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Research Paper

Edible Coating of Cherry Tomatoes (*Solanum lycopersicum*) Based on Chitosan Nanoparticles (NPCh) and Mint (*Mentha piperita*) Essentials Oil with Addition of Aloe Vera Gel

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Abstract
Cherry tomatoes, as climacteric fruits, continue ripening after harvest, making them susceptible to *Xanthomonas campestris* bacteria. One method that has been developed to prevent this from happening is applying edible coating with polysaccharides such as chitosan. However, the particles tend to be large and antibacterial activity is not optimal. Therefore, an edible coating was developed using nanochitosan (NPCh) and mint essential oil (EO), enhanced with aloe vera. NPCh was synthesized via ionic gelation with chitosan: STPP ratios of 2:1, 3:1, and 5:1, and mint EO added at 0.2, 0.4, and 0.6 mL. Coatings were applied by dipping, and quality was assessed over 11 days using weight loss, color, Lycopene, Vitamin C parameters, and data result was analyzed with ANOVA (Sig. 0.05). Texture organoleptic tests were evaluated by 10 panelist. Antibacterial activity against *Xanthomonas campestris* was analyzed in silico. Results showed the smallest NPCh particle size (197 nm) with a 5:1 ratio, and TEM confirmed spherical shapes. Tomatoes without coating (K-) had significantly lower quality compared to coated samples (K+, K1-K6). Samples with EO (K3-K5) preserved physical (weight, color) and nutritional quality (Vitamin C, Lycopene) better, with K5 (0.6 mL EO) showing optimal results. However, there are no significant differences were observed between K5 and K6 (adding aloe vera gel) in maintaining tomato quality. Texture analysis also identified K5 as the most preferred. In silico studies demonstrated strong antibacterial potential for mint EO and aloe vera compounds, with binding affinities (-3.97 to -5.76 kcal/mol) surpassing native ligand and positive control.

Keywords
Cherry Tomato, Coating, Nanochitosan, Mint EO, Aloe Vera

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1. INTRODUCTION

Fresh food products such as fruits, vegetables and meat are easily rotten during the storage process. Biotic factors such as microorganisms and abiotic factors such as temperature and humidity accelerate the decaying process (Priya et al., 2023). In recent years, research related to coating as one of the food preservation and preservation techniques has been widely developed as a solution to overcome the problem of produce decay. One type of coating that is widely used is edible coating. Edible coating is a thin and continuous layer, made of edible ingredients, formed to coat food components (coating) and functions as a barrier to mass transfer (e.g. moisture, oxygen, lipids, light, and solutes). Thus, it functions to extend the shelf life by inhibiting the transfer of water vapor and gas (oxygen and carbon dioxide) as a carrier of food ingredients (flavors, antioxidants and antimicrobials) (Armghan Khalid et al., 2022). In addition, edible coatings are also possible to contain additional beneficial substances such as antioxidants and phyto-nutrients that help improve food safety and stability.

Various materials have also been developed as basic coating materials. One of the popular polysaccharides used is chitosan. This is because chitosan coating has indigestible properties so that it has no calories and is directly excreted by the body along with feces, in addition chitosan has a positively charged amine functional group (NH_2) which helps bind the cell walls of fungi or bacteria and can inhibit them from causing decay. Chitosan also has biodegradability and low toxicity (Bhowmik et al., 2022). Although chitosan can be widely applied for coating, it has been found to have a less than optimal particle size and surface area, making it difficult to interact evenly with the material to be coated (Ghadi et al., 2014). Therefore, one of the latest solutions to maximize its function is to increase the surface area of the particles and reduce the particle size to nano in order to be evenly distributed.

Chitosan nanoparticles have been studied previously and

can be made using several methods including ionic gelation between chitosan and sodium tripolyphosphate (STPP). This method utilizes the interaction of the cationic amino group of chitosan with many negatively charged groups, such as sulfate, citrate, and tripolyphosphate. Chitosan-tripolyphosphate particles which form chitosan nanoparticles have been shown to be used to enhance drug delivery, enhance therapeutic effects and improve the quality of targeted compounds (Alehosseini et al., 2022). Previous research showed that chitosan nanoparticles are effective in inhibiting the growth of fungi and bacteria. However, its development and use as an edible coating, especially in combination with essential oils, has not been widely reported.

Meanwhile, a previous study Khan et al. (2019) combined chitosan with antibacterial agents such as monomethyl fumaric acid, and the results were proven to extend the shelf life of fresh strawberries from 4 to 8 days by reducing the number of microorganisms and fungi. Thus, based on the several studies, the combination of chitosan optimized into a nano size with essential oils is one method that can improve the quality of coating. Mint essential oil (*Mentha piperita*) is one of the essentials that have high antifungal effectiveness. Several components of its compounds such as menthol (41.7%) and menthone (21.8%) have been proven effective in overcoming the growth of microorganisms such as bacteria, fungi and others. Therefore, it is expected to be effective to be combined with chitosan.

One of the fruits that experiences a lot of deterioration and rots quickly is cherry tomatoes. Unlike other types of tomatoes, cherry tomatoes contain richer ascorbic acid, carotenoid and organic acids (Wang et al., 2022). Cherry tomatoes also contain various types of useful flavonoids, especially quercetin rutinoside (rutin), kaempferolrutinoside, and naringenin chalcone (Wang et al., 2018). Cherry tomatoes are classified as climacteric fruits, which means that after harvesting, the fruit is still undergoing a metabolic process so that it has the potential to experience damage in terms of texture, aroma, and water content from weight loss. This is also accelerated by abiotic factors such as air and pH which can accelerate the metabolic process of ripening tomatoes as climacteric fruits. In addition, tomatoes have a high water content which makes them a suitable medium for bacterial growth (Obeng et al., 2018).

One type of bacteria that causes decay and attacks climacteric fruits including cherry tomatoes is the fungus *Xanthomonas campestris*. This microorganism can cause black spot disease and slow rot on the leaves and fruit after harvest and will significantly reduce its quality, marked by the appearance of black spots and a sour aroma on tomatoes (Osdaghi et al., 2021).

Based on this background, a study was carried out in the development of an edible coating material, which is chitosan, by synthesizing it into nanosize using the ionic gelation method with the help of STPP cross-linker and was formulated with mint essential oil and aloe vera gel to improve the quality of the coating for cherry tomatoes. Cherry tomatoes were then observed for color changes, weight loss, and texture after coating application. In addition, the antibacterial effectiveness of compounds in mint essential oil and aloe vera were also be analyzed in silico on the microorganism *Xanthomonas campestris*.

2. EXPERIMENTAL SECTION

2.1 Materials

The materials used in this study included acetic acid, food-grade chitosan (DD 87%), food-grade STPP, NaOH and Iodine solution obtained from CV Sari Kimia Raya, Malang, East Java. Tween80 was gained from Merck and distilled water was taken from SMARTLAB. Mint essential oil 98% and aloe vera gel were obtained from Atsiri Farmer Indonesia, Bogor, West Java, and fresh cherry tomatoes were harvested in Malang, East Java. Meanwhile, for in silico, the materials included the *Xanthomonas campestris* protein that specifically attacks cherry tomatoes with the code 5JP1 (fromhttps://www.rcsb.org/) as a receptor and active compounds in mint essential oil and aloe vera as ligands (from https://pubchem.ncbi.nlm.nih.gov/)

2.2 Tools and Instruments

The equipment used in this research included hot plate, magnetic stirrer, thermometer, oven, Labware glass (100 mL measuring flask, 500 mL glass, measuring pipette, measuring cup), analytical balance, thermometer, refrigerator, FT-IR (Fourier-Transform Infrared) Shimadzu IRAffinity-1, PSA (Particle Syze Analyzer) Microtrac Nanotrac Wave II, TEM Hitachi HT7700, Spectrophotometer UV-Vis Shimadzu UV-1280, GCMS (Gas Chromatography Mass Spectrometry) Shimadzu QP2010 and Software include SPSS 23, Autodock Tools New, BIOVIA Discovery Studio 2021, OpenBabelGUI and OriginPro 2022 Version.

2.3 Methods

2.3.1 NPCh Synthesis and Characterization

A total of 1 g of chitosan was dissolved in 100 mL of acetic acid (1.0%). After dissolved, the pH of chitosan was conditioned to 5 with 1 M NaOH, stirred with a magnetic stirrer without heating until the pH was stable. This formulation was made in as many as 3 glasses. Furthermore, STPP (1.0%) was added by dripping slowly with ratio of volume chitosan: STPP (v/v) 2:1 in glass 1; 3:1 in glass 2; and 5:1 in glass 3 while being stirred with a stirrer at a temperature of 30°C for 1 hour. The results obtained were then measured with PSA for size determination, and TEM for texture and contour analysis. The sample also freeze-dried for FTIR analysis.

2.3.2 Edible Coating Formulation

The most optimum Nanochitosan (NPCh) based on the results of PSA and FTIR analysis, was added by 98% mint essential oil, as much as 0.2 mL, 0.4 mL and 0.6 mL for every 100 mL of coating solution and homogenized with 1 mL of tween 80. The mixture was stirred at a temperature of 27°C until the essential oil and NPCh coating solution was homogeneous and no phases were formed.

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Table 1. Test Groups

Group	Treatment
K-	Without Treatment
K+	Mint EO
K1	Aloe Vera Gel
K2	NPCh
K3	NPCh+Mint EO 0.2 mL
K4	NPCh+Mint EO 0.4 mL
K5	NPCh+Mint EO 0.6 mL
K6	NPCh+Mint EO 0.6 mL+Aloe Vera Gel

2.3.3 Application on Cherry Tomatoes

For the application of edible coating, cherry tomatoes were divided into 6 test groups with details in Table 1.

The number of cherry tomato samples in each group was determined using the Federer formula, so that 4 samples were obtained per group with each group repeated 3 times. The application began by preparing cherry tomatoes that had been washed and air-dried. Then they were dipped into the edible coating emulsion according to the group for 4 minutes, then lifted and left for a while. Following that, they were then dipped into aloe vera gel for 3 minutes. Furthermore, the fruit samples were hung and air-dried at room temperature for 1 hour. The samples were then stored in a container at a room temperature and observed for weight loss, color on days 0, 5, 7, 11 and texture on the 11th day after application.

2.4 Cherry Tomatoes Quality Test

2.4.1 Color Test of Cherry Tomatoes

The CIE Lab color test method was based on research by Muhandri et al. (2024) with modifications using software. Skin color was measured using a colorimeter software. The camera conditions used were with a 64MP rear camera (main), 2MP (depth), 0.08MP (AI). Color measurements were recorded using the L*, a* and b * scales.

2.4.2 Weight Loss

Weight loss measurements were carried out based on research by Flores-López et al. (2023) by calculating the percentage of weight loss from the sample. Here is the formula used (Equation (1)):

$$\%\ \text{Weight Loss} = \frac{(W_0 - W_a)}{W_0} \times 100\% \quad (1)$$

Description:
W_0 = initial storage material weight
W_a = final storage sample weight

2.4.3 Cherry Tomatoes Texture Analysis

At first, the qualitative texture test with organoleptic was performed by making a scale of 1-5, in which the scale 1 is the softest and 5 is the hardest. This test involved 10 Panelists who were selected using the Random Sampling method. The data obtained from the results of the color test and weight loss observations were tested using One-Way ANOVA and Post-Hoc analysis with a 95% confidence level (significance 0.05) to determine the effect of variations in the concentration of edible coating materials on the sample during 11 days of storage.

2.5 Cherry Tomatoes Chemical Analysis

2.5.1 Measurement of Vitamin C

Method was referred to Umbayda et al. (2024) with modifications. The sample were crushed with a mortar. The slurry was weighed 10 grams, then put into a 100 mL volumetric flask and then added with distilled water up to the mark. Put it in an Erlenmeyer flask and add distilled water until the volume is 100 mL. Filter with filter paper in a 10 mL beaker glass and add 2-3 drops of starch indicator. Titrate with standard 0.1 N iodine solution until the color becomes violet. Vitamin C levels are calculated by the Equation (2):

$$\text{Vitamin C} = \frac{\text{mL Iodine } 0.88 \times \text{Dilution Ratio} \times 100}{\text{Sample weight}} \quad (2)$$

2.5.2 Measurement of Lycopene

For lycopene analysis, the method was referred to Pholsin et al. (2024), 0.1 g of the sample from each group was mixed with 1 mL of distilled water and incubated in a water bath at a temperature of 30°C for 1 hour Then hexane: ethanol: acetone (2:1:1) solution was added, respectively. The samples were vortexed and incubated out of bright light for 10 min to allow phases to separate. The absorbance of samples was determined at a wavelength of 503 nm by Spectrophotometer. Calculation of the lycopene content was performed by the following Equation (3):

$$\text{Lycopene content } (mg/kg) = (A503) \quad (3)$$

2.6 In Silico Mint EO Antibacterial Activity

The receptor protein was cleaned of water molecules and separated from its native ligand using BIOVIA and stored in .pdb format. For the receptor, it was charged and prepared, while the energy of the native ligand, which was malonate or compounds in mint essential oil from GCMS and aloe vera (acemannan, aloeemoidin, aloesin, aloin, emodin) is minimized and prepared in Autodock. During the docking process, the docking area and grid box were evaluated for the coordinates (x, y, z) for the native ligand and then applied to the mint and aloe vera compound ligands. The docking process was carried out 100 times for each compound so that the binding energy read in the histogram was stable. The results of the ligand docking to the receptor were then visualized again using BIOVIA.

3. RESULTS AND DISCUSSION

3.1 FTIR of Synthesized NPCh

FTIR (Fourier-Transform Infrared) was used to identify organic compounds or sample mixtures by detecting functional groups without damaging the sample. The FTIR spectrum of synthesized NPCh is presented in Figure 1.

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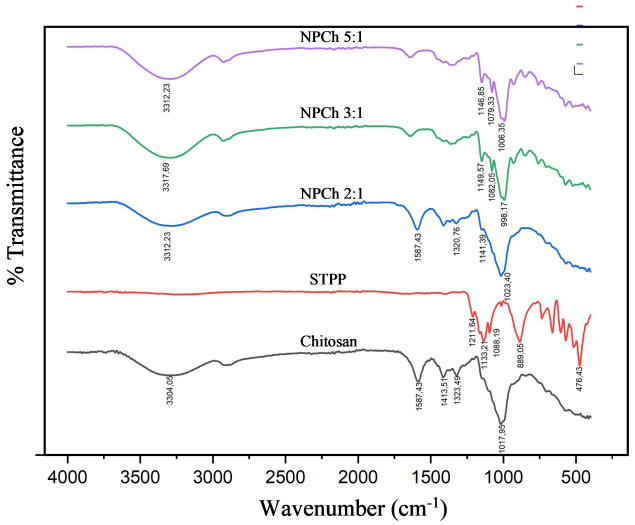

Figure 1. FTIR Results of Synthesized NPCh

The observed chitosan spectrum is similar to the previous research Mazancová et al. (2018), which show absorption of the C−N group in the 1323-1350 cm^{-1} region, amine bonds in the 1409-1610 cm^{-1} region, and O−H groups in the 3300-3400 cm^{-1} region. STPP had the main bonds P=O, PO_2, and PO_3 which were observed in the 1080 to 1220 cm^{-1} region. There was also a P=O=P bond in the 880-900 cm^{-1} region (Ferreira Tomaz et al., 2018).

For the three variations of NPCh compounds, a combination of spectra between pure STPP and pure Chitosan can be observed. Based on the Figure 1, in the synthesis formulation of NPCh 2:1, 3:1 and 5:1, it can be seen that the peak in the 3300 cm^{-1} region experienced an increased intensity and was wider, this indicates an increase in hydrogen bonds. Furthermore, the N−H bonds of Amine I and II were observed at 1587.43 cm^{-1}, and 1413.51 cm^{-1} respectively, which will weaken due to deformation of the N−H bond due to the combination of phosphoric ions from TPP with ammonium ions from the N−H bond in protonated chitosan. Instead, in NPCh, a PO_3 bond was observed at 1130-1190 cm^{-1} originating from STPP. The P=O bond of STPP was still observed in the NPCh spectrum at 1070-1150 cm^{-1} (De Carvalho et al., 2019).

The crosslink bond between chitosan and STPP in NPCh could not be observed via FTIR. This is due to the bond that occurs electrostatically, i.e. ionic bonds, so it did not cause group vibrations. In addition, under the same synthesis conditions (only different ratios of STPP and Chitosan according to variation) it can be observed that NPCh 2:1 had a less perfect formation spectrum than the other 2 variations. This can be caused by the condition of STPP which is difficult to bind perfectly with chitosan, because the presence of protonated chitosan is not much in the mixture solution (Valentino et al., 2022).

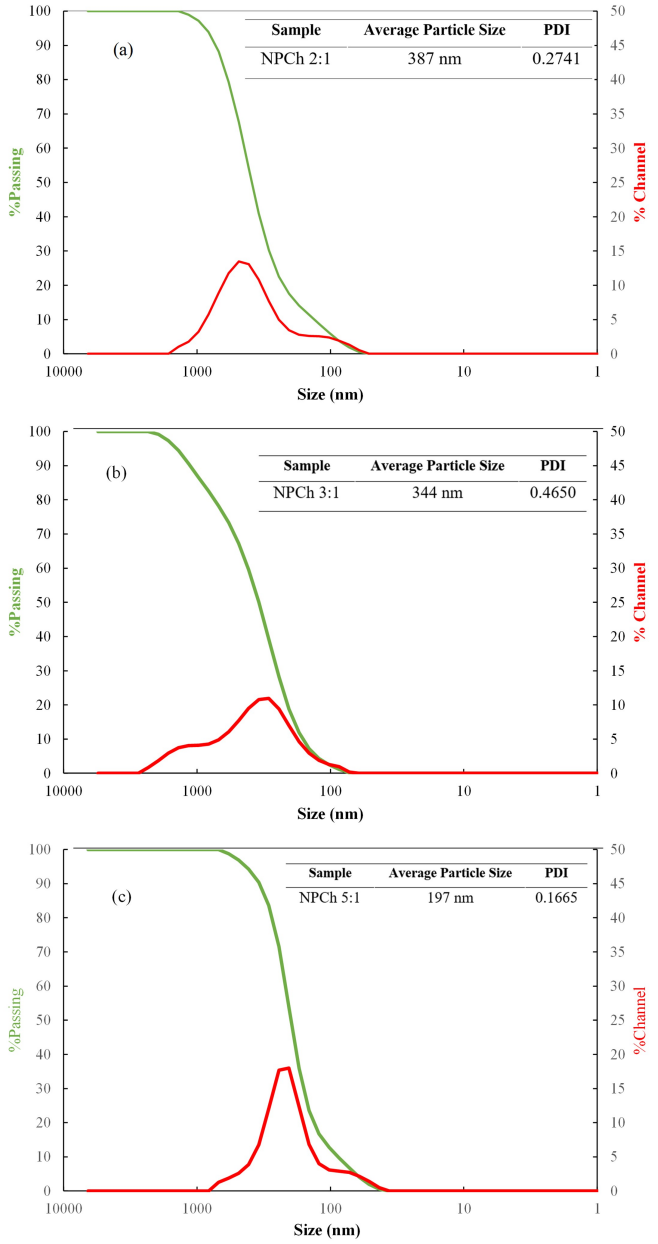

Figure 2. PSA Measurement Results of (a) NPCh 2:1, (b) NPCh 3:1, and (c) NPCh 5:1

3.2 NPCh Particle Size and Morphology

Nanoparticles are materials synthesized with different materials and have sizes varying between 1-1000 nm (Bashir et al., 2022). Figure 2 shows data about NPCh PSA measurement.

Based on the size measurement results, chitosan synthesized using organic materials can be categorized as nano-sized. For nanoparticles, especially for edible coatings, the reviews and past research show that the particle size tends to have a more influential effect on coating quality as compared to other factors like the particle shape, and surface charge (Zambrano-Zaragoza et al., 2018).

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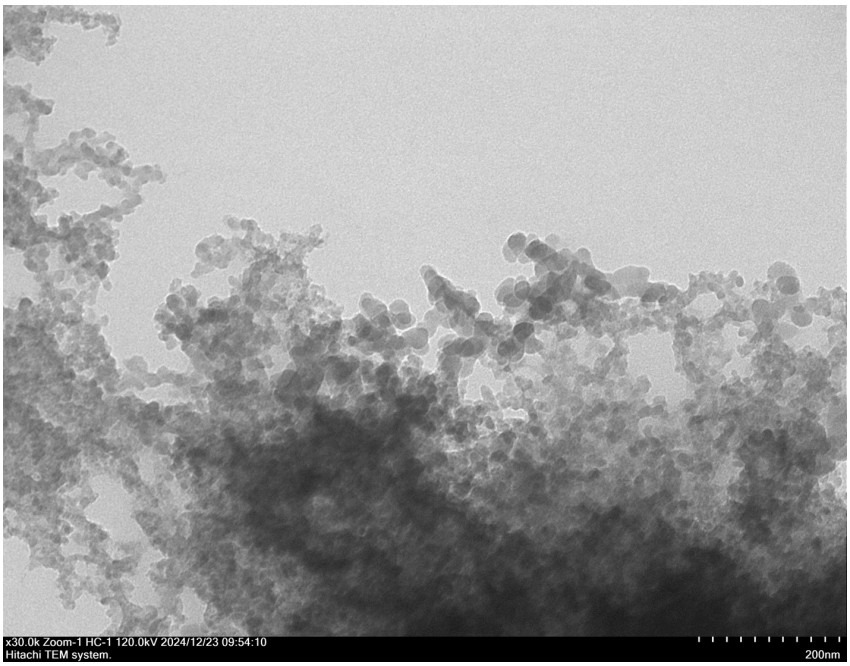
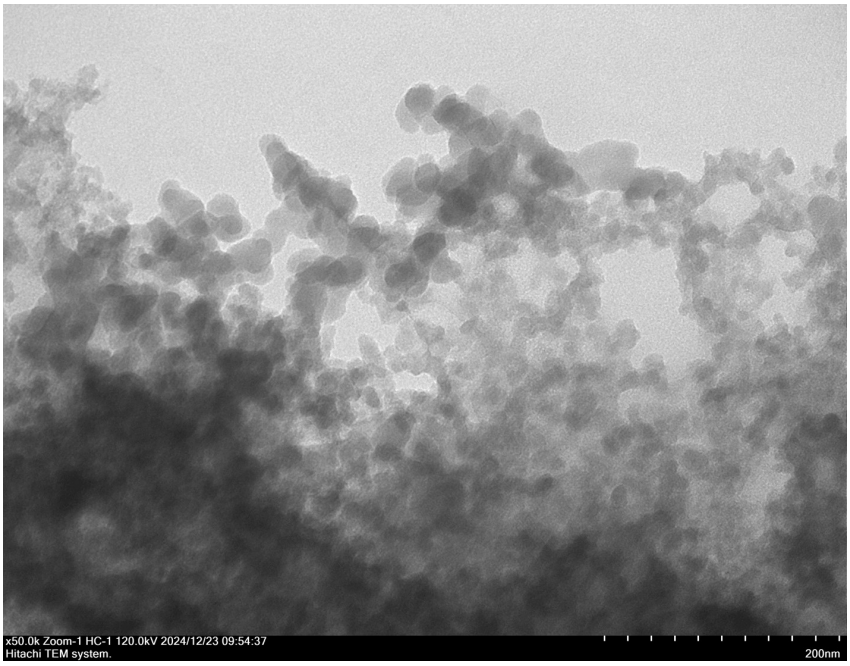


(a)



(b)

Figure 3. Chitosan Nanoparticle TEM Result: (a) ×30.0k Magnification, (b) ×50.0k Magnification

Meanwhile, from the PSA measurement results of the synthesized NPCh shown in Figure 2, the ratio between chitosan and STPP has a significant effect on the average size of the particles formed. The condition seen from the three variations of the chitosan and STPP ratio is that the greater the chitosan and the smaller the STPP in the mixture, the smaller the size of the NPCh would be. The previous research also showed the same trend where in the variation of Chitosan:STPP 2:1, 3:1 and 5:1 the smallest particle size was obtained in the 5:1 formulation with a size of 169 nm. Besides , NPCh 5:1 had the smallest PDI variation results, which shows that the nanoparticles formed were more homogeneous. For polymer especially,

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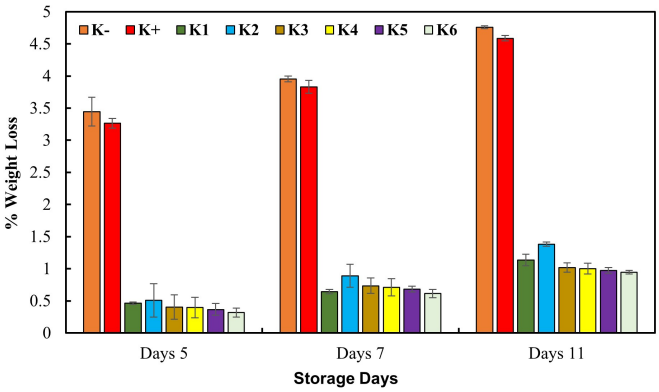

Figure 4. Weight Loss (%) of Cherry Tomato on Days 5, 7 and 11 of Storage at Temperature 25-26°C. Vertical Lines Represent Standard Deviation of 3 Replications of Each Sample

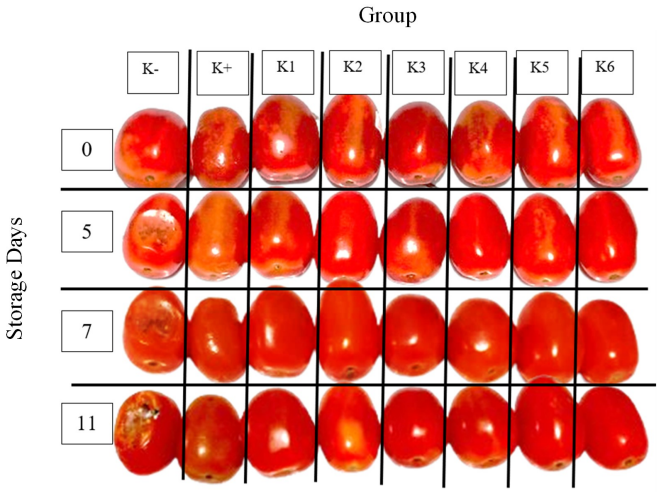

Figure 5. Comparison of Cherry Tomatoes from K- to K6 (Left to Right) on Day 0, 5, 7, 11

the ideal PDI number is < 0.2 (Shrivastava, 2018). The factor causing the smaller STPP in the mixing ratio resulting in a smaller size is that higher STPP will disrupt the binding balance process between CS and STPP and affect the physicochemical characteristics of NP, such as particle size, and increase the tendency for particle aggregation. This is mainly because with the relatively increased number of STPP particles, STPP in suspension can produce larger NP. In addition, the more STPP ratio in the mixture used causes precipitation or sedimentation in solution. Precipitation will result in a larger particle size in solution. This occurs because the interaction between CS and TPP reaches stoichiometry and produces an increasing number of CS-TPP complexes formed, but in irregular and imperfect sizes (Valentino et al., 2022).

TEM was observed at a size of 200 nm and at magnifications of ×30.0k and ×50.0k. TEM results showed that the synthesized chitosan nanoparticles had colloidal shapes, as shown in Figure 3. The TEM images also show that the nanoparticles are predominantly spherical with smooth contours, indicating uniformity in shape and morphology. This uniformity is a desirable feature for applications requiring consistent surface properties, such as edible coating. These results are also in line with previous research conducted by Khanmohammadi et al. (2015). Despite the uniformity of the particle shape, through TEM results it can be seen that chitosan nanoparticles are very easily aggregated. This is because chitosan nanoparticles have a small diameter and very high surface energy, resulting in unstable thermodynamics and to reduce the high surface energy, they will aggregate. Chitosan nanoparticles also have numerous hydroxyl and amino groups that can form hydrogen bonds with each other. These bonds promote close interaction and aggregation of the nanoparticles (Ghadi et al., 2014).

3.3 Weight Loss

In climacteric fruits such as cherry tomatoes, during the storage process after post-harvest, the weight of cherry tomatoes will tend to decrease. The main cause of the fruit weight loss process is the transpiration and respiration processes of the fruit during ripening. The weight loss of cherry tomatoes during storage days 0, 5, 7, 11 is shown in Figure 4.

In fresh fruit with a highwater content such as cherry tomatoes, the transpiration and respiration processes will tend to continue after harvest. In addition, during this process, it will also be easily influenced by environmental conditions and microbes that can increase the rate of transpiration and respiration in the fruit (Lufu et al., 2024). Transpiration emphasizes the complex nature of the process of water loss in fruit during post-harvest handling and storage, marked by the interaction between water evaporation that occurs on the surface of the product due to lack of water vapor and respiratory activity simultaneously. In addition to transpiration, respiration which is the process of oxidative breakdown of complex substrate molecules (starch, sugar, organic acids, etc.) into simpler molecules such as CO_2 and H_2O with the production of energy and intermediary molecules also occurs. This process will cause organic components such as carbohydrates and O_2 in the fruit degraded, causing the fruit to lose weight, water content, texture, and taste (Xanthopoulos et al., 2017). To slow down the rate of transpiration and respiration in fruit, the application of coating on fruit will greatly affect the quality of the fruit The results of observations in this study show that fruit coated with coating formulations (K+ to K6) tended to show smaller weight loss results on days 5, 7, 11 compared to the group without treatment (K-). indicating that the transpiration and respiration processes were slowed down.

From the data presented in Figure 4, it is seen that all groups of cherry tomatoes experienced a decrease in weight. Based on the Anova results, the treatment in each group gave a significant effect (sig< 0.05) on weight loss. The order of weight loss from highest to lowest was K-, K+, K2, K1, K3, K4, K5, K6.

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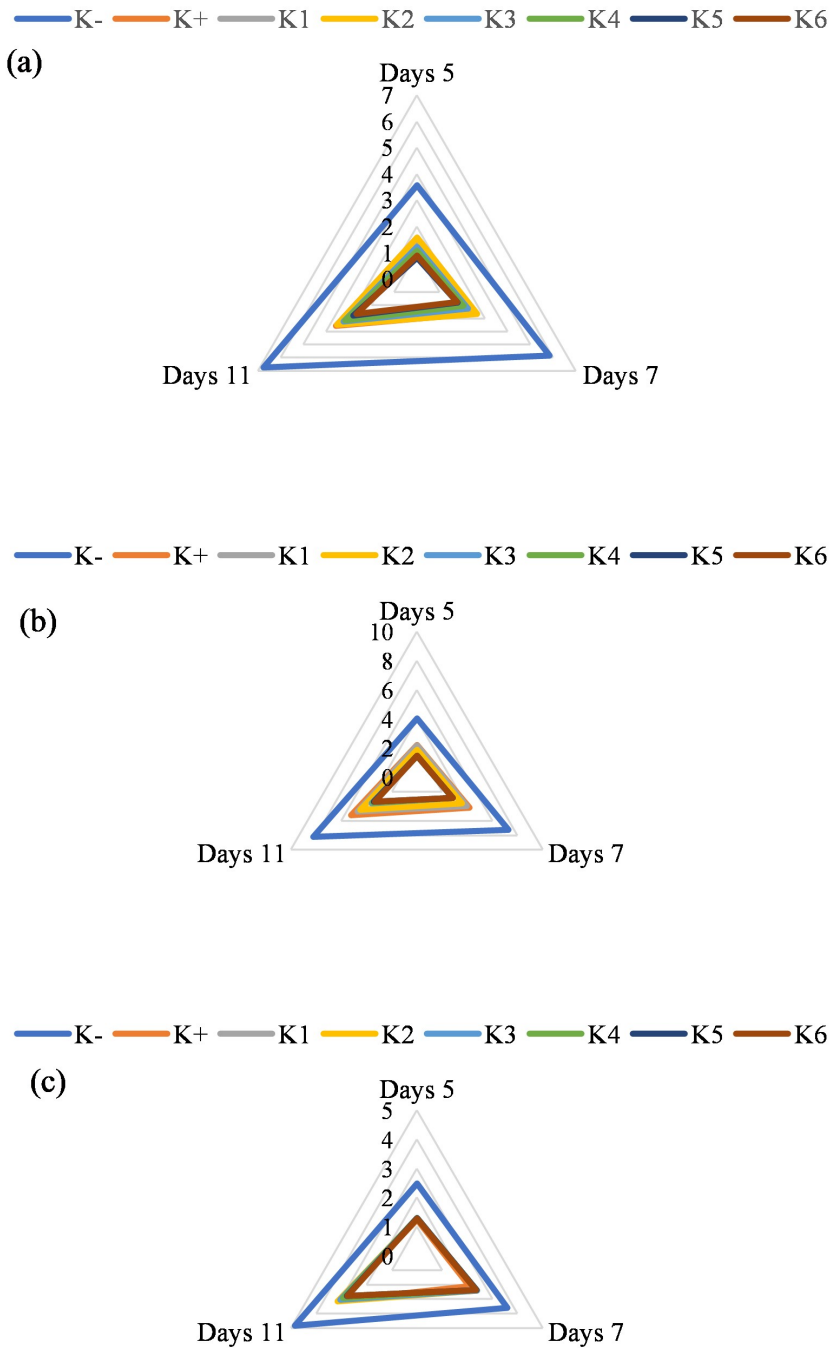

Figure 6. Change in (a) L, (b) a*, and (c) b* parameter value (%) in Cherry Tomatoes on Days 5, 7, and 11 of Storage at Temperatures of 25-26°

Thus, the highest weight loss on the 11th day was showed in the tomato group that was not given coating (K-) which was 4.76%, while the lowest weight loss with a value of 0.95% was K6 with NPCh+0.6 mL Mint EO treatment plus Aloe Vera

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Gel as a coating. The addition of additive compounds such as essential oils (in groups K3-K5) and aloe vera (K6) significantly increases the quality of the coating in preventing contact with bacteria and can reduce the process of compound loss due to respiration (Perdones et al., 2012).

3.4 Color Test Result and Lycopene

Color changes in cherry tomatoes during storage (Figure 5), indicate the ripening process of cherry tomatoes. Color test result from observations of cherry tomatoes is presented in Figures 6.

According to the Anova results, each treatment had a significant effect on the results of the color change in the fruit (sig.< 0.05). On the 5^{th}, 7^{th}, 11^{th} observation days, the addition of coating material and additives, mint essential oil and aloe vera, could maintain the L, a* and b* values of the fruit (Figure 6), seen from the color change percentage which was significantly different (sig.< 0.05) with cherry tomatoes without treatment, examined from the results of the Post Hoc LSD and Duncan tests.

In addition, when examined further, among K3-K5, the K5 group with the highest concentration of mint essential oil had the highest quality of maintaining color. The ability to maintain color also increases with the addition of aloe vera, as evidenced by K6 which had a lower color change percentage than K5. Although the addition of aloe vera gel had the best results, when compared to K5; NPCh + 0.6 mL of mint essential oil, the Post Hoc LSD and Duncan tests show that the addition of aloe vera had no significant effect (sig.> 0.05) on the color change.

Based on the results of this observation, the coating material added with additives has been proven able to maintain the color quality of cherry tomatoes by slowing down the ripening process. Ripening of climacteric fruits such as cherry tomatoes occurs due to respiration so that ethylene compounds are produced in large quantities during the fruit ripening process, where the 2 ethylene biosynthesis system is believed to be autocatalytic. The ethylene synthesis process occurs very easily if the fruit is in direct contact with CO_2 and O_2 which causes the respiration process thereby accelerating the ethylene production process. In addition, there are also several types of microbes that can help trigger the synthesis of Aminocyclopropane Carboxylic Synthase (ACS) and Aminocyclopropane Carboxylic Oxydase (ACO). In the fruit tissue, chlorophyll degradation occurs, while the accumulated synthesis of red carotenoids occurs rapidly. The biosynthesis pathway of lycopene-type carotenoids in tomatoes begins with the condensation of two molecules of geranylgeranyl diphosphate (GGPP) to form the colorless carotene. 15-cis-phytoene, a reaction catalyzed by phytoene synthase (PSY); is then desaturated and isomerized to all-trans-lycopene through the action of two desaturases and two isomerases: phytoene desaturase (PDS), carotene desaturase (ZDS), prolycopene isomerase (CRTISO) and carotene isomerase (ZISO) (Su et al., 2015). The formation of lycopene is accelerated by the production of ethylene, where ethylene triggers the formation of PSY to catalyze the synthesis of lycopene that contributes to color change on fruit.

3.5 Vitamin C Test Result

Cherry tomatoes contain a certain amount of vitamin C which will decrease during the ripening period. Figure 7 shows the decline of vitamin C in cherry tomatoes during storage days.

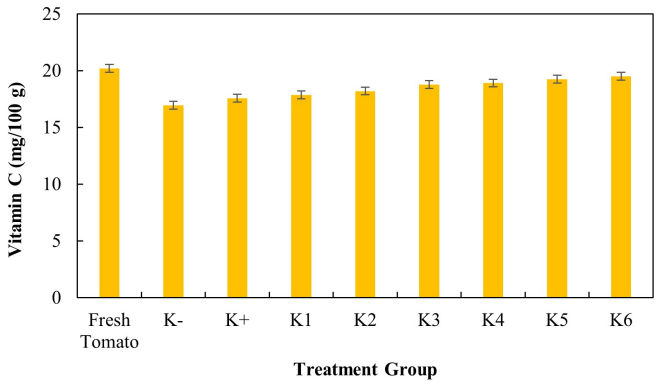

Figure 7. Vitamin C Content in Fresh Cherry Tomatoes and in Cherry Tomato Treatment Samples after 11 Days of Storage. Data is presented with Standard Deviation Lines

The results of observations in this study show that fruit coated with coating formulations (K+ to K6) tended to show smaller vitamin C loss on storage day 11 compared to the group without treatment (K-), indicating that the vitamin C loss processes were slowed down. From the data presented in Figure 7, it is seen that all groups of cherry tomatoes experienced a decrease in Vitamin C. Based on the Anova results, the treatment in each group had a significant effect (sig.< 0.05) on Vitamin C compound. The order of Vitamin C loss from highest to lowest was K-, K+, K2, K1, K3, K4, K5, K6. Thus, the highest vitamin C decline on the 11^{th} day was showed in the tomato group that was not given coating (K-) which was 0,16%, while the lowest vit c loss with a value of 0,03% was K6 with NPCh+0.6 mL Mint EO treatment plus Aloe Vera Gel as a coating. Even though has the better quality in retaining Vitamin C, the addition of additive compounds such as essential oils (in groups K3-K5) and aloe vera (K6) didn't have significant effect based on LSD and Duncan result.

3.6 Lycopene Test Result

Lycopene is a natural pigment synthesized by plants and microorganisms. Like other carotenoids, the function of carotenoids themselves is as light-absorbing pigments in photosynthesis. Cherry tomato contains lot of lycopene. Figure 8 shows the increase of Lycopene in cherry tomatoes during storage days with edible coating treatment.

The red color of cherry tomatoes is caused by a carotenoid derivative compound, lycopene. The mechanism of lycopene

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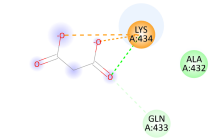
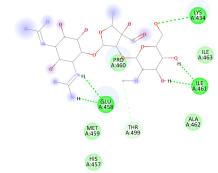
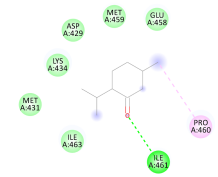
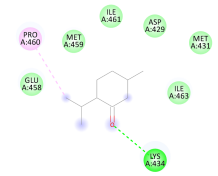
Table 2. Results of Mint Compound Docking on 5JP1 (Binding Affinity, Visualization and Types of Bond)

Compound	Binding Energy (kcal/mol)	Inhibition Constant (mM)	Interaction	Types of Bond		
				Hydrogen	Van der waals	Others
Malonat (Native Ligand)	-3.20	4.53		LYS A-434 GLN A:433	ALA A:433	LYS A-434
Streptomycin (Commercial Antibacterial)	-2.51	14.41		GLU A-458 ILE A:461 LYS A:434 THR A:499	ALA A:462 MET a:459 ILE A:463 HIS A:457 PRO A:460	ILE A-461
Isomenthone	-4.63	0.40		ILE A-461 MET A:431 LYS A:434 ASP A:429 MET A:459 GLU A:458	ILE A:463	PRO A-460
p-Menthone	-4.44	0.55		LYS A-434	GLU A-458 MET A:459 ILE A:461 ASP A:429 MET A:431 ILE A:463	PRO A:460

formation as tomatoes age is through chlorophyll degradation and a shift in the composition of carotenoids (especially lutein and neoxanthin) to carotenes (especially phytoene, lycopene and β-carotene). Chlorophyll degradation occurs in fruit tissue, while the accumulated synthesis of red carotenoids occurs rapidly. The biosynthesis pathway of lycopene-type

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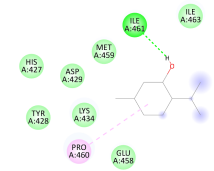
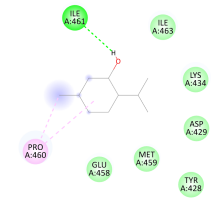
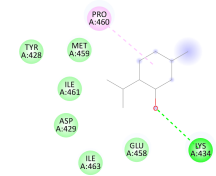
Compound	Binding Energy (kcal/mol)	Inhibition Constant (mM)	Interaction	Types of Bond		
				Hydrogen	Van der waals	Others
(+)-Menthol	-4.69	0.37		ILE A-461	GLU A:458 LYS A:434 TYR A:428 ASP A:429 HIS A:427 MET A:459 ILE A:463	PRO A-460
(-)-Menthol	-4.76	0.33		ILE A-461	ILE A-463 LYS A:434 ASP A:429 MET A:459 TYR A:428 GLU A:458	PRO A-460
Neomenthol	-4.17	0.87		lys A-434	TYR A-428 MET A:459 ILE A:461 ASP A:429 TYR A:428 ILE A:463 GLU A:458	PRO A-460

carotenoids in tomatoes begins with the condensation of two molecules of geranylgeranyl diphosphate (GGPP) to form colorless carotene. 15-cis-phytoene, a reaction catalyzed by phytoene synthase (PSY); 15-cis-phytoene is then desaturated and isomerized to all-trans-lycopene through the action of two desaturases and two isomerases: phytoene desaturase (PDS), carotene desaturase (ZDS), prolycopene isomerase (CRTISO) and carotene isomerase (ZISO) (Su et al., 2015). The formation of lycopene will be accelerated by the production of ethylene, where ethylene triggers the formation of PSY to catalyze lycopene synthesis.

The results of observations in this study show that fruit coated with coating formulations (K + to K6) tended to show smaller Lycopene upward trend on storage day 11 compared to the group without treatment (K-), indicating that rippening processes were slowed down. From the data presented in Figure 8, it is seen that all groups of cherry tomatoes experienced an increase in Lycopene. Based on the ANOVA results, the treatment in each group had a significant effect (sig.< 0.05) on Lycopene compound. The order of Lycopene increase from highest to lowest was K-, K+, K2, K1, K3, K4, K5, K6. This result was in line with the Color Test Result in Figure

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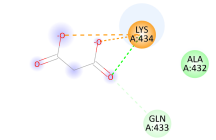
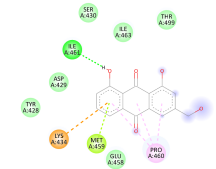
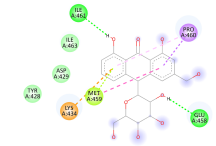
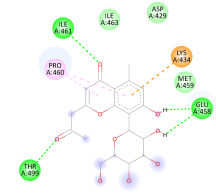
Table 3. Results of Aloe Vera Gel Compound Docking on 5JP1 (Binding Affinity, Visualization and Types of Bond)

Compound	Binding Energy (kcal/mol)	Inhibition Constant (mM)	Interaction	Types of Bond		
				Hydrogen	Van der Waals	Others
Malonat (Native Ligand)	-3.20	4.53		LYS A:434 GLN A:433	ALA A:433	LYS A:434
Streptomycin (Commercial Antibacterial)	-2.51	14.41		GLU A:458 ILE A:461 LYS A:434 THR A:499	ALA A:462 MET A:459 ILE A:463 HIS A:457 PRO A:460	ILE A:461
Aloe-emodin	-4.66	0.35		ILE A:461 MET A:431 ASP A:429 PRO A:460	MET A:459 ILE A:463 LYS A:434 GLN A:433	GLU A:458
Aloin	-4.18	0.57		GLU A:458 ASP A:429 LYS A:434 MET A:431	MET A:459 ILE A:463 PRO A:460 GLN A:433	ILE A:461

6. In detail, the highest Lycopene increase on the 11th day was shown in the tomato group that was not given coating (K-) which was 0,34%, while the lowest Lycopene increase with a value of 0,22% was K6 with NPCh+0.6 mL Mint EO treatment plus Aloe Vera Gel as a coating. Furthermore, the addition of Aloe Vera (K6) didn't have a significant effect on Lycopene detaining compared to K5 (NPCh+0.6 mL Mint EO only).

3.7 Organoleptic Texture Test Result

This test involved 10 panelists who were randomly selected to assess the texture of cherry tomatoes from each group. The texture level was given values ranging from 1 for the Softest to 5 indicating the Hardest. Figure 9 shows the distribution of

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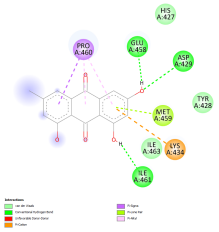
Compound	Binding Energy (kcal/mol)	Inhibition Constant (mM)	Interaction	Types of Bond		
				Hydrogen	Van der Waals	Others
Emodin	-5.76	0.06		GLU A:458 ILE A:461 MET A:431 GLN A:433	MET A:459 ASP A:429 LYS A:434 ILE A:463	PRO A:460

data from the organoleptic texture questionnaire.

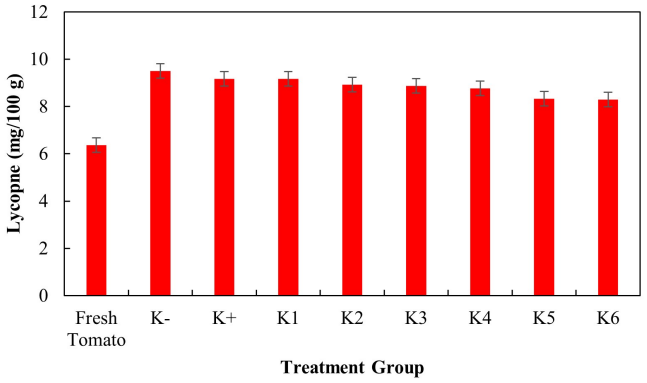


Figure 8. Lycopene Content in Fresh Cherry Tomatoes and in Cherry Tomato Treatment Samples after 11 Days of Storage. Data is presented with Standard Deviation Lines

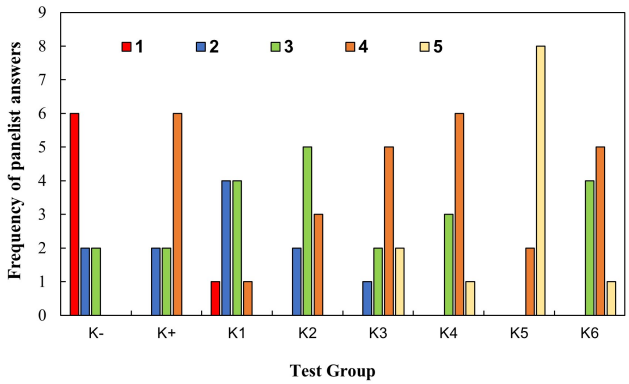


Figure 9. Panelist Response Diagram to Cherry Tomato Texture

In the organoleptic results of texture, most of respondents answered that the densest cherry tomato texture was group K5 with a value of 5, followed by groups K4 and K3, K6 and continued with K2, K +, K1 and K- (Figure 9.). This shows that the most preferred tomato texture is tomatoes with mint essential coating without aloe vera. Aloe vera gel as an additional coating gives the impression of a soft and wet texture on the surface of the tomato. In addition, in terms of appearance (Figure 5.), it is known that on the 7th and 11th days of storage cherry tomatoes without treatment (K-) began to show black spots suspected to be the result of the activity of *Xanthomonas campestris* bacteria or other microorganisms. Fruits that are overgrown with *Xanthomonas campestris* bacteria tend to experience a decrease in water content so that the texture quality will decrease, and the fruit will have sourer and rottener aroma. Meanwhile, in cherry tomatoes with coating or additives, these black spots were not found. This shows that the compound content in the additives and coating, both from mint essential oil and aloe vera gel, can act as an inhibitor of the cell wall protein of the bacteria *Xanthomonas campestris* and prevents the metabolism and growth of these bacteria in climacteric fruits such as cherry tomatoes.

3.8 Mint EO and Aloe Vera Antibacterial Activity In Silico

In silico test is conducted to determine the interaction between a molecule and a receptor protein. Interaction can be seen from the binding affinity value obtained between a compound ligand and a receptor. In this docking, the receptor protein used was 5JPI which was a *Xanthomonas campestris* protein that attacks tomatoes. Docking was carried out in the active area of the receptor which was first evaluated from the results of the native ligand docking of the receptor. The docking area was carried out at the protein coordinates x, y, and z which were 59.166, 18.924, -16.701, respectively. These coordinates were then applied to all mint and aloe vera essential compounds so that the compound docking point approached the original ligand docking point.

The compound ligand in mint essential oil and aloe vera that was docked to the 5JP1 protein were obtained from the results of GC-MS instrument. In mint essential oil, there were 5 major compounds namely isomenthone, p-menthone, (+)-menthol and (-)-menthol and neomenthol (Table 2). And in aloe vera, there were 4 major compounds namely: aloe-emodin,

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aloin, aloesin and emodin (Table 3)

In term of binding 5JPI protein with native ligands and Streptomycin (Table 2 & 3), which is used as a commonly used as antibacterial, the binding affinity values were -3.20 and -2.51 kcal/mol. Meanwhile, the amino acids bound to the native ligand were LYS A:434, GLN A:433 and those to Streptomycin were GLU A:458, ILE A:461, LYS A:434, THR A:499. In addition, the binding affinity value also affects the strength of the compound's bond in inhibiting the receptor protein. The more negative the binding value, the stronger the ligand is bound to the receptor, as well as the inhibition constant, where the inhibition constant shows the ability to inhibit the performance or interaction of the enzyme with the substrate, so that the smaller the value allows the maximal interaction of the active side of the ligand with the receptor and the strong bond (Taj and Chattopadhyay, 2024). Therefore, when examined from the binding affinity value and types of bonds, all compounds in mint (Table 2) and aloe vera (Table 3) essential oils had high effectiveness as inhibitors of 5JP1 proteins and its mechanism as an inhibitor of bacterial metabolism. Therefore, mint essential compounds (Table 2) and aloe vera gel compounds (Table 3) can be used as good candidates for antibacterial additives for *Xanthomonas campestris* in cherry tomato fruit coating in line with the application results.

4. CONCLUSIONS

To sum up, NPCh can be synthesized by an ionic gelation method by which the variation of chitosan: STPP 5:1 produces the smallest particle size distribution, so it is a good edible coating candidate. The addition of mint essential oil to NPCh formulation (K3-K5) can maintain the quality of cherry tomatoes for 11 days of storage significantly (sig< 0.05) compared to no treatment (K-) and NPCh alone (K2). Furthermore, the addition of aloe vera (K6) has no significant impact (sig> 0.05) on the quality of the coating, even the organoleptic texture test of group K5 (without aloe vera) tends to be preferred by panelists. In addition, the in-silico results of mint essential oil and aloe vera compounds show potential as antibacterial *Xanthomonas campestris* in terms of binding affinity values which are smaller than native ligands and positive controls. These in-silico results are also in line with the experimental results of application to cherry tomatoes.

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