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Article

Quality evaluation of cayenne pepper (*Capsicum frutescens* L.) stored in a Zero Energy Cool Chamber (ZECC), refrigerator, and at room temperature

Achmad Khusnun Nidhom

Faculty of Agricultural Technology, Hasanuddin University, Makassar 90245, Indonesia

Abstract

Cayenne pepper is widely produced and consumed in Indonesia, but high water content makes it highly susceptible to post-harvest damage. Cold storage can extend shelf life by reducing respiration, transpiration, and oxidation, but it is often impractical for farmers due to high costs and limited electricity in rural areas. As an alternative, the Zero Energy Cool Chamber (ZECC) offers an eco-friendly, electricity-free storage method suitable for preserving fruits and vegetables after harvest. This study aims to determine the quality of nutritional value in the Cayenne pepper such as vitamin C, total acid, total dissolved solids, and weight loss of cayenne pepper stored in ZECC, refrigerator and room temperature. And to find out the storage time (days) of cayenne pepper using ZECC, refrigerator and room temperature. The method of this research is that cayenne pepper was stored in 3 types of storage, namely with ZECC, room temperature, and refrigerator until it is damaged. Cayenne peppers stored in the ZECC maintained better vitamin C content, pH, moisture content, total acidity, and total dissolved solids compared to those stored at room temperature or in a refrigerator. ZECC storage also resulted in the lowest percentage of weight loss. Meanwhile, refrigerator storage produced the lowest total microbial counts among the three storage methods. Overall, cayenne peppers can be stored safely and with acceptable quality for up to 9 days in the ZECC, 2 days at room temperature, and 7–9 days in a refrigerator.

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Cayenne Pepper, Microbes, Storage, Vitamin C.

1. Introduction

Cayenne pepper is an agricultural commodity with high production and consumption levels in Indonesia. Its high moisture content causes significant post-harvest damage and losses. Post-harvest losses due to improper handling can reach 20–50% (1). sOne approach to prevent post-harvest damage is the use of cold storage.

Cold storage is one of post-harvest handling method used to maintain the freshness of fruits and vegetables by reducing respiration, transpiration, and chemical oxidation, thereby extending the shelf life of chilies. Lowering the storage temperature is generally beneficial, as its slow down the physiological activity of the chilies. In general, cold storage is carried out using a refrigerator, however this method is difficult apply at the farmer level due to high operational expenses and constraints on electricity supply in rural areas, which are typically agricultural centers(3). Moreover the use of refrigerators can also produce freon, which is not environmentally friendly (4).

* Correspondence : **Achmad Khusnun Nidhom** nidhomkhusnun1@gmail.com

An alternative method that can be used is Zero Energy Cool Chamber (ZECC) storage. ZECC is an environmentally friendly post-harvest technology that does not require electricity and can be used to store fruits and vegetables after harvest. Additionally, ZECC storage technology is relatively inexpensive, as it utilizes only bricks, sand, plastic roofing, and water in its construction (5). The working principle of ZECC is based on water evaporation, which helps lower the temperature, making it more economical and environmentally friendly (6).

Research on fruit and vegetable storage methods using ZECC technology has increased in recent years. Previous study study by (7), which examined the quality of golek mangoes and tomatoes stored in ZECC, while (8) investigated the combination of ZECC storage technology and pre-handling treatments on the quality of golek mangoes. However, no studies have yet examined the quality of cayenne peppers stored in ZECC, thereby highlighting the need for this research.

2. Materials and Methods

2.1. Materials and Tools

The tools and instruments used in this research are measuring cups, blenders, volumetric flasks, horn spoons, test tubes, petri dishes, analytical balances, stirring rods, knives, refrigerators, refractometers, moisture analyzers, colorimeters, and burettes. The materials used in this study were cayenne peppers obtained from chili farmers in Barombong, South Sulawesi, with a color uniformity level of ≥95%, NaOH solution, pH 4 and pH 7 buffer solutions, distilled water, phenolphthalein indicator solution, buffered peptone water, plastic wrap, aluminum foil, 0.1 N iodine solution, tissue and labels, Plate Count Agar (PCA) medium, filter paper, and alcohol.

2.2. Methods

2.2.1. Sample Preparation and Storage

Cayenne peppers were obtained from farmers in Barombong, South Sulawesi, with a color uniformity of ≥95%, and were thoroughly washed before use. The peppers were stored under three conditions: room temperature (28–30°C, RH = 30–70%), refrigerator (12 ± 2°C, RH = 44%), and ZECC (26 ± 2°C, RH = 72.9–87.2%). Quality analyses were conducted every two days for eight days, while qualitative observations were performed daily until the peppers showed signs of deterioration.

2.2.2. Quality Analyses

2.2.2.1. Weight Loss

Weight loss was measured gravimetrically by calculating the difference between the initial weight before storage and the final weight after storage. The weight loss percentage was calculated using the following formula (9):

$$W(\%) = \frac{(mi - mt)}{mi} \times 100\% \qquad (1)$$

ml Iod = Volume of iod used during titration
Fp = Dilution or dilution factor
B = Sample mass (g)

2.2.2.1. Vitamin C

Vitamin C analysis was carried out by dissolving 25 grams sample of cayenne pepper in 100 mL of distilled water, and then filtered. Two milliliters of the filtrate were taken and diluted with 100 mL of distilled water. The absorbance of the diluted solution was measured using a UV-Vis spectrophotometer (10).

2.2.2.2. Total Acid

The sample was ground, weighed, and dissolved in 100 mL of distilled water. Ten milliliters of the sample solution were taken, and 2-3 drops of phenolphthalein (pp) indicator were added. The total acidity was determined by titration with 0.10 N NaOH solution until a constant pink color was observed. The total acidity was calculated using the following formula (11):

$$\text{Total Acid} = \frac{ml\ NaOH \times N \times Fp \times Mr\ NaOH}{weight\ of\ sample} \times 100\% \quad (2)$$

Information:
Ml NaOH = Volume of NaOH used during titration
N = Normality of NaOH (0.1 N)
Fp = Dilution or dilution factor
Mr NaOH = Molar mass of NaOH

2.2.2.3. Microbiological Analyses

The total microbial count was determined using the Total Plate Count (TPC) method. One gram of the sample was mixed thoroughly with 9 mL sterile saline diluent for 1 min using a vortex and serially diluted (10^{-1}-10^{-8}). Subsequently, 1 mL aliquots of each dilution were dispensed on appropriate plates using the standard spread plate method. The plates were incubated at 37°C for 48 hours (12).

2.2.2.4. Total Soluble Solids

Total dissolved solids were measured using a refractometer. The samples were first homogenized using a blender. The prism or lens of the refractometer was cleaned with distilled water, and then 1–2 drops of the sample were placed on the lens. The total dissolved solids, expressed as %Brix, were read digitally on the refractometer display (13).

3. Results and Discussion

3.1. Weight Loss

Weight loss is one of the indicators used to assess the quality of fruits and vegetables. Weight loss during storage can reduce quality and cause physical and chemical damage to the product. One of the main causes of product weight loss is water evaporation from the respiration process (14). The statistics analyses showed that the type of storage (sig. 0.000) and storage duration (sig. 0.000) significantly affected the weight loss of cayenne pepper during storage ($p<0.05$). However, the interaction between storage type and storage duration (sig. 0.116) did not have a significant effect on the weight loss of cayenne pepper during storage ($p<0.05$).

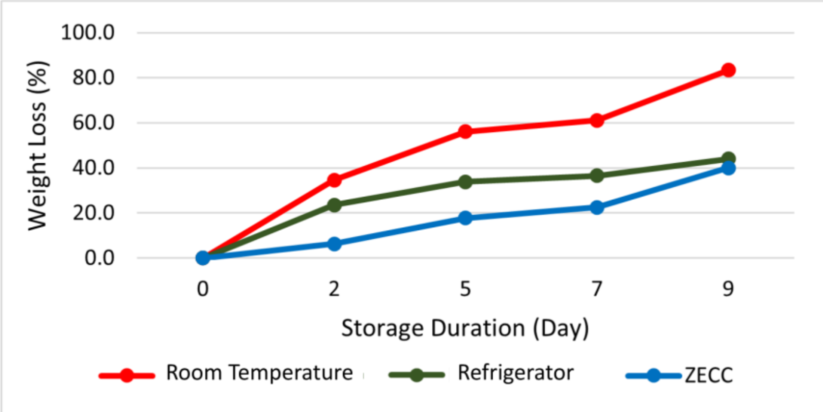

Figure 1. The effect of storage type and duration on weight loss of cayenne peppers.

Figure 1 shows that cayenne pepper stored at room temperature resulted in the highest weight loss compared to those stored in a refrigerator or ZECC. The high weight loss at room temperature was caused by uncontrolled temperature and humidity condition, while the lower weight loss in ZECC storage was due to its controlled humidity (15). Storage temperature and humidity significantly affected the metabolism and respiration of cayenne peppers. An increase in temperature within the range of 0°C to 35°C elevates the respiration rate, thereby accelerating metabolic reactions in cayenne peppers. ZECC storage can reduce product weight loss because it maintains a high air humidity of around ±87.2%, which can reduce transpiration and suppress water loss (7).

High temperatures in room temperature storage cause higher respiration rates, resulting in increased weight loss. In addition, higher temperatures promote transpiration, causing a reduction in the water content of cayenne peppers. The moisture content in a food product tends to equilibrate with the surrounding environment; consequently, water molecules migrate outward, leading to decreased fruit weight (14). Refrigerator and ZECC storage can suppress the respiration process in cayenne peppers, thereby reducing water loss, as both provide optimal temperature and humidity conditions. Low temperatures slow the rate of water evaporation, resulting in a lower rate of weight loss (16).

3.2. Vitamin C

Vitamin C, also known as ascorbic acid, is a water-soluble vitamin that is easily degraded, particularly through oxidation when exposed to oxygen (17). The statistics analyses showed that the type of storage (sig. 0.001) and storage duration (sig. 0.008) significantly affected the weight loss of cayenne pepper during storage ($p<0.05$). However, the interaction between storage type and storage duration (sig. 0.620) did not have a significant effect on the weight loss of cayenne pepper during storage ($p<0.05$).

Based on Figure 2, the vitamin C content of cayenne peppers decreased continuously during storage. On the 9th day, the vitamin C contents of cayenne peppers stored at room temperature, in the refrigerator, and in ZECC were 0.259%, 0.302%, and 0.321%, respectively. Statistical analysis showed no significant difference between refrigerator and ZECC storage. Both storage methods were able to reduce the respiration rate and enzyme activity of cayenne peppers (18). According to previous research, a temperature decrease of 8°C can reduce the reaction rate by half (19).

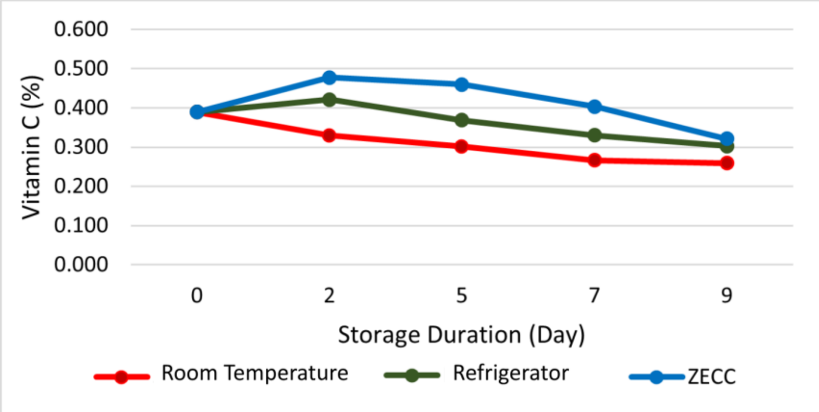

Figure 2. The effect of storage type and duration on vitamin C of cayenne peppers.

Cayenne peppers stored at room temperature exhibited lower vitamin C levels and a faster rate of decline. This is closely related to the characteristics of vitamin C, which is unstable and easily degraded by environmental factors such as oxygen and temperature. These factors promote respiration and oxidation reactions that convert vitamin C into L-dehydroascorbic acid, which subsequently transforms into L-diketogulonic acid, a compound with no vitamin C activity (18). In addition to temperature and oxygen effects, the high humidity maintained during ZECC storage helps slow down the metabolic reactions of cayenne peppers, thereby reducing the rate of vitamin C degradation (20).

3.3. Total Acid

Total acidity refers to the acidic compounds present in a material, which include organic acids such as citric acid, malic acid, and ascorbic acid (21). The statistics analyses showed that the type of storage (sig. 0.226), storage duration (sig. .647), and interaction between storage type and duration (sig. 0.988) had no significant effect on the total acidity of cayenne peppers ($p>0.05$).

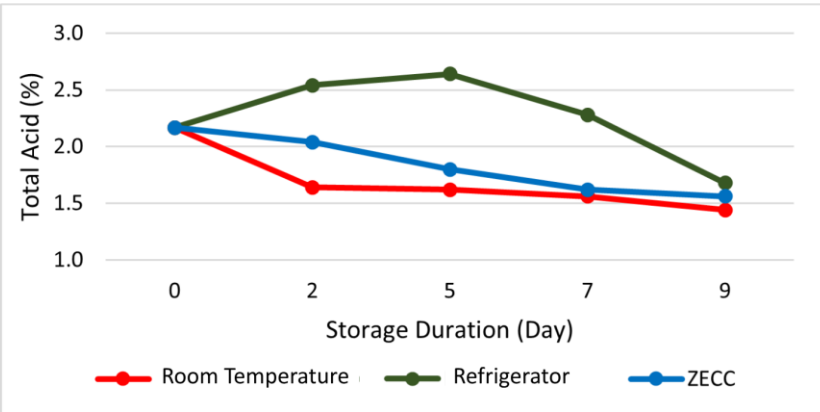

Figure 3. The effect of storage type and duration on total acid of cayenne peppers.

Based on Figure 3, the total acidity of cayenne pepper stored in the refrigerator and at room temperature decreased during storage. However, cayenne pepper stored in the refrigerator experienced an increase in total acidity on day 2 (2.5%) and day 5 (2.7%). On the 9th day, the total acidity of cayenne pepper stored at room temperature, in the refrigerator, and in the ZECC was 1.4%, 1.7%, and 1.6%, respectively. The increase in total acidity observed during refrigerator storage is thought to result from the conversion of glucose into organic acids during metabolic processes (22). Meanwhile, the decrease in total acidity during storage may be attributed to metabolic reactions that utilize substrates such as glucose and organic acids (23). The decrease occurred more rapidly at room temperature because higher temperatures accelerate respiration rates (22).

3.4. Total Soluble Solids

The Total soluble solids in fruits and vegetables are measured using a refractometer and expressed in %Brix, which indicate the concentration of dissolved sugars in the solution (11). The statistics analyses showed that the storage type (sig. 0.018) and storage duration (sig. 0.000) significantly affected the total soluble solids of cayenne pepper during storage ($p<0.05$). However, the interaction between storage type and storage duration (sig. 0.620) had no significant effect on the total soluble solids of cayenne pepper during storage ($p<0.05$)

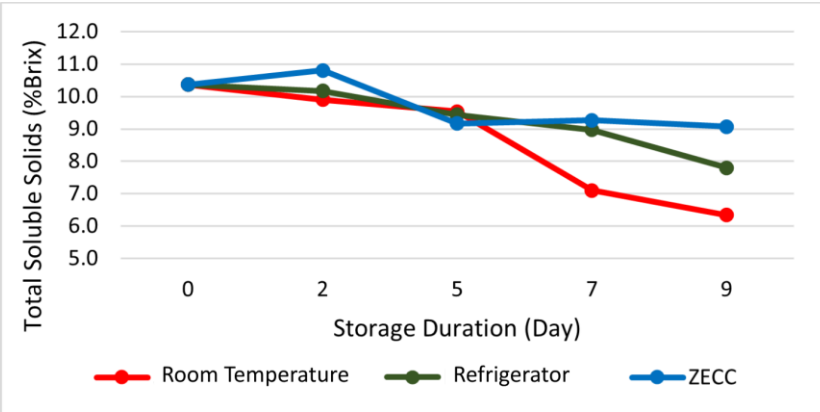

Figure 4. The Effect of storage type and duration on total soluble solids of cayenne peppers.

Based on Figure 4, the total solids content of cayenne pepper stored at room temperature and in the refrigerator decreased consistently to the end of storage. In contrast, in ZECC storage, the content fluctuated but showed an overall decreasing trend. The total soluble solids content of cayenne pepper on the 9th day at room temperature, refrigerator, and ZECC storage was 6.4 %Brix, 7.8 %Brix, and 9.1 %Brix, respectively. The total soluble solids decreased drastically and more rapidly in room temperature storage due to high temperatures, which caused a faster respiration rate and higher metabolic reactions, especially sugar reduction (24). Meanwhile, refrigerator storage at low temperatures caused a slower respiration rate, resulting in lower sugar reduction. In addition to temperature, high humidity in ZECC storage also slows down respiration and inhibits transpiration, thereby reducing sugar content. High ZECC humidity of ±87.2 %Brix (7) can slow down the respiration rate compared to room temperature and refrigerator storage with lower humidity (24).

3.5. Microbial Loads

Food products, including fruits and vegetables, have maximum permissible limits for total microbial counts to ensure food safety and maintain quality. One method commonly used to analyze the number of microorganisms in food is the Total Plate Count (TPC) test, which determines the microbial load by counting colonies that grow on agar media (25). Figure 5 presents the results of TPC analysis of cayenne peppers stored at room temperature, in a refrigerator, and in ZECC.

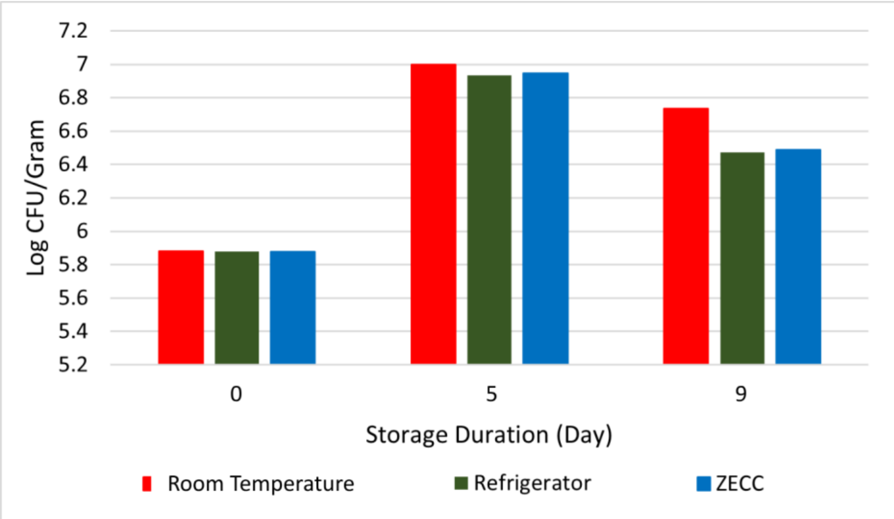

Figure 5. Color change profile of avocado freshness indicators based on hue values.

The total number of microbial colonies in cayenne peppers increased in all treatments on day 5 and decreased on day 9 of storage. At room temperature, the total microbial count reached 7 log cfu/g on day 5 and decreased to 6.74 log cfu/g on day 9. In refrigerator storage, the microbial count was 6.93 log cfu/g on day 5 and decreased to 6.47 log cfu/g on day 9. Similarly, in ZECC storage, the total microbial count was 6.95 log cfu/g on day 5 and decreased to 6.49 log cfu/g on day 9. The increase in microbial count on day 5 was attributed to the rise in glucose content, which serves as a nutrient source for microorganisms, produced during the respiration process (26). In addition, high water content in cayenne peppers creates a favorable environment for microbial growth, particularly fungi. The subsequent decrease in microbial count on day 9, especially in refrigerator storage, was due to the suppression of microbial growth at low temperatures that inhibit enzyme activity and chemical reactions within microbial cells (18). Prolonged storage in the refrigerator approaches the maximum threshold for microbial contamination in cayenne peppers. Low temperatures can slow down physiological activity, respiration, and other metabolic processes, thereby delaying senescence and reducing microbial spoilage caused by bacteria, molds, and yeasts (27).

3.6. Visual Observation of Cayenne Peppers

One indicator of cayenne peppers ripeness is the change in color from dark green to reddish-green and eventually to red, which occurs due to the formation of carotenoid pigments (28). Visual observations of cayenne peppers stored under different conditions revealed several types of damage, including mold growth and the appearance of blackish-brown spots that later developed into soft rot. Water loss during storage caused the fruit to dry and shrivel, accompanied by a change in color from red to blackish-brown. These blackish-brown areas gradually spread, resulting in tissue softening and decay.

Figures 6 present the visual appearance of cayenne peppers stored at room temperature, in the refrigerator, and in ZECC.

Figure 6. Results of visual observation on cayenne peppers during storage at: (a) Room Temperature; (b) Refrigerator; (c) ZECC.

Based on visual observations, cayenne peppers stored in ZECC exhibited the best quality, characterized by brighter colors and better texture. Room temperature storage showed poor visual quality due to black spots and wrinkles on the cayenne peppers. Meanwhile, cayenne peppers stored in the refrigerator maintained bright colors but were watery. The formation of black spots caused by the growth of *Colletotrichum sp*., inducing anthracnose disease, which initially appearing as dark brown spots that spread into soft rot (29). Although refrigerator storage effectively inhibits respiration, low temperatures and high air pressure can cause cayenne peppers to lose water and also trigger chilling injury. Chilling injury causes damage to the cell walls of cayenne peppers, resulting in a wrinkled and watery texture (30). In addition, low respiration rates also inhibit chlorophyll breakdown and reduce carotenoid biosynthesis, which affects the color of peppers (31).

4. Conclusions

Cayenne peppers stored in the ZECC maintained better vitamin C content, pH, moisture content, total acidity, and total dissolved solids compared to those stored at room temperature or in a refrigerator. ZECC storage also resulted in the lowest percentage of weight loss. Meanwhile, refrigerator storage produced the lowest total microbial counts among the three storage methods. Overall, cayenne peppers can be stored safely and with acceptable quality for up to 9 days in the ZECC, 2 days at room temperature, and 7-9 days in a refrigerator.

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Author Contributions

A.K.N. conceived and desig.ned the experiments; A.K.N. performed the experiments; A.K.N. analyzed the data; A.K.N. wrote the paper; A.K.N. monitored the planning and execution of the study

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Data Availability Statement

Available data are presented in the manuscript.

Conflicts of Interest

The author declares no conflict of interest.

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