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Chitosan coating and packaging to maintain the physical quality of beet tubers

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ABSTRACT

Beet tubers are perishable horticultural commodities, cannot be stored for long, and are commonly consumed in fresh conditions. Postharvest handling of beet tubers needs to be carried out to maintain their freshness Chitosan and other packaging used in postharvest handling of fresh beet tubers have not yet been reported. This study aims to determine the effect of chitosan coating and types of packaging on beet tubers on the physical quality of beet tubers. The study was a randomly designed group with two factors; the first factor was chitosan concentration, and the second factor was the kinds of packaging. Chitosan concentration consists of 5 levels, namely 0, 0.5%, 1%, 1.5%, and 2%, and the type of packaging includes no packaging (Without), plastic packaging with holes (Perforated), ordinary plastic packaging (Ordinary) and plastic vacuumed (Vacuum). The beet tubers were soaked in chitosan solution of 0, 0.5%, 1%, 1.5%, and 2% for 1 minute, air-dried, then were packaged with no packaging, plastic packaging with holes, ordinary plastic packaging, and plastic vacuumed. . The physical quality parameters observed were moisture content, weight loss respiration rate,electrolyte leakage, total dissolved solid (TDS), ascorbic acid, betacyanin, betaxanthins, tuber firmness, damage percentage, and visual quality rating (VQR). Data were analyzed using Anova variant analysis and then continued with Tuckey tests with a 95% confidence level using R studio software. The results showed that chitosan coating did not affect the physical quality of beet tubers, while packaging affected the quality of beet tubers. The most suitable packaging to maintain the physical quality of beet tubers is plastic packaging with holes (perforated).

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INTRODUCTION

Beet tubers are one of the essential functional foods because they have bioactive content that is beneficial for health (Bucur et al. 2016). Beetroot also has antioxidant properties (Bucur et al. 2016), anticancer and antimicrobial (Jovanovic et al. 2016, El-Beltagi et al. 2018) , natural dye (Attia et al. 2013), sweetener, and antihypertensive because it can lower blood pressure (Dewi and Astriana 2019). Beet tubers have the potential to be used as a companion sweetener to sugarcane; in Europe, sugar beet is a sugar-producing crop after sugar cane.

Beet tubers are classified as perishable horticultural products that cannot be stored for long. Beet tubers, after harvesting, are still living tissue with a high water content (80-90%), so during the process of movement and storage, there is a potential to experience a decrease in quality due to water loss/transpiration and metabolic activity from the respiration process. Transpiration causes water loss in beet tubers, causing wrinkled tubers and weight loss. Respiration causes changes in the physical structure and chemical composition of beet tubers, so the tubers become soft and juicy. This change in the quality of beet tubers depends on the rate of transpiration and respiration.

Chitosan is an edible coating that effectively improves the quality of mango fruit (Abbasi et al. 2009). Applying chitosan 1% on strawberries reduces weight loss, inhibits aging, and enhances the quality and shelf life of fruits (Benhabiles et al. 2013). Application of chitosan coating on plums maintains fruit firmness, slows down weight loss, suppresses respiration rate, inhibits metabolic, enzymatic activity and degradation of cell wall components (Kumar et al. 2017).

Fruit and vegetable packaging aims to extend shelf life, retain natural color, texture, aroma, and nutrients, reduce water loss and prevent wilting. Many kinds of packaging materials are used for packaging fruits and vegetables, including plastic packaging, cardboard packaging, and paper packaging. Various plastic packaging methods used in fresh fruits and vegetables include vacuum packaging, ordinary plastic packaging, and plastic packaging with perforation holes. Plastic packaging on pears can extend shelf life, reduce weight loss and spoilage, and maintain fruit hardness during storage (Nath et al. 2012). Packaging tomatoes using plastic bags can reduce weight loss, disease incidence and extend shelf life (Sinha et al. 2019).

Postharvest handling strategies of beet tubers are essential to maintain the freshness of horticultural products. Postharvest handling methods that can be done to prevent water loss in beet tubers include using chitosan coating and packaging using plastic. Research on beet tuber postharvest has not been widely done, especially chitosan coating and various packaging on beet tubers has never been done. Therefore, this study aims to determine the effect of chitosan coating and multiple types of packaging on beet tubers on the physical quality of beet tubers.

METHODS

The material used in this research was beet tubers of the Boro Bit variety with the trademark Ayumi 04 from PT Agrosid Manunggal Sentosa, the result of planting owned by farmers in Kiyudan Hamlet, Ketundan Village, District, Magelang Regency, Indonesia. Other materials used include chitosan powder, distilled water, and vacuum plastic. Tools used vacuum sealer machines, scales ACIS AD-I series, ovens Memmert UN30, gas analyzers Gasin-DH JD200, spectrophotometers UV-VIS genesys 10S, hand pocket refractometers merk Atago, penetrometers Barreis Prufgeratebau GmbH type BS 61 II, EC meters (electrical conductivity meters) portable merk Hanna, beakers, and pipettes.

This research used a Randomized Complete Block Design with two factors, the first was chitosan concentration, and the second was the kinds of packaging consisting of 20 treatment combinations with three blocks as repeats. Chitosan concentration consists of 5 levels, namely 0, 0.5%, 1%, 1.5%, and 2%, and the type of packaging includes no packaging (without), plastic packaging with holes (perforated), ordinary plastic packaging (ordinary) and plastic vacuumed (vacuumed).

The samples of beet tubers were cleaned and washed using clean water and then dried. Chitosan solution was obtained by dissolving chitosan powder (according to concentration) in aquades with a heating temperature of 40-50^{o}C (warm) and by stirring using a magnetic stirrer. A chitosan solution concentration of 0.5% was obtained by dissolving 0.5 grams of chitosan powder into 100 ml of aquades, a concentration of 1% by dissolving 1 gram of chitosan powder into 100 ml of aquades, 1.5% was obtained by dissolving 1.5 grams of chitosan powder into 100 ml of aquades, and a concentration of 2% was obtained by dissolving 2 grams of chitosan powder into 100 ml. The sample was dipped in chitosan solution according to each concentration for 1 minute and then dried. Beet tubers were inserted into the plastic (plastic dimensions 16 × 25 cm, thickness 0.1 mm), and the air in the plastic was removed using a vacuum sealer or according to treatment. Beet tubers were then stored at room temperature.

The moisture content of beet tubers was determined using the thermogravimetric method (drying in the oven) at a temperature of 60°C to constant weight (48 hours). Moisture content was determined by the Equation (1).

$$\begin{matrix} Moisture \\ content \end{matrix} = \frac{w1 - w2}{w1 - w0} \times 100\% \tag{1}$$

Note:
w0 = weight of oven cup
w1 = weight of oven cup + sample while wet
w2= weight of oven cup + sample while dry

The determination of weight loss involved weighing beet tubers using analytical scales and recording the weight loss. The weight loss was calculated using the method of weighing the initial weight and weight at the time of observation. Weight loss was determined by the Equation (2).

$$weight\ loss = \frac{x - y}{x} \times 100\% \tag{2}$$

Note:
x = initial weight
y = weight at the time of measurement

The respiration rate was measured by calculating the level of CO_2 produced using a gas analyzer with the brand Gasin-DH JD200. Beet tuber is put into a jar and, after 24 hours, calculated using a gas analyzer. CO_2 production was expressed in mgkg^{-1} tubers hour^{-1} using the Equation (3) – (4).

$$\begin{matrix} \text{Sample } \mathrm{CO_2} \\ \text{concentration (\%)} \end{matrix} = \begin{bmatrix} \mathrm{CO_2} \\ \text{concentration b} \end{bmatrix} - \begin{bmatrix} \mathrm{CO_2} \\ \text{concentration a} \end{bmatrix} \tag{3}$$

$$\begin{matrix} Respiration\ rate \\ mgCO_2\ kg^{-1}h^{-1} \end{matrix} = \frac{\%CO_2 \times \text{VAS}}{\begin{matrix} weight \\ sample \end{matrix} \times \begin{matrix} incubation \\ time \end{matrix}} \times \frac{44}{24} \tag{4}$$

Note:
A = CO_2 concentration in jars without fruit
B = CO_2 concentration in a jar of fruit
% CO2 = up to CO_2 (%)
44 = weight of molekul CO_2 (g mol^{-1})
VAS = *Volume Air Space* (ml)
24 = volume CO_2 at measurement temperature (ml)

Electrolyte leakage was determined by the method (Moradinezhad et al. 2019), disc-shaped pieces of beet peel with a diameter of 2.5 cm were taken from the tubers of each treatment and placed in 20 ml of deionized water at room temperature for 24 hours. Conductivity was measured using conductivity meter tools (C1). The same pieces of beet tuber were kept in a boiling water bath of 100°C for 1 hour to remove all electrolytes, then cooled at room temperature and conductivity was measured (C2). Electrolyte leakage was calculated using the Equation (5).

$$\text{Electrolyte leakage} = \frac{C1}{C2} \times 100\% \tag{5}$$

Total dissolved solids were measured using a 0-53° Brix digital refractometer (hand pocket refractometers merk Atago). Beetroot juice dripped onto the refractometer field, and then the start button was pressed to read the Brix value.

Determination of vitamin C followed the method carried out by (Vitara 2021) with modifications, extract 2.5 grams of sample with 50 ml of distilled water. The filtrate was diluted 10 times. The solution was measured using a UV-VIS spectrophotometer at 266 nm (Mulyani 2017) with distilled water as the blank.

Determination of betacyanin and betaxanthins levels followed the (Nistor et al. 2017) method with slight modifications. One gram of ground sample was extracted in 10 ml of 50% ethanol. The mixture was shaken at 450 rpm for 20 minutes and then centrifuged at 4500 rpm for 20 minutes. 1 ml of the resulting filtrate was mixed with 3 ml of distilled water. The absorbance of the solution was measured using a UV-Vis spectrophotometer at 540 nm for betacyanin and 480 nm for betaxanthin.

The firmness of the beet tuber was determined using the pnetrometer Barreis Prufgeratebau GmbH type BS 61 II. The beet tubers are placed on a penetrometer disk, and the hardness value of the tuber flesh is read on penetrometer scale.

The percentage of damage was calculated by counting the number of damaged/rotten fruits divided by the number of samples of healthy beet tubers and multiplied by 100%.

Visual quality rating (VQR) was determined by the scoring method with the highest value of 9, namely the condition of the beet tuber was still fresh without defects, and the lowest value was 0, namely the beet tuber had 100% damage.

Data analysis using the Anova univariate diversity analysis method followed by a Tuckey test with a confidence level of 95% to determine the level of difference in values between treatments using R studio software.

RESULTS AND DISCUSSION

The water content of week two tends to be higher than week three's (Table 1, Table 2). Chitosan coating did not affect the water content of beet tubers during storage (Table 1). Packaging could maintain the moisture content of tubers to remain high (Table 2). However, the use of perforated plastic results in tubers' moisture content being higher than without packaging and comparable to vacuum-sealed plastic.

Beet tubers had higher weight loss in week three compared to week two (Table 1, Table 2). Chitosan coating did not influence the weight loss of beet tubers during storage (Table 1). Packaging could reduce the weight loss of beet tubers during storage. Using ordinary plastic or plastic vacuumed-on, beet tubers reduced weight loss smaller than perforated plastic (Table 2).

Chitosan coating did not affect the respiration rate (Table 3). The use of packaging could reduce the respiration rate in the 3rd week (Table 4). However, using ordinary plastic packaging results in the respiration rate of beet tubers being no different from vacuumed. The use of perforated packaging had a lowers respiration rate until the 3rd week of storage. The respiration rate of without packaging (196,8%) and perforated (90,5%) beet tubers increased from week 2 to week 3, whereas in ordinary packaging (-35%) and vacuum packaging (-49,4%), it decreased.

The chitosan coating showed no effect on electrolyte leakage in weeks 2 or 3 (Table 3). However, the type of packaging had an impact on electrolyte leakage in weeks 2 and 3 (Table 4). During storage up to the 3rd week, the use of perforated plastic packaging resulted in the lowest electrolyte leakage.

The chitosan coating showed no effect on total dissolved solids (Table 5). The type of packaging influenced the total dissolved solids (Table 6). The total dissolved solids in unpackaged beet tubers increased in the third week, while in packaged beet tubers, there was a tendency to decrease. Chitosan coating had no effect on vitamin C in week 2 or week 3 (Table 5). The use of packaging in week 2 and week 3 affected vitamin C levels (Table 6).

Chitosan coating had no effect on betacyanin and betaxanthins in week 2 or week 3 (Table 4). The use of packaging in week 3 affected betacyanin and betaxanthins levels. The more tightly sealed the packaging used, the decrease in betacyanin and betaxanthins levels observed in week 3 of storage.

Tabel 1 Water content and weight loss with chitosan coating treatment

Concentration	Moisture content (%)		Weight loss (%)	
	Week 2	Week 3	Week 2	Week 3
Without	91.09	85.09	18.87	22.62
0,5%	89.98	86.60	15.53	22.64
1 %	91.73	86.47	15.86	20.69
1,5%	90.45	86.97	16.07	21.81
2 %	90.76	85.43	14.66	22.53

Tabel 2 Water content and weight loss with packaging treatment

Treatment	Moisture content (%)		Weight loss (%)	
	Week 2	Week 3	Week 2	Week 3
Without	88.30 b	81.43 c	33.45 b	51.71 c
Perforated	90.52 ab	85.98 b	13.56 a	19.27 b
Ordinary	92.11 a	89.32 a	8.39 a	8.78 a
Vacuumed	92.29 a	87.72 ab	7.39 a	8.47 a

Note: Values within the same column followed by different letters were significantly different at HSD 5%; Without = without packaging; Perforated = plastic packaging with holes; Ordinary = ordinary plastic packaging without vacuum or perforated; Vacuumed = vacuum packaging.

Tabel 3 Respiration rate and electrolyte leakage with chitosan coating treatment

Concentration	Respiration rate (mg CO2 $kg^{-1}hour^{-1}$)		Electrolyte leakage (%)	
	Week 2	Week 3	Week 2	Week 3
Without	27.16	18.26	62.12	69.66
0,5%	27.11	25.95	55.25	68.68
1 %	32.35	38.11	59.58	62.40
1,5%	25.75	30.36	60.05	60.18
2 %	26.32	30.31	65.33	78.24

Tabel 4 Respiration rate and electrolyte leakage with packaging treatment

Treatment	Respiration rate (mg CO2 $kg^{-1}hour^{-1}$)		Electrolyte leakage (%)	
	Week 2	Week 3	Week 2	Week 3
Without	16.06 a	47.67 c	42.11 a	78.58 b
Perforated	9.73 a	18.54 a	55.43 ab	43.68 a
Ordinary	36.31 b	23.46 b	69.25 b	73.45 b
Vacuumed	48.85 b	24.73 b	75.08 b	75.63 b

Note: Values within the same column followed by different letters were significantly different at HSD 5%; Without = without packaging; Perforated = plastic packaging with holes; Ordinary = ordinary plastic packaging without vacuum or perforated; Vacuumed = vacuum packaging.

Tabel 5 Total Dissolved Solid (TDS) and ascorbic acid with chitosan coating treatment

Concentration	Total Dissolved Solid (TDS) (^{o}brix)		Vitamin C (mg/100gram)	
	Week 2	Week 3	Week 2	Week 3
Without	8.27	8.89	3.75	3.62
0,5%	8.51	7.61	4.49	3.52
1 %	8.19	8.77	4.49	3.42
1,5%	8.35	8.65	3.85	3.17
2 %	9.10	9.30	4.26	3.10

Tabel 6 Total Dissolved Solid (TDS) and ascorbic acid with packaging treatment

Treatment	Total Dissolved Solid (TDS) (^{o}brix)		Vitamin C (mg/100gram)	
	Week 2	Week 3	Week 2	Week 3
Without	9.56 a	14.05 a	5.15 a	5.51 a
Perforated	8.15 ab	8.14 b	4.57 a	3.56 b
Ordinary	8.61 ab	6.04 c	3.95 ab	2.49 c
Vacuumed	7.60 b	6.36 bc	3.01 b	1.91 c

Note: Values within the same column followed by different letters were significantly different at HSD 5%; Without = without packaging; Perforated = plastic packaging with holes; Ordinary = ordinary plastic packaging without vacuum or perforated; Vacuumed = vacuum packaging.

Chitosan coating had no effect on the firmness of beetroot during 3 weeks of storage (Table 9). However, in both week 2 and week 3, the type of packaging used had an effect on the firmness of the tubers (Table 10). The firmness of tubers up to week 3 of storage with packaging perforated packaging showed higher hardness values compared to the others. Unpackaged beet tubers exhibit the softest texture throughout storage until week 3.

Chitosan coating had no effect on the percentage of damage in week 2 (Table 11), but in week 3, it did have an effect (Table 7). The type of packaging influenced tuber damage up to the 3rd week of storage (Table 12). The use of perforated plastic packaging prevented beet tubers from experiencing damage until week 2. The use of perforated plastic packaging resulted in the lowest damage compared to all other packaging types. Even when combined with chitosan coating at concentrations of 0.5 to 1.0%, no tubers were damaged after 3 weeks of storage (Table 13). The use of regular or vacuum-sealed plastic caused severe damage to almost or even all of the bulbs, regardless of whether chitosan coating was applied or not.

Chitosan coating did not have a significant effect on the visual quality rating (VQR) (Table 11). The type of packaging influenced the visual quality rating (VQR) after packaging up to week 3 (Table 12). The visual quality rating (VQR) of unpackaged beetroot decreased by 76.7% up to the 3rd week of shelf life, while those packed using perforated plastic decreased by 24.7%. However, for those packed using regular and vacuum packaging, the decrease was more significant, at 82.7% and 96.7%, respectively. Beetroot tubers packed using perforated plastic packaging had the highest visual quality rating up to week 3 of storage.

Discussion

Packaging influenced the observation parameters, while chitosan coating did not. The minimal effect of chitosan coating was likely due to the immersion method and the incomplete coating of the beetroot stalk cuts. In this study, beetroot tubers were immersed in a room-temperature chitosan solution, increasing the solution's viscosity and reducing penetration ability, resulting in suboptimal coating. The beetroot stalk cuts were not well-coated because they were not completely dry, allowing air to enter and exit the tubers freely.

The physical quality of beetroot determined its visual appearance and post-storage edibility, as indicated by the Visual Quality Rating (VQR). The VQR depended on the percentage of beetroot damage, which was caused by weight loss leading to wrinkles (due to transpiration) and decreased hardness (due to respiration). Transpiration was the main cause of weight loss during postharvest. It occurred due to the difference in water vapor pressure between the fruit tissues and the surrounding air, causing water to escape from the fruit (Hung et al. 2011). Transpiration in beetroot led to water and weight loss, and drastic occurrences resulted in wrinkling.

The use of perforated, regular, or vacuum packaging maintained high water content in beet tubers until week 3 compared to no packaging (Table 2). Packaging modified the atmosphere inside (Adhikari et al. 2020), keeping vapor pressure close to that in the tubers, resulting in a low vapor pressure deficit and minimal water loss (Azene et al. 2014). Water loss affected weight loss. Packaging reduced weight loss until week 3 (Table 2). Regular and vacuum packaging was tightly sealed, resulting in less weight loss compared to no packaging or perforated packaging. Trapped water vapor and low transpiration created saturated conditions inside the packaging, minimizing weight loss (Jiang et al. 2010).

The use of packaging reduced respiration rates compared to no packaging, but by the third week, respiration tended to increase, with the lowest respiration in perforated plastic packaging (Table 4). Beet tubers packaged in regular plastic and vacuum experienced anaerobic respiration due to oxygen levels in the packaging dropping below 1%, with oxygen levels of 0.21% for regular packaging and 0.17% for vacuum packaging. Unpackaged beet tubers experienced normal respiration but accelerated, with respiration rates in the third week increasing by 196.82%. Beet tubers packaged in perforated plastic experienced normal and slowed respiration. Slowing occurred because oxygen reaching the surface of the tubers was trapped by the packaging, preventing easy air entry into the tubers (Asgar 2020) and packaging could inhibit the respiration process (Buthelezi and Mafeo 2024).

Tabel 7 Betacyanin and betaxanthins with chitosan coating treatment

Concentration	Betacyanin (g/L)		Betaxanthins (g/L)	
	Week 2	Week 3	Week 2	Week 3
Without	0.21	0.20	0.18	0.14
0,5%	0.28	0.33	0.22	0.20
1 %	0.27	0.24	0.21	0.17
1,5%	0.29	0.22	0.21	0.15
2 %	0.29	0.26	0.19	0.18

Tabel 8 Betacyanin and betaxanthins with packaging treatment

Treatment	Betacyanin (g/L)		Betaxanthins (g/L)	
	Week 2	Week 3	Week 2	Week 3
Without	0.30 a	0.46 a	0.23 a	0.30 a
Perforated	0.28 a	0.32 b	0.19 a	0.19 b
Ordinary	0.26 a	0.10 c	0.21 a	0.11 c
Vacuumed	0.24 a	0.12 c	0.18 a	0.08 c

Note: Values within the same column followed by different letters were significantly different at HSD 5%; Without = without packaging; Perforated = plastic packaging with holes; Ordinary = ordinary plastic packaging without vacuum or perforated; Vacuumed = vacuum packaging.

Tabel 9 Tuber firmness with chitosan coating treatment

Concentration	Firmness of tubers (N)	
	Week 2	Week 3
Without	72.00	50.07
0,5%	76.82	48.03
1 %	75.51	58.44
1,5%	80.11	59.76
2 %	76.59	46.03

Tabel 10 Tuber firmness with packaging treatment

Treatment	Firmness of tubers (N)	
	Week 2	Week 3
Without	64.83 b	36.84 b
Perforated	87.24 a	78.56 a
Ordinary	83.71 a	44.52 b
Vacuumed	69.05 b	50.07 b

Note: Values within the same column followed by different letters were significantly different at HSD 5%; Without = without packaging; Perforated = plastic packaging with holes; Ordinary = ordinary plastic packaging without vacuum or perforated; Vacuumed = vacuum packaging.

Respiration is a metabolic process involving oxygen consumption to break down starch, sugar, and organic compounds into simpler molecules such as carbon dioxide, water, and energy (Kandasamy 2022). Respiration in beet tubers leads to physicochemical changes, including electrolyte leakage, changes in total dissolved solids (TDS), vitamin C, betacyanin, betaxanthin, and tuber hardness.

Membrane damage was evident in the difference in electrolyte leakage results in week 3, where the use of perforated packaging resulted in the smallest electrolyte leakage compared to no packaging and regular or vacuumed packaging (Table 4). Electrolyte leakage occurs due to cell membrane damage, causing ions to leak out of the cell. In this study, increased electrolyte leakage could be linked to increased respiration rate, leading to increased activity of degrading enzymes. Increased enzyme activity led to electrolyte leakage (Guan et al. 2024). Cell wall damage resulted from pectin degradation by cell wall degrading enzymes, namely polygalacturonase (PG), pectin methylesterase

(PME), and pectate lyase (PL) (Díaz-Rincón et al. 2023).

Beet tubers packaged with perforated plastic underwent normal but slow metabolism (respiration tended to be lower). Lower respiration reduced the activity of cell wall-degrading enzymes (Shinga and Fawole 2023), resulting in smaller electrolyte leakage in tubers packaged with perforated plastic. Electrolyte leakage in unpackaged tubers was due to increased metabolism (respiration). Electrolyte leakage in tubers packaged in regular or vacuumed plastic occurred because of anaerobic metabolism (anaerobic respiration). Anaerobic respiration produces ethanol, excessive production of which can cause fruit cell damage, leading to faster tuber decay (YuRu et al. 2019).

Unpackaged beet tubers had higher total dissolved solids (TDS) compared to the use of perforated, regular, or vacuum packaging (Table 6). Total dissolved solids are influenced by sugar accumulation, respiration rate, and rapid water loss (Gol et al. 2013). The higher total dissolved solids in unpackaged beet tubers were due to greater water loss (Table 2) and higher respiration rates (Table 4). Increasing total dissolved solids indicate fruit maturity and reduce its shelf life (Adhikari et al. 2020). Beet tubers packaged in regular or vacuum packaging had low total dissolved solids because anaerobic metabolism resulted in ethanol production rather than total dissolved solids.

In the 3rd week of storage, beet tubers without packaging had the highest levels of vitamin C, betacyanin, and betaxanthin (Table 6 and Table 8). This was because beet tubers underwent rapid normal metabolism, resulting in higher synthesis of vitamin C, betacyanin, and betaxanthin. The use of perforated packaging resulted in lower levels of vitamin C, betacyanin, and betaxanthin compared to unpackaged tubers, as metabolism proceeded normally but at a slower rate. Regular and vacuum packaging led to lower levels of vitamin C, betacyanin, and betaxanthin due to disrupted vitamin C synthesis caused by abnormal metabolism (anaerobic respiration).

In this study, tuber firmness until the 3rd week of storage with perforated packaging showed higher values than other treatments (Table 10), indicating that the presence of packaging with holes could maintain tuber hardness. Plastic packaging can preserve firmness by inhibiting fruit ripening and reducing water loss (Azene et al. 2014). During storage, tubers experienced decreased firmness due to increased dissolved pectin (degradation) caused by chemical and biochemical changes and modification of the pectin matrix structure (reduction in pectin aggregate amount) (Paniagua et al. 2017). The ripening process is influenced by respiration.

Damage to beet tubers was caused by weight loss due to transpiration, resulting in wrinkles and softening of the tubers (reduced hardness) due to respiratory metabolism, causing physicochemical changes. The use of perforated packaging had the smallest percentage of damage to beet tubers. Perforated plastic packaging could maintain air circulation inside the packaging, thereby preventing excessive water and water vapor loss from the beet tubers and allowing the heat from respiratory processes to escape. Regular plastic or vacuum packaging resulted in higher beet tuber damage due to decreased oxygen levels inside the packaging, leading to anaerobic reactions. Anaerobic reactions produce ethanol, and excessive ethanol production can damage fruit cells, hastening beet tuber spoilage (YuRu et al. 2019). The percentage of beet tuber damage increased with increasing respiration rate (Table 12, Table 4). Higher respiration rates led to faster commodity deterioration due to increased breakdown of organic compounds, accelerating aging, loss of nutritional value, and flavor changes (Kandasamy 2022).

Tabel 11 Beet tuber damage percentage and visual quality rating (VQR) with chitosan coating treatment

Concentration	Percentage of damage (%)	Visual quality rating (VQR)	
	Week 2	Week 2	Week 3
Without	37.96	6.25	2.67
0,5%	24.42	6.50	2.92
1 %	31.48	6.33	3.17
1,5%	28.70	6.41	3.08
2 %	32.41	6.33	3.08

Tabel 12 Water content and weight loss with packaging treatment

Treatment	Percentage of damage (%)	Visual quality rating (VQR)	
	Week 2	Week 2	Week 3
Without	8.89 a	7.73 ab	2.33 b
Perforated	0.00 a	8.53 a	7.53 a
Ordinary	39.54 b	5.53 bc	1.73 c
Vacuumed	75.56 c	3.67 c	0.33 c

Note: Values within the same column followed by different letters were significantly different at HSD 5%; Without = without packaging; Perforated = plastic packaging with holes; Ordinary = ordinary plastic packaging without vacuum or perforated; Vacuumed = vacuum packaging.

Tabel 13 Percentage of damage in week 3

Packaging treatment	Percentage of damage (%)				
	Without chitosan	Chitosan 0.5%	Chitosan 1 %	Chitosan 1.5%	Chitosan 2%
Without	4,17 ab	42,26 c	7,14 ab	87,50 d	82,14 d
Perforated	3,70 ab	0,00 a	0,00 a	8,33 ab	16,67 ab
Ordinary	100,00 d	96,30 d	95,24 d	85,71 d	75,00 cd
Vacuumed	100,00 d	100,00 d	100,00 d	100,00 d	100,00 d
CV	20,29				
Interaction	(+)				

Note: Values within the same column followed by different letters were significantly different at HSD 5%; Without = without packaging; Perforated = packaging without vacuum is perforated; Ordinary = packaging without vacuum or perforated; Vacuumed = vacuum packaging; (+) = interaction.

Beet tubers packaged with perforated plastic packaging until week 3 of storage maintained a high Visual Quality Rating (VQR) (Table 12), indicating minimal defects/damage (Damage table) and still suitable for consumption. Regular plastic, vacuum, and unpackaged beet tubers had low VQR values (Table 12). (Jia et al. 2009) reported that modified packaging with holes could preserve visual quality in agricultural products. The VQR value correlates with the percentage of damage; the higher the damage percentage, the lower the VQR value, and vice versa. Beet tubers with minimal damage percentages had high VQR values until week 3 of storage (Table 12, Table 13).

CONCLUSION

Chitosan could not coat the surface of beet tubers perfectly, so the chitosan coating did not affect the shelf life and quality of the beet tubers. At the same time, the use of perforated plastic packaging had a positive effect on the shelf life and quality of the beet tubers. Perforated packaging could reduce respiration rate and electrolyte leakage, maintain high tuber hardness, minimize damage percentage, and keep the Visual Quality Rating (VQR) high, making them still suitable for consumption until week 3 of storage.

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