Physicochemical Characteristics of Potato (*Solanum tuberosum* L.) after Chitosan Coating and Storage at Various Temperature

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ABSTRACT

Potato (*Solanum tuberosum* L.) plant is widely favored due to its versatility in various processed products, but perishable. This study aimed to determine the effect of chitosan coating and storage at various temperatures on the physiological and chemical characteristics of potato tubers. This research used 2 variables, namely the concentration of chitosan (0, 1, 1.5 and 2%) and storage temperatures of 0, 10 and 25°C. The parameters observed included tuber skin color, weight loss, hardness, the thickness of the chitosan layer and tissue penetration, oxygen levels, water content, starch degradation, reduced sugar content, and sprouting amount. Furthermore, data were analyzed using the Analysis of Variance (ANOVA) test. The results showed the effect of chitosan coating and storage temperature on weight loss, color, oxygen level, hardness, water content, starch degradation, and reduced sugar content in potato tubers during storage. The most effective treatment was 1.5% chitosan coating combined with a storage temperature of 10°C.

Keywords: Chitosan; low temperature; *Solanum tuberosum* L.; storage technology

INTRODUCTION

Potato (*Solanum tuberosum* L.) is a crop of significant economic value, with carbohydrate content that can serve as a substitute for other food crops. The crop has the potential to support Indonesia's food diversification efforts, which aim to strengthen national food security (Mulyono et al., 2018). Potato is in high demand, in both the public and industry due to its versatility as raw materials for making various types of nutritious foods. The quality standards of this crop are greatly influenced by post-harvest handling.

Potato damage, often resultedfrom improper storage, is largely driven by post-harvest processes such as respiration, transpiration, and tuber sprouting (Emragi et al., 2022). This damage leads to shrinkage, affecting both material weight and nutritional value. The application of edible coating, such as chitosan offers a potential solution for enhancing the level of potato freshness. This material is environmentally friendly, edible, and can function in preventing the growth of pathogenic microorganisms (Kinasih et al., 2019).

Low storage temperatures are known to extend shelf life by preserving ingredient freshness through cooling (Asgar & Rahayu, 2014). By regulating storage temperature, damage from respiration and transpiration can be prevented. However, publications on combining chitosan coating with low-temperature storage to

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extend the shelf life of potato remain limited. This study was conducted to determine the effect of the two treatments by observing the physiological and biochemical characteristics of potato.

METHODS

Materials

The materials used were potato tubers of the Granola variety, sourced from a garden in Kopeng, Salatiga. The tubers were selected at 115 days after planting, with uniform maturity and weight ranging from 50-100 g. Subsequently, the harvested crop was washed with water and dried. The chemicals used were distilled water, Nelson's reagent, arsenomolybdate reagent, chitosan (E Merck), and 1% acetic acid. The tools used were Munsell Color Charts for Plant Tissues, magnetic stirrer, Thermo Scientific laboratory refrigerator, UV-Vis spectrophotometer (Hitachi UH 5300), cup, analytical balance (Mettler Toledo), penetrometer (Takemura type RHM-1), DO (Dissolved Oxygen) meter (Lutron 5510), microscope (E Clipe 600 Nikon), oven (ESCO), measuring flask (Iwaki), i*ncubator shaker* (Thermo), *vortex mixer*, Erlenmeyer flask (Pyrex), and micropipette (Eppendorf).

Study Design

This study adopted a two-factor Completely Randomized Design (CRD). The first factor, chitosan concentration, was tested at 4 levels (0, 1, 1.5, and 2%), while the second factor, storage temperature, was tested at 3 levels (0, 10, and 25 °C). This design led to 12 treatment combinations with three replications. Data were analyzed using *Analysis of Variance* (ANOVA), followed by Duncan's test for further comparison where significant differences were identified.

Experimental Procedure

Chitosan layers were prepared at concentrations of 0, 1, 1.5, and 2% by dissolving 1, 1.5, and 2 g in 100 mL of chitosan powder in 1% acetic acid, followed by filtration. The solution was homogenized using a magnetic stirrer for 15 minutes. The samples were put into the solution, drained, and stored at 3 different temperatures. Weight loss measurements were conducted every 3 days (Mudyantini et al., 2023), color was assessed weekly, and O_2 K levels were measured every 6 hours for 14 days. Oxygen levels were monitored by placing the potato tubers into jars, each containing 500-600 g of the sorted samples, and using a DO meter to perform the required measurement (Mudyantini et al., 2023). To determine water content, a porcelain cup was first put in a 100-105 °C oven for 30 minutes, then cooled and weighed (A). A 2 g sample was placed in a dry cup (B). and heated in a 100-105 °C oven for 5-6 hours. After cooling, the cup was weighed until a constant weight was obtained (C) (AOAC, 2005).

The calculation of the amount of corroded starch was conducted by pricking the potato with a toothpick. The sample fluid was observed under a microscope (Dhital et al., 2011), and the amount of corroded starch was calculated using the ImageJ application. Subsequently, the number of shoots was determined from the first day of appearance and counted until the last day of observation. Changes in potato color were observed by matching with the Munsell Color Charts and documented.

Reducing sugar levels were measured using the spectrophotometric method (Amjad et al., 2019). A sample of 5 g was mashed, mixed with distilled water to the 50 mL mark, transferred into an Erlenmeyer flask, homogenized for 1 hour, and filtered. Approximately 1 mL of the filtrate was collected, mixed with 1 mL of Nelson's reagent, and heated for 20 minutes. Subsequently, the sample was cooled to room temperature, 1 mL of arsenomolybdate reagent was added, and homogenized. A total of 7 mL of distilled water was added to the mixture and homogenized again. Finally, analysis was conducted by measuring the absorbance value at a wavelength of 540 nm.

RESULTS AND DISCUSSION

Weight Loss

The analysis result showed that chitosan concentration, storage temperature, and the interaction of both affected the weight loss of potato. Figure 1 shows that the wet weight of potato with chitosan coating treatment experienced a smaller increase. In this study, 2% chitosan treatment produced the smallest value of 42.12 g. The largest wet weight value of 56.89 g was produced by potato with 1.5% treatment.

Perkasa et al. (2021) stated that chitosan coating on curly red chilies reduced weight loss during 20 days of storage. The provision of chitosan coating reduced water loss, reduced fruit weight loss, delayed changes in internal quality, and maintained fruit quality. Meindrawan et al. (2017) stated that the presence of coating on the fruit decreased the rate of water vapor transmission. According to Hilma at el. (2018), high transpiration processes caused increased weight loss.

The highest weight loss in the treatment with 2% chitosan coating at 0 °C was attributed to the formation of an excessively thick layer. Consequently, penetration into the tissue was prevented, leading to peeling or

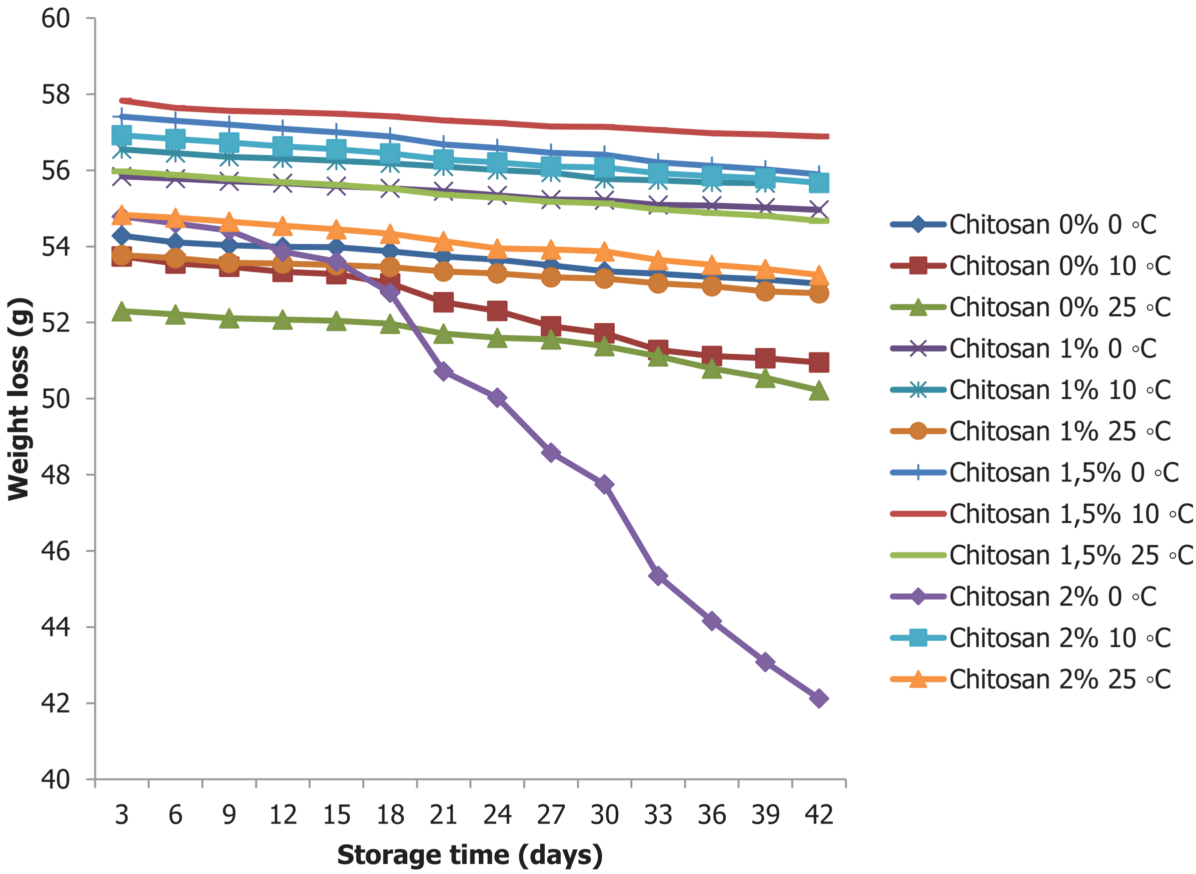

Figure 1. Wet weight (g) of potato after chitosan coating and variations in storage temperature

breaking of the layer. This exposed the skin to low temperatures, causing rapid water loss from the cells. The high concentration of 2% chitosan contributes to a thicker layer on the skin surface, making penetration into the intercellular spaces difficult and leading to greater accumulation. At 0 °C, water, serving as a solvent for chitosan, was extracted. This is in line with the study conducted by Mudyantini et al. (year) on coating sapodilla with 2% chitosan stored at a temperature of 0 °C. The peeling increased respiration activity in potato. The increase in weight loss at 0 °C was caused by the extraction of water from the tissue due to low humidity in the refrigerator. Potato can freeze, and the ice crystals that form lead to tissue damage. The thawing process occurs when frozen food is removed from the low-temperature storage space. This is followed by increased enzyme activity which supports the growth of microbes (Sudjatha & Wisaniyasa, 2017).

Figure 1 shows that potato with storage temperature treatments of 0 and 10 °C experienced a smaller increase in weight loss when compared to room temperature of 25 °C. The treatment of 10°C had a better prevention effect on weight loss. Storing potato at 10 C for 6 days can reduce the lowest weight loss by 2.82% compared to other treatments (Asgar & Rahayu, 2014). According to Saputri et al. (2019), cold storage also effectively minimized weight loss in cauliflower. The lowest average weight loss was observed after 20 hours at a temperature of 8±1 °C. A relatively good storage temperature for horticultural products was 6-10 °C. The rate of decline in vegetable quality can be inhibited by storage at low temperatures.

Color

Potato color can signify the level of ripeness and freshness. During the post-harvest storage, the development process continued and was marked by changes in color due to respiration and transpiration. Color changes can be used as a parameter for quality degradation.

Table 1 shows that the color of the potato treated with chitosan was brighter. The samples treated with and without chitosan, produced values of 5Y (7/8) and 5Y (7/6) and 5Y (7/8) on day 0, respectively. After 49 days of storage, the color of the untreated samples did not change, while the potato treated with chitosan

Table 1. Average color changes of potato after chitosan coating at various storage temperature variations

Chitosan (%) \ Temperature (°C)	0 °C	10 °C	25 °C
0%	5Y 7/6	5Y 7/6	5Y 7/6
1%	5Y 7/8	5Y 7/8	5Y 7/8
1.5%	5Y 7/8	5Y 7/8	5Y 7/8
2%	5Y 6/8	5Y 7/8	5Y 7/8

coating changed to 5Y (6/8) at 2%. This showed that the material produced better color brightness. A study conducted by Purbasari & Karuniasari (2022) stated that edible coating treatment of carrageenan and glycerol inhibited color changes in guava during storage. The treatment prevented the increase in the respiration rate, hence, chlorophyll degradation and carotenoid formation were low. The edible coating offers several advantages, including a shiny surface, inhibition of the oxidation process, and enhanced product appearance (Parreidt et al., 2018).

The color of potato treated with 2% chitosan changed to brownish, possibly due to the excessively thick layer that peeled off easily, allowing the penetration of oxygen. The peeling of chitosan layer increased respiration activity in potato. The loss of water in fruits and vegetables leads to decreased turgor at the cellular level, which can cause wilting and softening of the texture (Asiah et al., 2020). Potato coated with 2% chitosan at 0°C experienced a decrease in quality, evidenced by the appearance of brownish spots, a softened texture, an unpleasant odor, and wrinkled skin.

Oxygen Level

The analysis results showed that the concentration of chitosan and variations in storage temperature, as well as the interaction of these factors, affected the oxygen content of potato. According to Figure 2, the oxygen content in all treatments decreased during storage. The percentage oxygen content in potato treated with 2% chitosan coating was higher. This treatment optimally suppressed respiration rate compared to 1% and 1.5% chitosan.

Coating treatment functioned as a barrier or separator between the fruit surface and the open air, leading to a low oxygen binding which minimized respiration rate. The study by Agustina et al. (2015) stated that the edible coating formed a selective barrier to inhibit the respiration rate. The percentages of oxygen content in potato at 0 and 25 °C were 0.33% and 10.56%, respectively. At 0 °C, the sample effectively suppressed the respiration rate compared to 10 °C and 25 °C. Low-temperature storage was discovered to slow down the respiration process (Rahmadhanni et al., 2020). Enzyme activity that plays a role in respiration was inhibited under low-temperature conditions. The oxygen content of potato at 25 °C is lower due to the faster respiration process, leading to the rapid release of oxygen (Mutia, 2019).

Layer Thickness and Penetration into Tissue

The analysis results showed that chitosan concentration affected layer thickness and penetration into the tissue. Layer thickness influenced the rate of water vapor and gas transmission from the edible coating. Based on Table 2, the concentration of chitosan was directly proportional to the thickness of the edible coating, and inversely proportional to the penetration into the tissue.

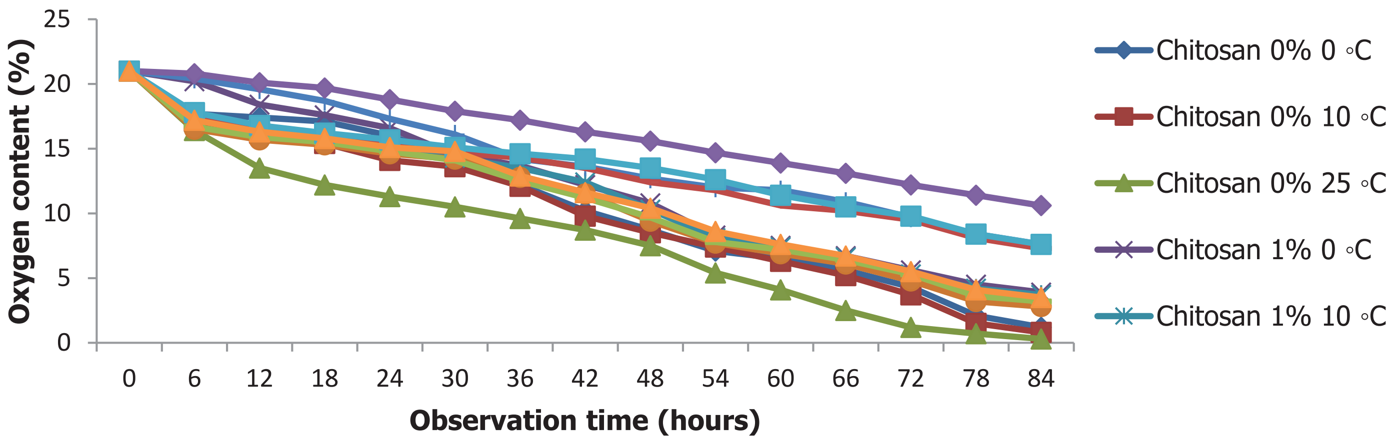

Figure 2. Oxygen content (%) of potato after chitosan coating at various storage temperature variations

Table 2. Layer thickness (µm) and penetration (µm) into potato tissue after chitosan coating at various storage temperatures

Chitosan concentration (%)	Thickness (µm)	Penetration (µm)
1	2.12 ± 0,494^{c}	5.96 ± 1.535^{a}
1.5	3.50 ± 0,495^{ab}	4.81 ± 0.815^{a}
2	4.76 ± 1,240^{a}	1.94 ± 0.696^{b}

Description: Numbers followed by the same letter in the same column indicate no significant difference based on the 5% DMRT test.

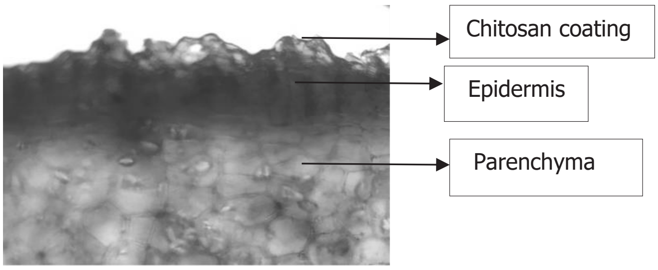

Figure 3. Cross-section of potato tuber skin coated with chitosan (magnification 400X)

At concentrations of 2%, the chitosan layer had the highest thickness values at 4.76 µm, but with the lowest solution penetrations of 1.94 µm. At a concentration of 1%, the layer is thinnest at 2.12 µm, with the highest penetration of 5.96 µm. The optimal concentration for balancing layer thickness and tissue penetration was 1.5%. The study by Mudyantini et al. (2017) stated that at 4% chitosan solution produced high viscosity and low penetration, and a layer of sapodilla stored at 5 °C, was peeled off. According to Nairfana and Ramdhani (2021), increased concentration of chitosan led to a thicker *edible film* due to higher solid content in the solution. As the concentration rose, more solid deposits were formed, and the resulting film was thicker after evaporation (Mustapa et al., 2017).

Hardness

Hardness was measured using a Hand Penetrometer. Data analysis showed that the concentration of chitosan, storage temperature, and the interaction of both affected the hardness of the potato. Based on Table 3, potato treated with chitosan and stored at a low temperature had higher hardness than the untreated sample at room temperature. However, an exception was observed in potato coated with 2% and stored at 0 °C, which did not follow this trend.

Table 3. Hardness (kg/mm^2) of potato after chitosan coating at various storage temperatures

Chitosan (%) \ Temperature (°C)	0 °C	10 °C	25 °C
0%	0.12^{e}	0.14^{d}	0.12^{e}
1%	0.17^{bc}	0.17^{bc}	0.14^{de}
1.5%	0.19^{b}	0.17^{bc}	0.16^{cd}
2%	0.08^{f}	0.22^{a}	0.18^{bc}

Description: Numbers followed by the same letter in the same column show no significant difference based on the 5% DMRT test.

The 2% chitosan-coated potato had the lowest and highest hardness values at 0.08 kg/mm^2 and 0.22 kg/mm^2, respectively. This treatment showed the most significant improvement in hardness compared to 1% and 1.5%. The study conducted by Sanaa et al. (2017) stated that the level of hardness of taro tubers was maintained alongside the increasing concentration of the coating material. This led to a higher level of hardness compared to the control sample. The slowing down of softening can be caused by inhibition of hydrolase enzyme formation in the cell wall, which helps maintain membrane stability and reduce hardness (Wang & Willey, 2000). Chitosan coating can slow down metabolism and enzymatic activity, thereby inhibiting the degradation process of components in the fruit (Kumar et al., 2017).

Potato stored at a low temperature had higher hardness compared to room temperature. However, an exception was observed in the sample coated with 2% chitosan at 0 °C, as it experienced decreased hardness due to a thick layer. At storage of 10 °C, the greatest increase in hardness was detected. Low temperatures reduce the respiration and metabolism processes, thereby slowing the loss of hardness during storage (Brizzolara et al., 2020). Respiration and transpiration activities contribute to changes in fruit texture from hard to soft. Water loss leads to decreased cellular turgor at the cellular level, resulting in losses such as wilting and softening of the texture (Asiah et al., 2020).

Water Content

The analysis showed that chitosan concentration, storage temperature, and the interaction of both affected the water content of potato. Based on Figure 4, the water content of the treated sample increased compared to the untreated counterpart, with an exception for potato coated with 2% chitosan at 0 °C.

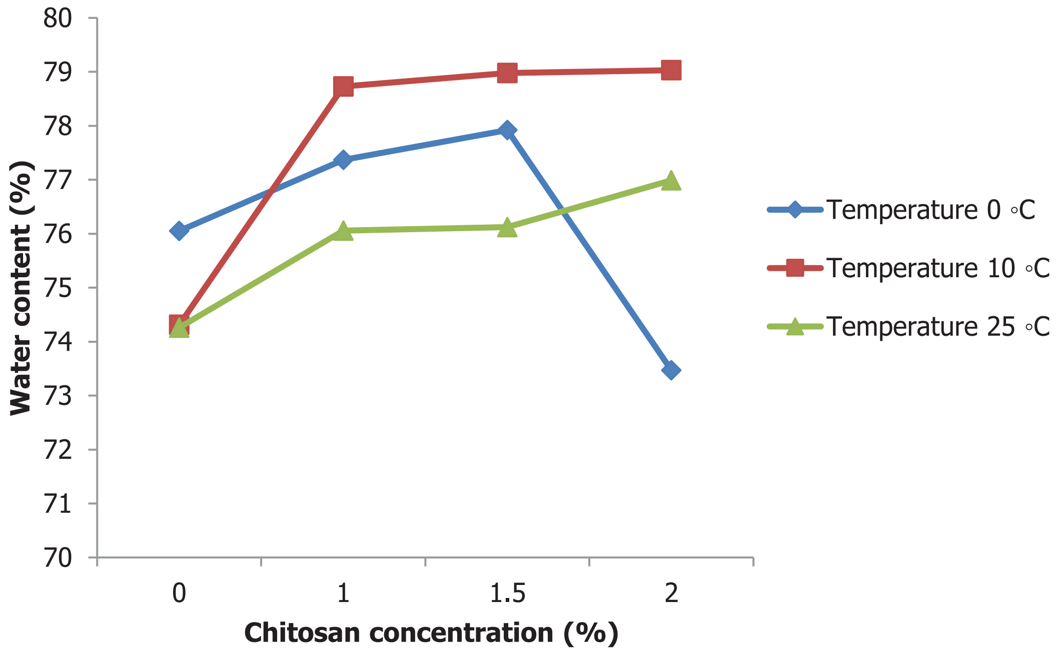

Figure 4. Water content (%) of potato after chitosan coating at various storage temperature variations

Water content of potato coated with 2% chitosan was the lowest value at 73.47%, while the highest was observed to be 79.03% in the sample treated with 2% chitosan. This treatment featured the highest water content due to the formation of the thickest layer. However, the coating began to peel off after a prolonged storage period. The potato treated with chitosan had lower rates of respiration and transpiration compared to the untreated sample. The study by Nawab et al. (2017) stated that edible coating formed a layer on the surface of the product, thereby inhibiting water loss. The coating layer covered the lenticels and cuticles on the fruit, preventing an increase in the rate of respiration and water release.

The potato subjected to low-temperature treatment had increased water content compared to room temperature, except for the sample coated with 2% chitosan coating at 0 °C. The optimal water content was observed during the 10 °C storage compared to 0 °C and 25 °C. This observation was in line with the study conducted by Siahaan et al. (2020) where garlic stored at 12-14 °C better retained its water content. However, a temperature below 7 °C led to chilling injury (Nugraeni et al., 2020). Cooling slows down metabolic reactions but at 0 °C, freezing occurs, leading to the formation of ice crystals and subsequent tissue damage. According to Sujatha & Wisaniyasa, 2017, the thawing process, which occurred when frozen food was removed from the storage space, triggered increased enzyme activity and supported microbial growth.

The Number of Corroded Starch

Based on the analysis results, only the concentration of chitosan affected the amount of corroded starch. Table 4 shows that potato treated with chitosan at low temperatures produced less corroded starch than the untreated sample at room temperature. However, an exception was observed in the 2% chitosan treatment at 0 °C.

Table 4 shows that starch corrosion was inhibited by increasing chitosan concentration. Chitosan coating treatment of 1%, 1.5%, and 2% concentrations led to a decrease in corroded starch compared to untreated

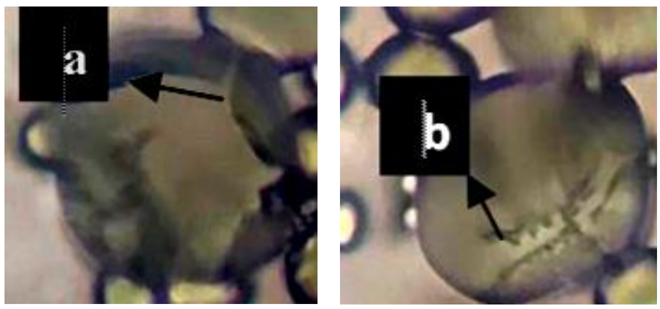

Figure 5. Potato starch (Source: study results). Description: a. *exocorrosion*; b. *endocorrosion*

Table 4. The amount of starch that experienced corrosion of potato after chitosan coating at various storage temperatures

Chitosan (%) \ Temperature (°C)	0 °C	10 °C	25 °C
0%	15[cd]	16[bc]	19[b]
1%	9[ghi]	12[def]	14[cde]
1.5%	9[hi]	10[fgh]	12[efg]
2%	26[a]	7[i]	10[fghi]

Description: Numbers followed by the same letter in the same column indicate no significant difference based on the 5% DMRT test.

samples. At 2% chitosan, the lowest corrosion value of 7 was observed. The highest amount of corroded starch in this treatment was 26.

Chitosan concentration is inversely proportional to starch corrosion. Diao et al. (2017) stated that high chitosan concentrations led to stronger particle bonds between chitosan and starch granules, with a binding strength of up to 6 times greater than the control. This binding strength reduces the potential for swelling in the granules. It was important to acknowledge that chitosan formed a semipermeable layer or barrier surrounding the fruit surface. The interior atmosphere was changed by decreasing oxygen or increasing carbon dioxide levels. This reduced fruit respiration and metabolic activity and slowed the rate of fruit ripening and aging (Ali et al., 2010; Gol et al., 2015).

Reducing Sugar Level

Based on the results of the data analysis, only chitosan concentration affected the reduced sugar level. Figure 6 shows that potato treated with chitosan at low temperatures had lower sugar levels than the sample without chitosan at room temperature. An exception was observed in potato treated with 2% chitosan at 0 °C, which did not follow the trend.

Figure 6 shows that the reduced sugar content decreased with increasing chitosan concentration. The content in potato coated with 2% chitosan was the lowest at 4.08%, while the highest value produced by this treatment was 12.62%. At 2% chitosan, an increase in the reduced sugar content was prevented effectively compared to 1% and 1.5%.

Parvin et al. (2023) stated that chitosan coating on mango produced lower sugar content compared to the uncoated counterpart. The presence of a chitosan layer on the surface of the fruit closed the pores of the surface, thereby reducing respiration rate and metabolic activity. The coating treatment delayed ripening and aging, and reduced the sugar content due to slow starch conversion (Anjum et al., 2020).

The reduced sugar content of potato stored at 25 °C increased due to the rapid respiration rate, which accelerated the hydrolysis of carbohydrates into sugar. At 0 °C, the content was highest because the tubers experienced chilling injury signified by the formation of ice on the skin surface. This causes the potato to

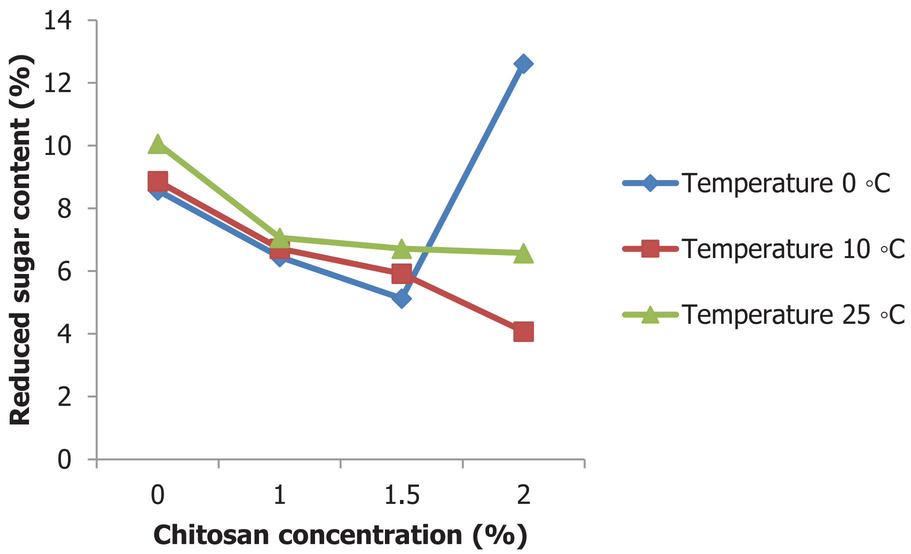

Figure 6. Reducing sugar content (%) of potato after chitosan coating at various storage temperatures

retain water when removed from storage, speeding up the carbohydrate hydrolysis process. It was important to acknowledge that at 25 °C shoots were developed. The respiration rate affected the process of converting starch into simple sugars (Tyas et al., 2023).

Number of Shoots

Potato has a dormancy period during which shoot growth occurs gradually. Shoots began to appear on the 33rd day of storage without chitosan coating treatment at a temperature of 25 °C, and over time tended to increase (Alfiani, 2019).

Potato without chitosan coating (0%) at a temperature of 25 °C stored for 48 days had the largest and highest number of shoots of 3 per tuber. According to Olsen and Hornbacher (2002), at a high temperature, the dormancy period of the potato was shortened. Storage at 2 °C as well as 18 to 25 °C, was observed to damage and accelerate shoot growth, respectively (Nonnecke, 1989).

During low-temperature storage, respiration activity decreased but respiration rate increased at room temperature. The observation results showed a decrease in sucrose with increased storage temperature. Respiration is a catabolic process to obtain the energy needed for life processes. This process was observed to increase at a high temperature. A standard reference for using potato as a raw material for consumption is the development of shoots. The development of increasingly taller and larger numbers of shoots signified a process of chemical changes, hence, the quality of the nutritional content in the tuber was decreased (Purnomo et al., 2014).

CONCLUSION

In conclusion, as chitosan concentration increased, the respiration rate decreased, which led to reduced weight loss, lower sugar content, water content, and decreased oxygen content levels, while tuber hardness increased. However, a 2% concentration, caused the chitosan layer to peel off. Lower storage temperatures also reduced the respiration rate, helping to limit weight loss, maintain water and oxygen content, and enhance tuber hardness. The most effective treatment was considered to be 1.5% chitosan concentration combined with a storage temperature of 10 °C over 49 days.

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CONFLICT OF INTEREST

The authors declare no conflict of interest with other parties.

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