, no mold, and minimal weight loss) were selected for analysis. A 10 g sample of crushed strawberry was placed in a 100 mL volumetric flask, filled to the mark with deionized water, and homogenized by inverting 12 times. A burette was filled with 50 mL of iodine solution, ensuring no air bubbles were present. A 10 mL aliquot of the homogenized sample solution was transferred to an Erlenmeyer flask. The iodine solution was then slowly titrated into the sample while stirring until the solution turned a stable white or limpid color, indicating the endpoint. The volume of iodine solution used was recorded and the vitamin C level was calculated using the following formula:

Vitamin C Levels (mg) = iodine volume (mL) x 0.88 g ascorbic acid

Data Analysis

All collected data, including water content, weight loss, °Brix, pH, appearance, and vitamin C content, were processed using Microsoft Excel. Descriptive analysis was performed by calculating the average values for each parameter. The processed data were also visualized in the form of line graphs to illustrate trends over the storage period.

RESULT AND DISCUSSION

Water Content

The water content analysis was conducted to measure the amount of moisture lost from the fruit during storage. The primary purpose of this test was to evaluate the edible coating's effectiveness in inhibiting the rate of water vapor transfer from the fruit tissue to the surrounding environment (Figure 1). As shown, the water content values for all treatments varied over the seven-day storage period. On day 0, the initial water content was similar across all treatments: P1 (92.13%), P2 (90.72%), P3 (90.16%), and P4 (90.10%). The application of the edible coating was proven to significantly inhibit the rate of water loss. While minor fluctuations were observed, all coated samples maintained a higher water content than the control throughout storage, reflecting the coating's ability to reduce moisture evaporation. For instance, the P3 and P4 treatments exhibited the best water retention on day 5. Ultimately, the higher water content values in the coated strawberries indicated that the edible coating created an effective barrier, keeping the fruit tissue hydrated and fresh. This is consistent with findings by Husain et al. (2022), who reported that edible coatings can reduce excessive evaporation in fruits like crystal guava, thus maintaining their freshness. Our results confirm that increasing the PVA concentration in the chitosan-based coating enhances its effectiveness in preserving strawberry freshness, as reflected by the high water content values and corresponding fresh visual appearance.

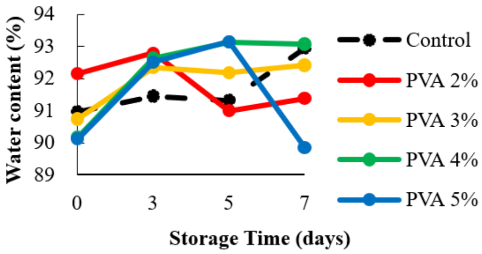

Figure 1. Edible coating chitosan PVA water content graph.
Descriptions: PVA 2% = P1, PVA 3% = P2, PVA 4% = P3, PVA 5% = P4

Weight Loss

The application of an edible coating based on a chitosan and PVA polymer composite had a significant effect on mitigating weight loss in strawberries during storage (Figure 2). The control sample experienced the highest weight loss, reaching 72% on day 7, while the P3 treatment (4% PVA) showed the lowest weight loss at 40.2% on the same day. The data indicate that increasing the PVA concentration generally led to a reduction in weight loss. However, an interesting finding was an increase in weight loss at the highest concentration (5%). This is likely because the 4% PVA concentration formed an optimal coating matrix, effectively inhibiting the rate of transpiration and respiration. In contrast, an excessively high concentration, such as 5%, may create an overly thick layer that disrupts proper gas exchange. This disruption can lead to anaerobic respiration, which starves the fruit of oxygen and encourages the growth of microorganisms, thereby accelerating weight loss. This phenomenon is consistent with the findings of Asrafil and Daniel (2023), who reported that increasing the concentration of coating materials can produce a thicker film, and with Afifah et al. (2023), who found that an overly thick coating can lead to anaerobic conditions that increase microbial activity and weight loss. Therefore, the optimal concentration of PVA as a reinforcing agent in edible coatings is a crucial factor to consider.

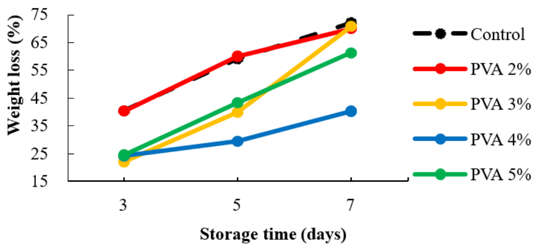

Figure 2. Weight loss graph.
Descriptions: PVA 2% = P1, PVA 3% = P2, PVA 4% = P3, PVA 5% = P4

Total Dissolved Solids (°Brix)

The analysis of total soluble solids (°Brix) using a hand refractometer revealed fluctuations in the Brix values across all treatments during storage (Figure 3). The °Brix value is a measure of the total dissolved solids within the fruit. The data in Figure 3 show a general decrease in °Brix values for strawberries in all treatments towards the end of the storage period. The 5% PVA treatment (P4) exhibited a slightly higher °Brix value compared to the control on day 7, while the P2 treatment showed the lowest. When compared to the control, the chitosan PVA composite coating had no significant influence on the overall trend of °Brix values. This can be attributed to the fact that strawberries are non-climacteric fruits, meaning they do not undergo a respiratory climacteric, which typically drives significant changes in sugar content after harvest. Therefore, the PVA concentration in the edible coating did not have a major effect on the Brix content. Furthermore, the addition of a high PVA concentration appeared to accelerate spoilage in some cases, possibly due to restricted gas exchange. As noted by Asrafil and Daniel (2023), an optimal edible coating can inhibit water vapor transfer and slow down the metabolic process of fruits. However, this effect is highly dependent on the type of fruit. Our results suggest that edible coatings may be more effective for climacteric fruits, which exhibit a post-harvest surge in respiration and ripening.

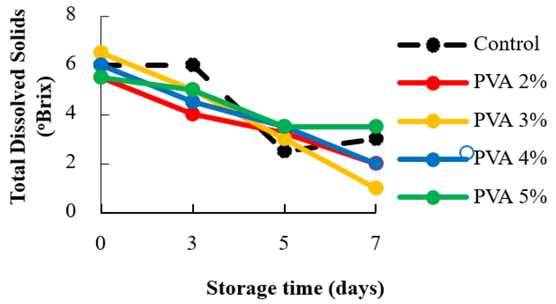

Figure 3. Total dissolved solid (°Brix) graph.
Description: PVA 2% = P1, PVA 3% = P2, PVA 4% = P3, PVA 5% = P4

This result differs from Pigozzi et al. (2025) on avocados. Their study showed that using various PVA concentrations (0.5% to 2%) could maintain fruit quality for up to 11 days of storage. In that research, the °Brix value tended to increase over time as part of the natural maturation process, with no significant differences among treatments. The final °Brix values for PVA-coated avocados ranged from 7.17% to 7.58%, and all treatments successfully inhibited the respiration rate and slowed physical deterioration. These contrasting results strengthen the view that the effectiveness of PVA as an edible coating material is highly dependent on the type of fruit. For climacteric fruits like avocados, a PVA-based coating provides significant protection. However, for non-climacteric fruits such as strawberries, PVA may be ineffective or even accelerate deterioration.

Acidity Levels (pH)

The application of a chitosan and PVA polymer composite edible coating on strawberries had a significant influence on the increase in pH during storage (Figure 4). The lowest pH was observed in the P2 treatment (2% PVA) on day 3, while the highest pH was found in the P4 treatment (4% PVA). On day 7, all coated treatments (P1 to P4) showed a higher pH value compared to the control. This increase in pH suggests that the edible coating, particularly at higher concentrations, may have inhibited the permeability of the strawberries, leading to the accumulation of gases. This can trigger anaerobic respiration and the subsequent formation of ethanol, which raises the fruit's pH. This finding aligns with Afifah et al. (2023), who stated that the formation of ethanol by microorganisms during anaerobic respiration is believed to influence the pH value. Therefore, the ineffectiveness of the coating in preventing pH increase may be related to an overly restrictive barrier that promotes anaerobic conditions.

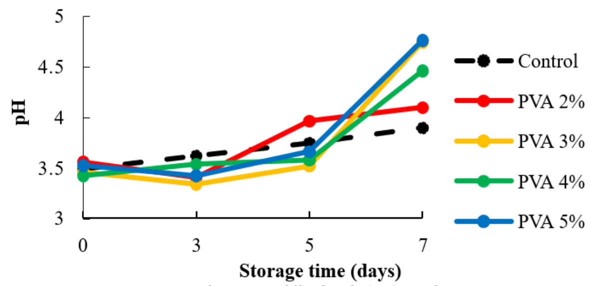

Figure 4. Acidity levels (pH) graph.
Description: PVA 2% = P1, PVA 3% = P2, PVA 4% = P3, PVA 5% = P4

Color

This research demonstrated that the edible coating based on a chitosan and PVA composite polymer resulted in varying changes to strawberry color during the storage period. The color changes observed from day 0 to day 7 for each treatment are presented in Table 2. Color degradation in strawberries is a key indicator of the rate of physiological damage during storage. The data in Table 2 show that fruit without the edible coating (control) experienced a faster color change, progressing to a blackish-red hue and mold growth. In contrast, treatments with the water-soluble chitosan nanoparticle and PVA-based coating were able to maintain a vibrant red color for the longest duration, particularly at PVA concentrations of 4% (P3) and 5% (P4). This indicates that the combination of chitosan and PVA formed an effective semipermeable layer that inhibits gas transfer and moisture loss, thereby suppressing the oxidative processes and microbial activity responsible for color degradation. This finding is supported by Wardalia et al. (2022), who stated that edible coatings function to inhibit O_2 and CO_2 transfer, and by Karimullah and Handarini (2024), who highlighted chitosan's antimicrobial properties. Therefore, a higher PVA concentration in the food-grade layer provides more effective protection against color changes during storage.

Table 2. The effect of edible coating on strawberries color.

Treatments	Day to			
	0	3	5	7
Control	Red	Red black	Dark red (black mold)	Dark red (black mold)
P1	Red	Red black	Dark pink	Blackish brown
P2	Red	Dark red	Dark red	Blackish red
P3	Red	Dark red	Dark red	Dark red
P4	Red	Dark red	Dark red	Dark red

Vitamin C

Vitamin C content was measured on day 0 and day 7 of storage using the best-performing treatment, which was the 4% PVA concentration, as it had the lowest weight loss. The test was conducted using the iodometric titration method to determine the coating's ability to preserve vitamin C in strawberries (Figure 5). The data show a significant decrease in vitamin C concentration over the storage period. On day 0, the initial vitamin C level was 40.48 mg. However, by day 7, the concentration had decreased by approximately 22% from this initial level. This result is consistent with Salha and Gedanken (2021), which reported a 22.73% decrease in vitamin C content in strawberries coated with chitosan nanoparticles, compared to a 64.73% decrease in the control group. These data prove that the edible coating formulation effectively reduces the rate of vitamin C degradation in strawberries. Furthermore, there is an inverse relationship between PVA concentration and the percentage of vitamin C loss: higher PVA concentrations result in a lower percentage of vitamin C loss. This finding is supported by Chinchkar et al. (2024), who showed that a 5% PVA coating resulted in a lower vitamin C loss (28.53%) on day 8 compared to a 2.5% PVA coating (31.6%). Chinchkar et al. (2024) also attributed this effect to the increased viscosity provided by PVA, which creates a stronger coating. This stronger barrier reduces the ingress of oxygen from the air into the fruit tissue, thereby slowing down the oxidation of vitamin C. The degradation process of vitamin C involves the oxidation of L-ascorbic acid to L-dehydroascorbic acid, which can further convert to L-dicotiledonate, a compound with no vitamin C activity. Therefore, the PVA-enhanced coating plays a critical role in slowing this degradation and preserving the nutritional value of the strawberries.

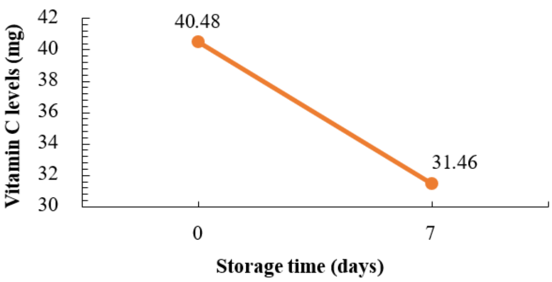

Figure 5. Vitamin C levels graph.

CONCLUSIONS

The application of an edible coating based on water-soluble chitosan (WSC) nanoparticles and polyvinyl alcohol (PVA) significantly affected the physical and chemical quality of strawberries during storage. Various concentrations of PVA exhibited different levels of effectiveness, with the 4% PVA concentration demonstrating the best overall performance. On day 7, this optimal formulation yielded a pH of 4.46, total soluble solids of 2 °Brix, a water content of 93.06%, and a weight loss of 40.2%. Visually, the strawberries coated with 4% PVA maintained their dark red color without any signs of mold or microbial growth. Additionally, this treatment effectively slowed the degradation of vitamin C, retaining 31.46% of its initial content. Although fluctuations in pH and a general decrease in total soluble solids were observed, the findings confirm that a WSC nanoparticle-based edible coating with an optimal PVA concentration of 4% offers a promising approach to extending the shelf life of strawberries.

Authors' Contributions: Likia Salsa Billa, Yunita Rachmawati, Titis Kusumaninghayu, Pandu Lintang Nugroho, Angela Merici Pusparani, and Esa Ghanim Fadhallah design the study and wrote the manuscript in Bahasa. Likia Salsa Billa, Yunita Rachmawati, Titis Kusumaninghayu, Pandu Lintang Nugroho, and Angela Merici Pusparani conducted the research and wrote the manuscript. Esa Ghanim Fadhallah supervised the research and proofreads the manuscript. Pandu Lintang Nugroho translates to English. All authors read and approved the final version of the manuscript.

Competing Interests: All authors stated that there was no conflict of interest in this study.

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