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Effectiveness of Zero Energy Cool Chamber in Extending the Shelf Life of Cherry Tomatoes with Packaging Treatment

Sufri Yanto Syahputra[1], Emmy Darmawati[1*], Leopold Oscar Nelwan[1]

[1]Department of Mechanical and Biosystem Engineering, Faculty of Agricultural Engineering and Technology, IPB University, Lingkar Akademik Street, IPB Dramaga Campus, Babakan, Bogor, West Java 16680, Indonesia.
*Corresponding author, email: darmawatihandono@gmail.com

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Abstract

Cherry tomatoes are of high economic value due to their better nutrition, sweet flavor, and crunchy texture. They are in modern markets due to specific demand and intensive cultivation. Periodic harvesting poses distribution and storage challenges as cherry tomatoes are perishable, leading to price fluctuations and quality deterioration. Temporary storage is required to maintain quality before marketing. Zero Energy Cool Chamber (ZECC) is a low-cost and environmentally friendly cold storage alternative. This study aims to determine the combination of zeolite particle size combined with sand as a cooling medium on the ZECC wall that produces a shelf room temperature according to the temporary storage needs of cherry tomatoes. Cherry tomatoes were stored in retail (250 g) and bulky (1500 g) packaging to assess the effectiveness of the packaging in maintaining quality. Parameters measured included moisture content, texture, color, vitamin C content, and organoleptic. The results showed that chamber 1 (zeolite No. 1 mesh 14-20) was more stable than chamber 2 (zeolite No. 2 mesh 8-16). When loaded, the temperature of chamber 1 ranged from 24.6°C to 27.7°C with RH 94.7% to 95.4%. Retail packaging gave the best results with an organoleptic score of 4.03-4.16 on day 15, higher than the control. The vitamin C content in the retail packaging reached 35.83 mg/100 g, higher than the control (28.94 mg/100 g).

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1. Introduction

Cherry tomatoes are a commodity rich in nutrients, including vitamin C and antioxidants, and have increased consumer demand in modern markets (Putra & Setiawan, 2021; Sakanti et al., 2024). Their sweeter flavor and crunchier texture make them a top choice for consumers in modern markets such as supermarkets and high-end restaurants. The content of lycopene, a compound that gives tomatoes a red color and has anti-inflammatory effects, also contributes to the fruit's popularity in the health context (Carolina et al., 2019). This makes cherry tomatoes more than just a food item, but also an important source of nutrition, and thus, their value in the market.

The periodic harvest of tomatoes poses challenges in distribution, storage, and technology to maintain good quality in the market. Cherry tomatoes are horticultural products with a relatively short shelflife; therefore, low-temperature storage is crucial to minimize postharvest losses due to

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physiological and microbial activity. Therefore, temporary cold storage is necessary to maintain the quality of cherry tomatoes before marketing (Marina & Sukmawati, 2017).

The zero-energy cooling chamber (ZECC) has several advantages over other temporary cooling solutions. One of the main advantages of ZECC is its low operational cost as it does not require electricity, making it a more economical option, especially in rural areas or regions without stable access to electricity. In addition, ZECC is more environmentally friendly because it uses an evaporative cooling system made from natural materials, such as sand and zeolite. Refrigeration technology such as Zero Energy Cool Chamber (ZECC) is an economical alternative for small businesses (Islam et al. 2012; Mishra et al. 2020).

Previous research has shown that the 50:50 sand-zeolite combination can maintain the ZECC temperature at 23°C-25°C with RH 92%-98% lower than the ambient temperature of 26°C-30°C with RH 69%-73% (Paluseri et al. 2023). The types of sand and zeolite used in this study are not explained. Zeolite particle size affects the adsorption process and the thermal properties of zeolites (Kurniasari et al., 2011). This study aimed to assess the combination of sand and zeolite particle sizes for the optimal temperature of cherry tomato storage and the effectiveness of packaging in maintaining quality during storage at ZECC.

2. Material and Methods

2.1 Materials and Tools

The materials used for fabricating the ZECC are red bricks, sand, bamboo matting, and zeolite. Water tanks, pipes, and water were used for the wall wetting. The type of horticulture used as research material was cherry tomatoes obtained from Agribusiness and Technology Park, IPB University. The tools used were a T-type/0.3 mm copper rod thermocouple, mini data logger (type GL260 produced in Japan), rheometer (type Sun Scientific CR-500DX produced in Japan), chromameter (type CR-400 produced in Japan), oven (type ISUZU produced in Japan), fruit rack, beaker glass, Erlenmeyer, funnel, burette, measuring pipette, digital balance (Ohaus AX224 produced in the United States), small container, and polypropylene plastic packaging.

2.2 Research Procedure

The procedure in this research consists of making ZECC (a zero-energy cool chamber (ZECC), preliminary research, and main research.

2.3 ZECC Manufacture

The ZECC type was above-ground. The first step was to clear the land area where the ZECC was built. The base layer or floor of the ZECC room was made of sand leveled on the ground, with a thickness of 1 cm. The ZECC design is illustrated in Figure 1.

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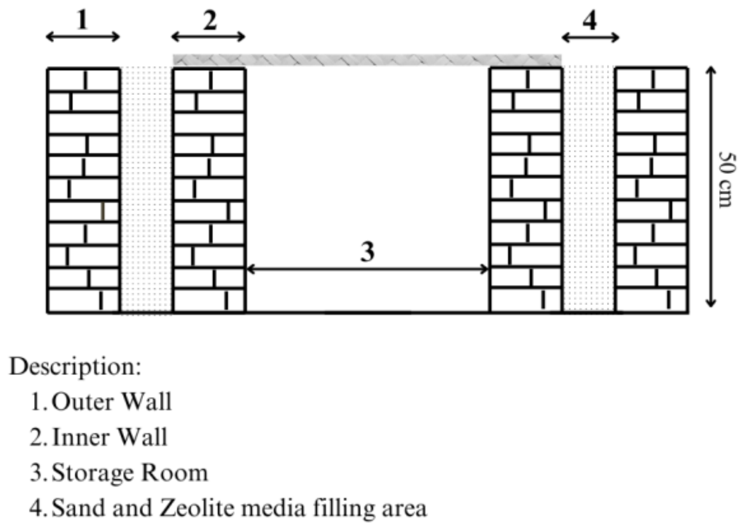

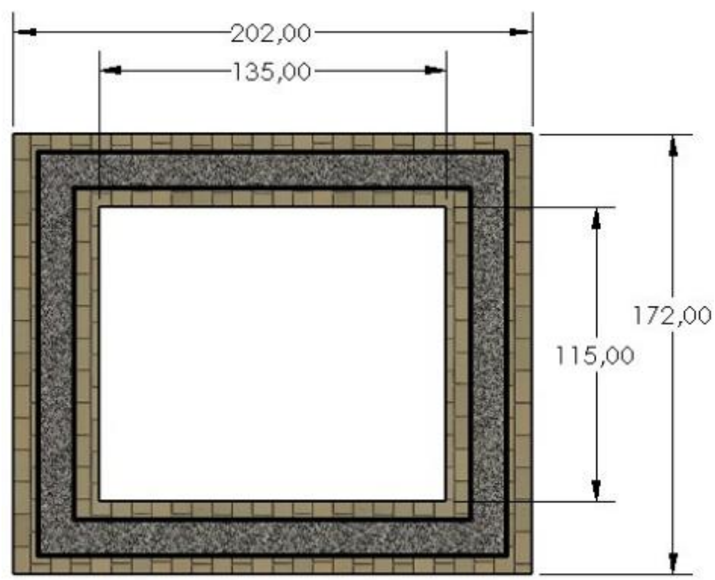

Figure 1. Schematic drawing of a) front view and b) top view of the ZECC.

The ZECC wall consisted of an outer wall measuring 172 x 202 x 50 cm and an inner wall measuring 115 x 135 x 50 cm. A 10 cm gap separates the two walls, filled with a mixture of 50% sand and 50% zeolite as the evaporation medium. The two zeolite particle sizes studied were 14-20 mesh (Chamber 1) and 8-16 mesh (Chamber 2). The ZECC cover was composed of woven bamboo. To assist the evaporation process in reducing the temperature inside the ZECC, the evaporation medium was wetted.

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2.4 Preliminary research

Preliminary research was conducted to determine the amount of water to be used in wetting ZECC walls to produce cold temperatures in the storage chamber. The amount of water and wetting duration that produce the best temperature and RH are applied to storage using the ZECC method.

2.5 Main research

The cherry tomatoes used in this study were sourced from Agribusiness and Technology Park, Bogor Agricultural University, and were collected from local farmers. The fruits had mixed ripeness levels, ranging from the turning stage (10–30% pink surface) to the light red stage (60–90% pink to red surface). Defective or damaged tomatoes were removed to prevent quality deterioration, and the fruits were packed into 250 g retail packs and 1500 g bulky packs according to the treatment. The temperature of the ZECC was regulated by wetting the evaporation medium, after which the tomatoes were placed in the appropriate containers, i.e. 9 retail packs (250 g) and one bulky pack (1500 g) per container. The temperature, relative humidity (RH), and quality of tomatoes up to presumed spoilage for up to 15 days of storage were measured. Each experimental run was replicated three times to ensure data reliability.

2.6 Observation parameters

In a preliminary study, the temperature and RH in ZECC were measured before the product was present (no load). In the main study, the temperature and RH were measured after the tomatoes were placed in ZECC (with load). Quality data were collected every 3 days until 15 days of storage, including water content, hardness, color, organoleptic test results, and vitamin C content during storage.

2.7 Temperature and relative humidity (RH) measurement

Temperature measurements were performed inside and outside the ZECC using thermocouples placed around the product and outside the environment. Temperature and relative humidity (RH) data were recorded daily from 06:00 to 19:00. RH was calculated using the wet bulb and dry bulb data from the thermocouples with the help of Psychometric Chart.

2.8 Moisture content

The moisture content test method used in this study was the oven method (AOAC, 2000). The moisture content was calculated using Equation 1.

$$MC\ (\%wb) = \frac{B-C}{B-A} \times 100\% \quad (1)$$

Description: MC: Moisture content (%), A: Weight of cup (g), B: Weight of cup and material before drying (g), C: Weight of cup and material after drying (g)

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2.9 Weigth loss

Fruit weight loss was determined by comparing the weight of the fruit on day n with the initial weight of the fruit before storage. Each experimental run was replicated three times to ensure data reliability. The fruit weight loss was measured using a digital scale. Weight loss was calculated using Equation 2:

$$Weigt\ Loss\ (\%) = \frac{w_o - w_t}{w_o} \times 100 \quad (2)$$

Description: W_o: Initial storage weight (g), W_t: Final storage weight (g)

2.10 Hardness

Fruit hardness measurements were performed using a calibrated rheometer with a puncturing speed of 60 mm/s, a depth of 20 mm, and a tube-type probe diameter of 5 mm. The samples were placed on the rheometer table and punctured three times at the base, center, and tip of the tomato to calculate the average hardness value. Each experimental run was replicated three times to ensure data reliability.

2.11 Vitamin C content

The test method for vitamin C content used is the Iodimetric Method of Vitamin C Content Analysis (AOAC 1995). Each experimental run was replicated three times to ensure data reliability. The vitamin C content was calculated using Equation 3.

$$Vit.C\ (mg/100g^{-1}) = \frac{(VI_2) \times 0.88 \times fp}{Ws\ (gram)} \times 100\% \quad (3)$$

Description: V I_2 : Iodine volume (ml), 0.88: 0.88 mg of ascorbic acid is equivalent to 1 ml of 0.01 N I_2 solution, fp: Dilution factor, Ws: Sample weight (g)

2.12 Colors

Fruit color measurements were performed using a chromameter with coordinate values of L*, a*, and b*. The test was performed by shooting a light at the measured part of the fruit. The measurement results were obtained in L* and °hue units, where the hue value is the result of the conversion of the a* and b* values into °hue chromatic units. The L* value indicates the brightness or how light/dark the surface is, whereas the °hue value provides a direct description of the dominant color. Each experimental run was replicated three times to ensure data reliability.

2.13 Organoleptic test

The organoleptic testing method used was the hedonic or favorability test (Soekarto 1985). The organoleptic test was conducted by 20 semi-trained panelists who were students at IPB University. The assessment criteria were converted into numbers, namely (5) very like, (4) like, (3) quite like, (2)

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less like, and (1) do not like. This test aimed to determine the acceptance of panelists regarding the color, texture, and aroma of tomato fruits based on the panelists' level of preference.

2.14 Experimental design

This study was conducted using a complete randomized design (CRD) and replicated three times. The factors used were:

- Bulky Control (KB): Room temperature
- Retail Control (KR): Room temperature
- Retail (R): ZECC
- Bulky (B): ZECC

Statistical tests began with analysis of variance to determine the effect and interaction of treatments and continued with the Tukey test as a determinant of the difference in the real level of 5% of the calculation results using Minitab 17.

3. Results and Discussion

3.1 ZECC Manufacture

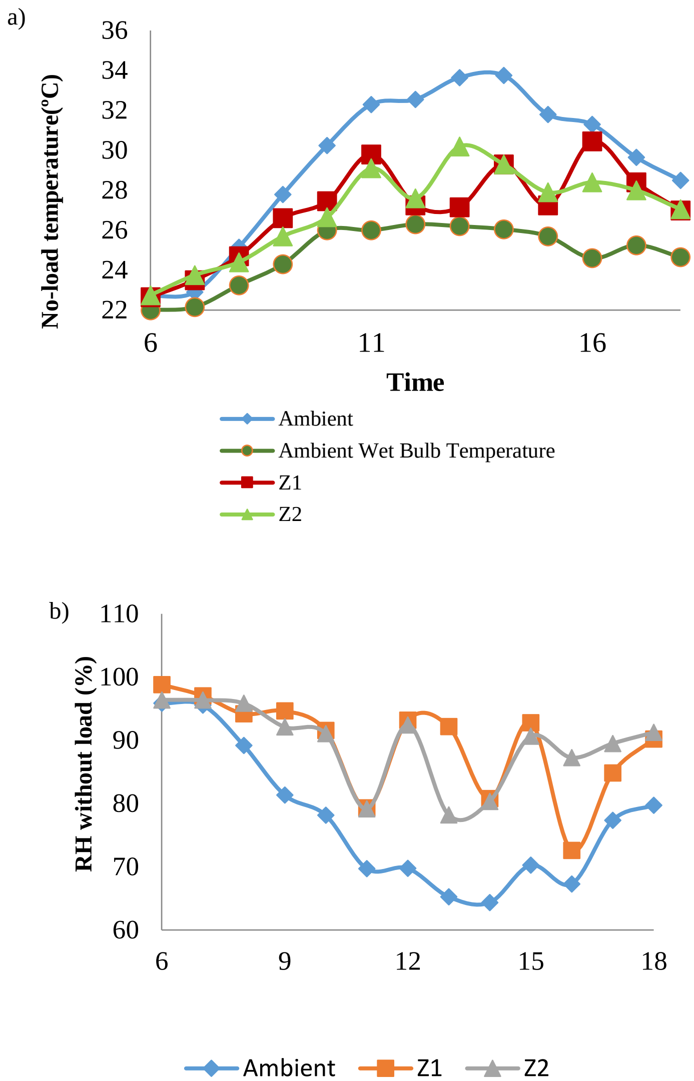
This study modified the ZECC developed by Paluseri et al. (2023) by expanding the storage chamber dimensions to 115 cm × 135 cm × 50 cm (0.776 m^3 capacity), which is larger than the previous version (0.32 m^3). No-load testing showed that the temperature and RH in the chamber fluctuated more than the small size with a temperature range of 22.7°C-30.5°C and RH of 72.6%-98.8% while the maximum ambient temperature and RH were 33.8°C and 33.8%. The temperature and RH range in the ZECC chamber of Paluseri et al. (2023) was 22.6°C-26.05°C with an RH 93.0%-98.2%. A small ZECC is more effective in maintaining a stable temperature and RH. Factors such as the media thickness, water temperature, and chamber size affect the efficiency of ZECCs (Liu et al., 2017).

3.2 Preliminary research

A preliminary study was conducted for two days to determine the amount of water and wetting settings that produced the best temperature and RH. The results showed that wetting with ±30 liters of water per day resulted in a lower temperature and higher RH in the ZECC storage chamber compared to the ambient temperature and RH.

3.3 Temperature and RH conditions inside the ZECC without load

Temperature measurements of ZECC in the empty state were used to determine the wetting pattern that resulted in the best temperature and RH for storage. Figure 2 shows the changes in the temperature and relative humidity inside and outside the ZECC when there is no load.



Note: Z1 = ZECC chamber filled with zeolite of mesh size 14–20; Z2 = ZECC chamber filled with zeolite of mesh size 8–16

Figure 2. Changes in temperature (a) and RH (b) outside and inside ZECC without load.

This study shows that the gradual wetting of the evaporation media (sand and zeolite) in the ZECC can significantly affect temperature and RH. The difference between the ambient temperature and RH in the ZECC chamber can occur because the wet evaporation media (sand + zeolite) functions well to reduce the temperature and maintain a higher relative humidity in the chamber (Islam et al., 2012). The temperature of the chamber is higher when there is a load, because there is heat generated by the respiration process of fresh cherry tomatoes inside, but it is still below the ambient temperature.

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3.4 Moisture content

Storage using ZECC was effective in maintaining the moisture content of the cherry tomatoes, with a smaller decrease than the room temperature control. In retail packaging, the daily decrease in ZECC was 0.0535%, which was lower than that of the 0.0787% control. In the bulky packaging, the daily decrease in ZECC was only 0.0318%, which was much smaller than that in the 0.0801% control. High temperature and humidity stability in ZECC slowed transpiration and respiration, thereby maintaining the fruit moisture content. The changes in tomato moisture content during storage in ZECC are shown in Figure 4.

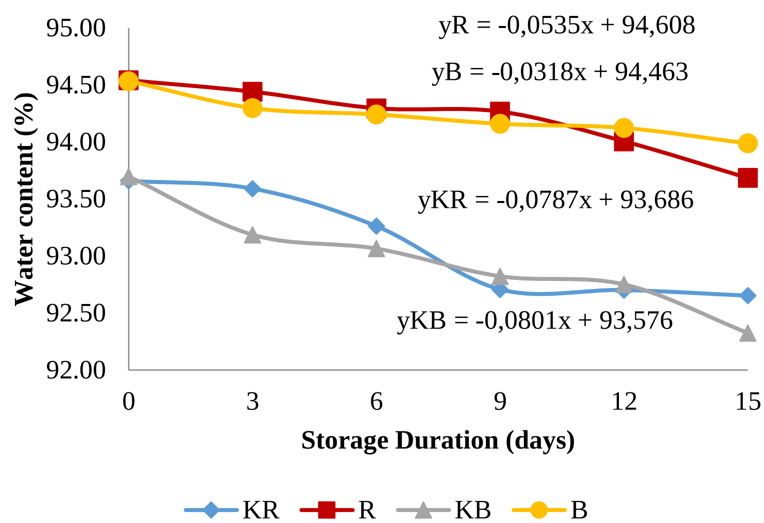

Figure 4. Changes in moisture content of tomato fruits during storage in ZECCs.

Bulky packaging is more effective in maintaining the moisture content of cherry tomatoes than retail packaging, because a smaller surface area reduces evaporation. The results of the variance analysis (ANOVA), as shown in Table 1, indicate significant differences in moisture content on days 6 (P=0.021), 9 (P=0.000), 12 (P=0.000), and 15 (P=0.029). Further analysis using Tukey's test (see Table 2) showed that on days 9 and 12, the moisture content in tomatoes stored in ZECC with bulky packaging (KB) was significantly higher than that in tomatoes stored at room temperature with either packaging type (R and B), as indicated by different superscript letters. This suggests that the combination of ZECC and bulky packaging (KB) was the most effective in retaining the water content during storage.

Storage in ZECC, especially with bulky packaging, maintained the moisture content better than room temperature control. The cold temperature in ZECC slowed transpiration and respiration, maintaining the moisture content and freshness of tomatoes for a longer period (Pattiruhu & Breemer, 2024). Storage at room temperature causes a greater decrease in the moisture content of tomatoes owing to lower external water pressure, thus accelerating evaporation. In contrast, cold temperatures

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are more effective in maintaining water content because respiration and transpiration metabolism maintain the water content balance during storage (Rianto et al., 2024).

Table 1. P-value of the results of analysis of variance (ANOVA) of cherry tomato moisture content on various days of observation.

Day	P-value	Description
0	0.081	Not significantly different ($p > 0.05$)
3	0.069	Not significantly different ($p > 0.05$)
6	0.021*	Significantly different at the 5% level ($p < 0.05$)
9	0.000**	Significantly different at the 1% level ($p < 0.01$)
12	0.000**	Significantly different at the 1% level ($p < 0.01$)
15	0.029*	Significantly different at the 5% level ($p < 0.05$)

Table 2. Average cherry tomato moisture content (% w.b) and Tukey's further test results.

Treatment	Moisture content (% w.b)					
	Observation day					
	0	3	6	9	12	15
R	94.541 ± 0.528^{a}	94.442 ± 0.082^{a}	94.296 ± 0.321^{a}	94.267 ± 0.281^{a}	94.007 ± 0.076^{a}	93.685 ± 0.587^{ab}
B	94.535 ± 0.554^{a}	94.298 ± 0.241^{a}	94.242 ± 0.504^{ab}	94.160 ± 0.018^{a}	94.124 ± 0.055^{a}	93.988 ± 0.769^{a}
KR	93.660 ± 0.394^{a}	93.591 ± 0.113^{a}	93.262 ± 0.633^{ab}	92.708 ± 0.376^{b}	92.702 ± 0.111^{b}	92.652 ± 0.314^{ab}
KB	93.698 ± 0.410^{a}	93.187 ± 1.058^{a}	93.065 ± 0.305^{b}	92.823 ± 0.213^{b}	92.751 ± 0.266^{b}	92.325 ± 0.679^{b}

Notes: Numbers accompanied by different letters in the same column indicate a significant effect (sig <0.05); Retail (R) in ZECC; Bulky (B) in ZECC; Bulky Control (KB) in Room temperature; Retail Control (KR) in Room temperature

3.5 Weight loss

Storage in ZECC significantly reduced the weight loss of tomatoes compared with that of the control. Daily weight losses in ZECC were lower at 0.0987% (retail packaging) and 0.1545% (bulky packaging) compared to the control, which reached 0.221% and 0.2202%, respectively. High humidity and stable temperature in the ZECC slowed transpiration and respiration. The weight loss of cherry tomatoes during storage in ZECC is shown in Figure 5.

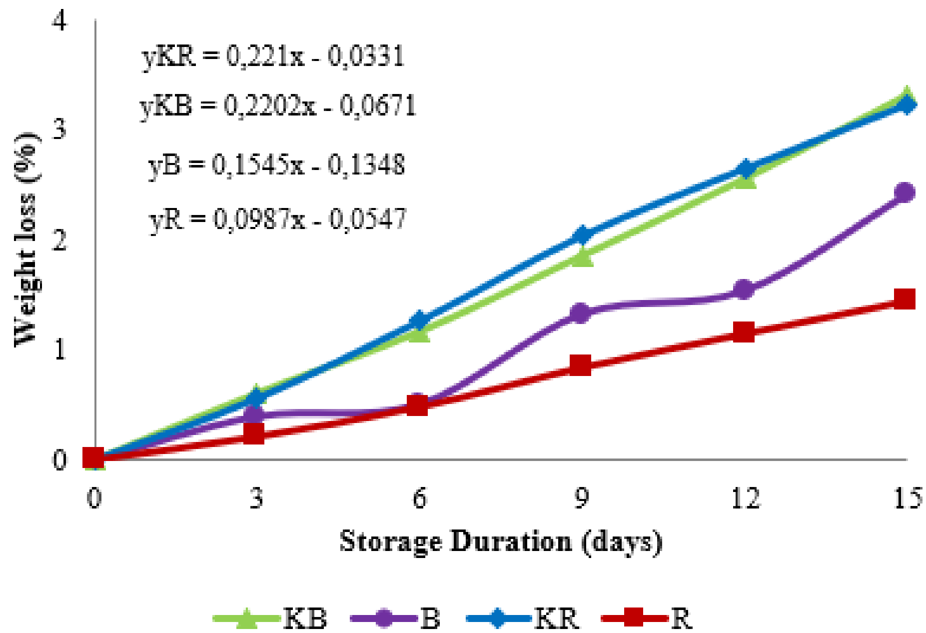

Figure 5. Changes in weight loss of tomato fruits during storage in ZECCs.

The weight loss of the cherry tomatoes in retail packaging was lower than that in bulk packaging. Factors, such as temperature, humidity, packaging type, and fruit maturity, affect the rate of weight loss (Lamona et al., 2015). However, as shown in Table 3, the results of the variance analysis (ANOVA) at all observation days (days 3, 6, 9, 12, and 15) showed no statistically significant differences ($P>0.05$) among the treatments. This finding was further confirmed by the results of Tukey's test in Table 4, where all treatments at each observation time are labeled with the same letter, indicating no significant difference in weight loss between treatments.

Although statistically non-significant, the data in Table 4 show that retail packaging in ZECC (KR) resulted in consistently lower weight loss than bulky packaging in ZECC (KB), particularly noticeable at the end of storage (day 15), where KR was 1.442 ± 0.593, while KB reached 2.400 ± 2.110. This suggests that retail packaging may help to reduce surface area exposure and slow water loss through transpiration and respiration.

In this study, the best treatment in terms of weight loss reduction was retail packaging for ZECC storage. Weight loss increases over time owing to evaporation and respiration; however, ZECC is effective in maintaining moisture and reducing weight loss (Selly Andriani & Hintono, 2018). Stable temperature and high humidity in ZECCs help reduce tomato weight loss by slowing transpiration and water evaporation. Tomatoes absorb and release heat slowly, maintaining a more stable temperature in the chamber than that in the environment. Weight loss is also affected by respiration, in which glucose is broken down into CO_2 and H_2O (Herdiana, 2011).

Table 3. P-value of analysis of variance (ANOVA) of weight loss of cherry tomatoes on various days of observation.

Day	P-value	Description
3	0.203	Not significantly different ($p > 0.05$)
6	0.062	Not significantly different ($p > 0.05$)
9	0.216	Not significantly different ($p > 0.05$)
12	0.121	Not significantly different ($p > 0.05$)
15	0.264	Not significantly different ($p > 0.05$)

Table 4. Average weight loss of cherry tomatoes (%) and Tukey's further test results.

Treatment	Weight loss (%)				
	Observation day				
	3	6	9	12	15
R	0.211 ± 0.061[a]	0.480 ± 0.279[a]	0.838 ± 0.349[a]	1.144 ± 0.620[a]	3.232 ± 0.916[a]
B	0.392 ± 0.421[a]	0.503 ± 0.463[a]	1.320 ± 1.104[a]	1.529 ± 1.145[a]	3.316 ± 0.295[a]
KR	0.561 ± 0.143[a]	1.263 ± 0.403[a]	2.039 ± 0.616[a]	2.649 ± 0.823[a]	1.442 ± 0.593[a]
KB	0.608 ± 0.024[a]	1.167 ± 0.341[a]	1.857 ± 0.446[a]	2.556 ± 0.417[a]	2.400 ± 2.110[a]

Notes: Numbers accompanied by different letters in the same column indicate a significant effect (sig <0.05); Retail (R) in ZECC; Bulky (B) in ZECC; Bulky Control (KB) in Room temperature; Retail Control (KR) in Room temperature

3.6 Hardness

Storage in ZECCs slowed the deterioration of tomato hardness, with retail packaging showing the lowest rate of deterioration (0.017 kgf a day) compared with bulky packaging (0.0341 kgf). The stability of temperature and humidity in ZECC maintains moisture content and suppresses the activity of pectinase, which slows down softening (Deglas, 2023). The changes in the hardness of tomatoes during storage in ZECC are shown in Figure 6.

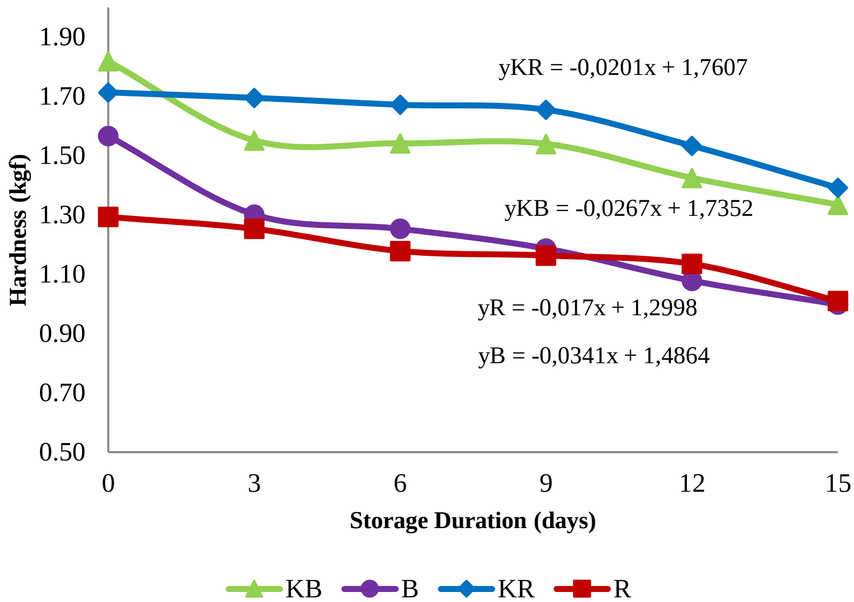

Figure 6. Changes in hardness of tomatoes during storage in the ZECCs.

The results of the variance analysis of cherry tomatoes showed that their hardness of cherry tomatoes was not significantly different on days 0, 3, and 6. However, based on Table 5, significant differences were observed on days 9 (P=0.006) and 12 (P=0.029), indicating that storage treatment began to affect firmness starting from day 9. Further analysis using Tukey's test (Table 6) showed that on day 9, tomatoes stored at room temperature in retail packaging (R) had significantly lower hardness (1.163 ± 0.162, marked with "c") compared to ZECC treatments (KR and KB), which retained higher firmness. Similarly, on day 12, the retail ZECC treatment (KR) maintained a higher firmness (1.533 ± 0.232) than the room temperature bulk (B), which showed the lowest value (1.078 ± 0.158).

Table 5. The p-value of the analysis of variance (ANOVA) of cherry tomato hardness on various days of observation.

Day	P-value	Description
0	0.179	Not significantly different (p > 0.05)
3	0.282	Not significantly different (p > 0.05)
6	0.173	Not significantly different (p > 0.05)
9	0.006**	Significantly different at the 1% level (p < 0.01)
12	0.029*	Significantly different at the 5% level (p < 0.05)
15	0.139	Not significantly different (p > 0.05)

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Table 6. Average cherry tomato hardness (kgf)and Tukey's further test results.

Treatment	Hardness (kgf)					
	Observation day					
	0	3	6	9	12	15
R	1.293 ± 0.224[a]	1.253 ± 0.247[a]	1.672 ± 0.133[a]	1.163 ± 0.162[c]	1.135 ± 0.187[ab]	1.010 ± 0.059[a]
B	1.567 ± 0.114[a]	1.302 ± 0.183[a]	1.253 ± 0.107[a]	1.187 ± 0.190[bc]	1.078 ± 0.158[b]	0.998 ± 0.221[a]
KR	1.713 ± 0.280[a]	1.695 ± 0.183[a]	1.672 ± 0.133[a]	1.655 ± 0.066[a]	1.533 ± 0.232[a]	1.392 ± 0.344[a]
KB	1.818 ± 0.394[a]	1.552 ± 0.465[a]	1.542 ± 0.414[a]	1.540 ± 0.115[ab]	1.425 ± 0.039[ab]	1.335 ± 0.208[a]

Notes: Numbers accompanied by different letters in the same column indicate a significant effect (sig <0.05); Retail (R) in ZECC; Bulky (B) in ZECC; Bulky Control (KB) in Room temperature; Retail Control (KR) in Room temperature.

These results suggest that ZECC is more effective at maintaining fruit firmness, especially in retail packaging. Retail packaging with ZECC (KR) consistently showed higher firmness values across storage days, particularly on days 9 and 12, indicating a slower rate of softening. Overall, retail packaging was more effective at maintaining hardness than bulky packaging. The stable condition of ZECC slows down softening owing to ripening, transpiration, and respiration, which reduces turgor pressure and changes the structure of the cell wall (Rozana et al., 2021). As the fruit ripened, textural changes became more pronounced. Longer storage durations contribute to a decrease in tomato fruit firmness (Fertiasari et al., 2023).

3.7 Vitamin C content

The vitamin C levels of cherry tomatoes decreased during storage, but storage in ZECC slowed this decrease compared with the control outside the chamber. Retail packaging in ZECC showed the best results in maintaining vitamin C levels with temperature stability (24.5°C - 27.7°C) and high humidity (92.1% - 96.6%), which reduced vitamin C oxidation. Changes in vitamin C levels in cherry tomatoes are shown in Figure 7.

The vitamin C levels decreased in almost all treatments at different rates and patterns. Fluctuations occurred due to destructive testing of different samples with varying moisture contents. In ZECC with bulky packaging, the daily decrease was approximately 0.1371 mg/100 g, which was slower than that in the room temperature control with bulky packaging, which decreased by 0.2265 mg/100 g. Retail packaging at ZECC showed that vitamin C levels tended to stabilize and even increase slightly, indicating the effectiveness of the combination in maintaining vitamin C. Meanwhile, retail packaging at room temperature decreased slower by approximately 0.0611 mg/100 g than bulky packaging but was still not as good as that at ZECC.

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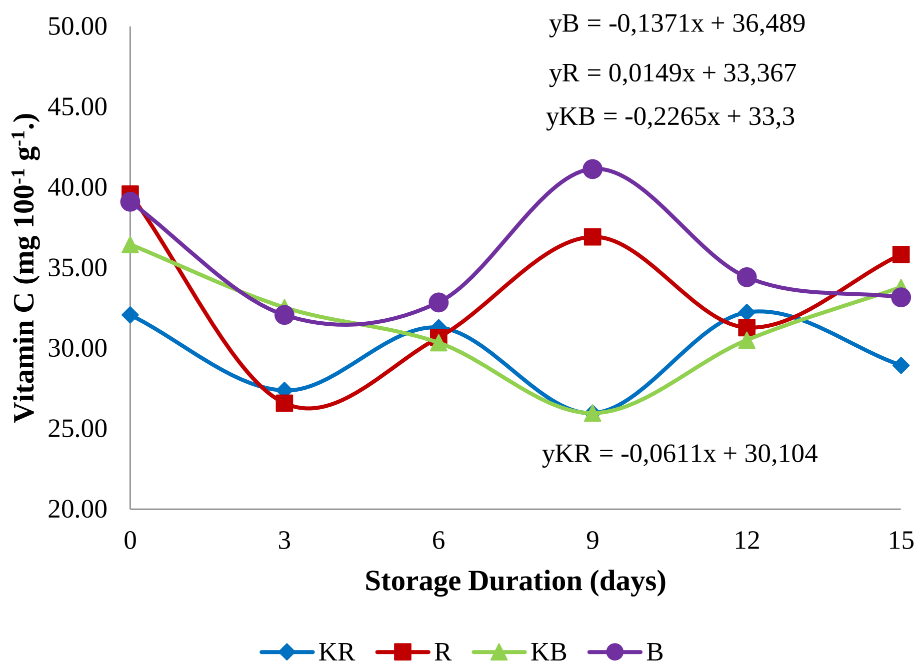

Figure 7. Changes in vitamin C content of tomatoes during storage in ZECCs.

As shown in Table 7, the ANOVA test indicated a significant difference ($p < 0.05$) in vitamin C levels among treatments on day 9 only, whereas no significant differences were observed on other storage days. This suggests that the differences between treatments became more apparent as storage progressed. Further analysis using Tukey's post-hoc test (Table 8) revealed that on day 9, the vitamin C content of the bulky control (KB) treatment was significantly lower than that of the other treatments, as indicated by the different superscript letters. This supports the conclusion that ZECC, especially with proper packaging, helps maintain higher vitamin C levels than non-ZECC storage.

ZECC's ability to maintain stable temperature and humidity likely slows down the oxidative degradation of vitamin C, making it an effective storage method for cherry tomatoes. The optimal storage temperature is critical for preventing chilling injury and minimizing oxidation (Pattiruhu & Breemer, 2024). As storage time increases, vitamin C levels tend to decrease owing to the oxidative nature of vitamin C when exposed to air, especially at higher temperatures (Fitriani et al., 2022). Therefore, maintaining optimal conditions and using appropriate packaging are essential to preserve the nutritional quality of tomatoes.

Table 7. The p-value of the analysis of variance (ANOVA) of vitamin C content of cherry tomatoes on various days of observation.

Day	P-value	Description
0	0,66	Not significantly different (p > 0.05)
3	0,07	Not significantly different (p > 0.05)
6	0,948	Not significantly different (p > 0.05)
9	0,002**	Significantly different at the 5% level (p < 0.05)
12	0,754	Not significantly different (p > 0.05)
15	0,103	Not significantly different (p > 0.05)

Table 8. Mean vitamin C content of cherry tomatoes and Tukey's further test results on various days of observation.

Treatment	Vitamin C content (mg 100^{-1} g^{-1}.)					
	Observation day					
	0	3	6	9	12	15
R	39.58 ± 3.33 ^{a}	26.60 ± 1.18 ^{a}	30.66 ± 5.56 ^{a}	36.92 ± 1.18 ^{a}	31.29 ± 4.88 ^{a}	35.83 ± 3.12 ^{a}
B	39.11 ± 7.86 ^{a}	32.07 ± 3.12 ^{a}	32.85 ± 7.90 ^{a}	41.14 ± 6.74 ^{a}	34.42 ± 3.99 ^{a}	33.17 ± 0.27 ^{a}
KR	32.07 ± 10.03 ^{a}	27.38 ± 3.76 ^{a}	31.29 ± 4.82 ^{a}	25.97 ± 3.12 ^{b}	32.23 ± 4.51 ^{a}	28.94 ± 4.70 ^{a}
KB	36.45 ± 9.15 ^{a}	32.54 ± 2.75 ^{a}	30.35 ± 3.46 ^{a}	25.97 ± 1.65 ^{b}	30.51 ± 4.97 ^{a}	33.79 ± 1.69 ^{a}

Notes: Numbers accompanied by different letters in the same column indicate a significant effect (sig <0.05); Retail (R) in ZECC; Bulky (B) in ZECC; Bulky Control (KB) in Room temperature; Retail Control (KR) in Room temperature

3.8 Colors

During storage, the color of cherry tomatoes decreased. During storage in ZECC, the decrease in brightness (L*) and °hue was more rapid, especially in bulky packaging. The decrease in brightness in ZECC reached 0.3709% per day for bulky and 0.2433% per day for retail, whereas the decrease in hue occurred at a rate of 1.5754% per day in bulk and 1.1138% per day in retail. This shows that ZECC accelerates the degradation of both the brightness (L*) and °hue. Figure 8 shows the change in brightness (L*) and °hue values of the cherry tomatoes.

The results of variance showed that on days 0 to 6, there was no significant difference in brightness (L*) or °hue, indicating stable fruit conditions. Based on Table 1, ANOVA results showed that significant differences in L* values appeared on day 9 (*P*=0.004), and for hue on days 3 (*P*=0.003), 6 (*P*=0.031), and 12 (*P*=0.010). These results suggest that, as storage progressed, especially after day 6, the treatment effects on fruit color became more pronounced.

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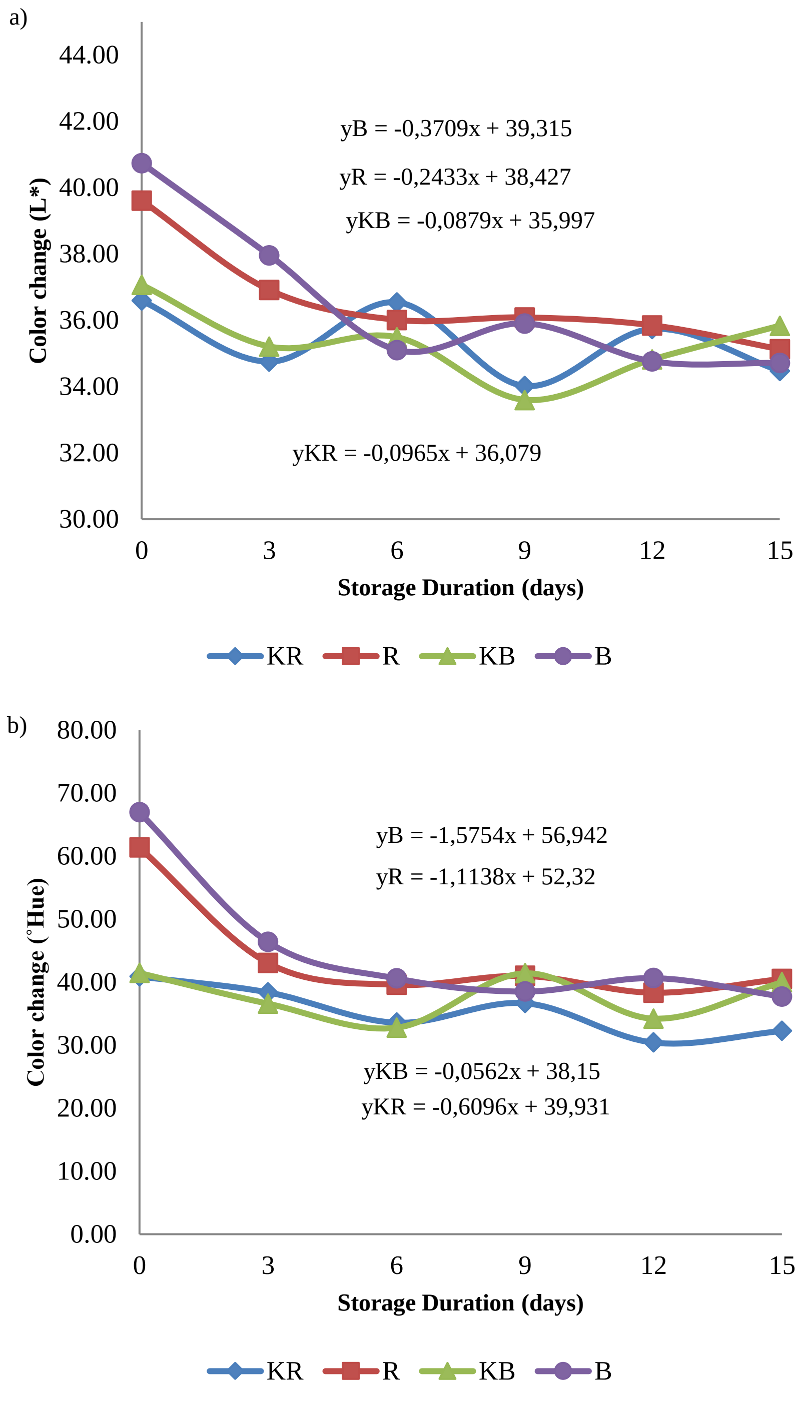

Figure 8. Changes in brightness value (L*) (a) and hue value (°Hue) (b) of tomato fruits during storage in ZECCs.

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Further analysis with Tukey's test, as shown in Table 10 and Table 11, indicated that on day 3, the hue values of bulky ZECC packaging (KB) were significantly lower (32.85 ± 1.66 c) than the control (43.0 ± 2.74 ab), suggesting an accelerated color shift due to over-ripening or degradation. Similarly, L* values for the same treatment (KB) on day 9 remained relatively stable (34.82 ± 0.37 a) compared to others, but the numerical decrease in brightness across all treatments indicated ongoing degradation, which was more evident in bulky packaging.

After day 9, ZECC was better at maintaining the hue, even though the brightness decreased. This decline was more pronounced on days 12–15, especially in bulky packaging in ZECC, indicating accelerated visual degradation. Overall, retail packaging is better at maintaining the brightness and hue in ZECC, especially for short-term storage.

Tomato brightness is affected by the reduction of natural waxy substances due to skin wrinkling and oxidation of polyphenolic compounds that damage cell walls, causing browning (Gultom et al., 2024). In addition, skin wrinkling causes a color change from reddish-yellow to intensely red, indicating a decrease in the antioxidant content.

Table 9. The p-value of the results of the analysis of variance (ANOVA) of brightness value (L*) and °hue value of cherry tomatoes on various days of observation.

Day	Parameter			
	L*		°hue	
	P-value	**Description**	**P-value**	**Description**
0	0.276	Not significantly different ($p > 0.05$)	0.062	Not significantly different ($p > 0.05$)
3	0.118	Not significantly different ($p > 0.05$)	0.003**	Significantly different at the 1% level ($p < 0.01$)
6	0.278	Not significantly different ($p > 0.05$)	0.031*	Significantly different at the 5% level ($p < 0.05$)
9	0.004**	Significantly different at the 1% level ($p < 0.01$)	0.533	Not significantly different ($p > 0.05$)
12	0.628	Not significantly different ($p > 0.05$)	0.010*	Significantly different at the 5% level ($p < 0.05$)
15	0.249	Not significantly different ($p > 0.05$)	0.221	Not significantly different ($p > 0.05$)

Notes: Numbers accompanied by different letters in the same column indicate a significant effect (sig <0.05); Retail (R) in ZECC; Bulky (B) in ZECC; Bulky Control (KB) in Room temperature; Retail Control (KR) in Room temperature

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Table 10. Mean brightness value (L*) of cherry tomatoes and Tukey's further test results.

Treatment	Brightness value (L*)					
	Observation day					
	0	3	6	9	12	15
R	39.61 ± 3.12 a	36.92 ± 1.65 a	36.02 ± 0.91 a	36.09 ± 0.43 a	35.85 ± 1.47 a	35.13 ± 0.46 a
B	40.74 ± 3.38 a	37.97 ± 1.75 a	35.11 ± 0.72 a	35.91 ± 1.09 a	34.76 ± 1.58 a	34.72 ± 0.34 a
KR	36.60 ± 1.15 a	34.75 ± 2.05 a	36.54 ± 0.98 a	34.02 ± 0.68 a	35.74 ± 1.37 a	34.48 ± 0.78 a
KB	37.07 ± 2.89 a	35.21 ± 0.07 a	35.49 ± 0.88 a	33.60 ± 0.25 a	34.82 ± 0.37 a	35.84 ± 1.26 a

Notes: Numbers accompanied by different letters in the same column indicate a significant effect (sig <0.05); Retail (R) in ZECC; Bulky (B) in ZECC; Bulky Control (KB) in Room temperature; Retail Control (KR) in Room temperature

Table 11. Mean °hue value of cherry tomatoes and Tukey's further test results.

Treatment	°hue value					
	Observation day					
	0	3	6	9	12	15
R	62.43 ± 10.86 a	43.30 ± 2.74 ab	39.62 ± 4.11 a	40.98 ± 3.71 a	38.41 ± 3.20 a	40.67 ± 4.04 a
B	69.40 ± 20.10 a	46.46 ± 1.04 a	40.65 ± 4.32 a	38.55 ± 3.12 a	40.71 ± 1.99 a	37.76 ± 4.07 a
KR	40.96 ± 3.72 a	38.30 ± 2.24 bc	33.55 ± 1.04 a	36.81 ± 2.55 a	30.44 ± 2.33 a	32.24 ± 0.58 a
KB	41.28 ± 12.66 a	36.68 ± 2.62 c	32.85 ± 1.66 a	41.80 ± 7.01 a	34.36 ± 3.51 ab	40.30 ± 8.14 a

Notes: Numbers accompanied by different letters in the same column indicate a significant effect (sig <0.05); Retail (R) in ZECC; Bulky (B) in ZECC; Bulky Control (KB) in Room temperature; Retail Control (KR) in Room temperature

3.9 Organoleptic test

The organoleptic test results on day 15 indicated that the storage method and packaging type influenced the quality of the cherry tomatoes, particularly in terms of aroma and texture. As shown in Table 12, the analysis of variance (ANOVA) revealed highly significant differences ($p < 0.01$) in aroma and texture, while no significant difference was observed in color ($p > 0.05$). Furthermore, the post-hoc test results presented in Table 13 show that treatment R had significantly higher scores for aroma and texture than the other treatments, as indicated by the different superscript letters assigned to each mean value. Storage in ZECC with retail packaging yielded the best results, with the highest

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scores for color (4.08), aroma (4.03), and texture (4.16). The average results of the hedonic test on day 15 for the tomatoes are shown in Table 1.

Table 1. Organoleptic tomato fruit on day 15.

Parameters	KR	KB	R	B
Hedonic test				
Color	3,58	4,06	4,08	3,87
Aroma	3,33	3,54	4,03	3,46
Textures	2,74	4,19	4,16	3,79

Notes: Retail (R) in ZECC; Bulky (B) in ZECC; Bulky Control (KB) in Room temperature; Retail Control (KR) in Room temperature

ZECC with stable temperature (24.5-27.7°C) and high RH (92-96%) effectively maintained the organoleptic quality of cherry tomatoes. Retail packaging prevented excess moisture, resulting in the best aroma score (4.03) and better texture compared with the control. Bulky packaging at ZECC recorded lower scores for aroma (3.46) and texture (3.79) owing to the high humidity. The bulky control recorded the best texture score (4.19), but retail decreased due to water loss. The color was maintained with no significant difference between the treatments. Follow-up test results showed no significant differences in color scores between treatments, indicating that both ZECC and control were effective in maintaining color. Aroma was preferred in ZECC with retail packaging (4.03), whereas texture was better in ZECC with retail and bulky packaging than in the control.

Table 12. p-value of analysis of variance (ANOVA) for organoleptic scores of cherry tomatoes.

Day	P-value	Description
Color	0.209	Not significantly different ($p > 0.05$)
Aroma	0.008**	Significantly different at the 1% level ($p < 0.01$)
Texture	0.002**	Significantly different at the 1% level ($p < 0.01$)

Table 13. Mean organoleptic scores of cherry tomatoes and Tukey's further test results.

Treatment	Parameter		
	Color	Aroma	Texture
R	4.08 ± 0.16 a	4.03 ± 0.07 a	4.16 ± 0.08 a
B	3.87 ± 0.13 a	3.46 ± 0.25 b	3.79 ± 0.09 a
KR	3.58 ± 0.41 a	3.33 ± 0.15 b	2.74 ± 0.56 b
KB	4.06 ± 0.36 a	3.54 ± 0.22 b	4.19 ± 0.30 a

Notes: Numbers accompanied by different letters in the same column indicate a significant effect (sig <0.05); Retail (R) in ZECC; Bulky (B) in ZECC; Bulky Control (KB) in Room temperature; Retail Control (KR) in Room temperature

4. Conclusion

This study showed that Zero Energy Cool Chamber (ZECC) with a combination of 50% sand and 50% zeolite was effective in maintaining temperature and humidity stability during storage of cherry tomatoes, especially with the use of 14-20 mesh zeolite. The combination of ZECC and polypropylene (PP) packaging, especially retail packaging, maintained the quality of cherry tomatoes better than storage at room temperature, with higher sensory quality after 15 days of storage. Cherry tomatoes stored in ZECC with retail packaging had a higher sensory quality than the control, with scores for color (4.08), aroma (4.03), and texture (4.16). The vitamin C content in ZECC with retail packaging remained higher (35.83 mg/100 g) than the control (28.94 mg/100 g), indicating the effectiveness of ZECC in slowing down nutrient degradation. In addition, ZECC suppressed moisture loss and reduced weight loss, keeping the fruit fresh for longer. These findings confirm that ZECC can be an energy-efficient and environmentally friendly storage solution for the horticulture industry, especially for small-scale farmers in areas with limited access to electricity, which can be improved by optimizing the wetting system. For further research, the ZECC wetting system needs to be improved because the water is not evenly distributed, causing the storage room temperature to be higher than the wet bulb temperature. Further studies are needed to optimize wetting, for example, with sensor-based drip irrigation, and to determine the ideal ZECC dimensions for temperature and RH stability.

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