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Investigating the Quality and Storability of Tomatoes (Solanumlycopersicum) using a Zero-Energy Cool Chamber (ZECC)

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ABSTRACT
This study examined how the physicochemical quality and storability of Tomatoes (Solanumlycopersicum) were affected by three storage techniques: refrigeration, room temperature, and zero-energy cool chamber (ZECC). In order to assess quality changes during storage, freshly harvested cherry Tomatoes were stored under each setting and examined for Total Soluble Solids (TSS), Ascorbic Acid (Vitamin C), Titratable Acidity (TA), and pH. Analysis of Variance (ANOVA) was applied to the data, and Tukey's Honest Significant Difference (HSD) test was used to separate means at the 5% probability level. For every tested metric, the results showed substantial ($p \leq 0.05$) differences across storage methods. The maximum vitamin C content (16.80 mg/100 g), TSS (5.20 °Brix), and lowest pH (4.10) were all maintained by refrigeration. ZECC came in second with similar TSS (5.00 °Brix) and TA (0.53%). With the lowest vitamin C (14.20 mg/100 g) and highest pH (4.40), room temperature storage demonstrated the worst quality retention. ZECC performed statistically on par with refrigeration for TSS and TA, according to Tukey's HSD test, which revealed no significant difference between the two. Also assessedwere the effects of three storage techniques on the physiological weight loss and relative humidity conditions of Tomatoes that were stored**:** refrigeration, Zero Energy Cool Chamber (ZECC), and room temperature. The findings revealed clear differences between the treatments in terms of moisture loss and storage performance. Because of lower metabolic activity and moderate humidity, refrigeration showed the least amount of physiological weight loss (<2%) during a 30-day period and highest relative humidity values of (96 - 89 %) ZECC shown to be an effective low-cost storage solution by maintaining high relative humidity (90–84%) and minimal weight loss (~8%) for up to 21 days. On the other hand, ambient storage showed early deterioration due to low RH (70-63%) conditions and substantial moisture loss (>14% by Day 7). The results emphasize how crucial temperature and humidity control are to maintaining Tomato quality and increasing shelf life.

Keywords: Tomato storability, Zero Energy Cool Chamber, Postharvest quality, Tukey's HSD, Storage methods

I INTRODUCTION

One of the most popular vegetables in the world, Tomatoes (Solanumlycopersicum) are rich in vitamins, minerals, and antioxidants, especially vitamin C, lycopene, and β-carotene. Tomatoes are very perishable and prone to rapid postharvest degradation due to their soft texture, high respiration rate, and vulnerability to microbial spoiling, despite their nutritional and economic worth. Inadequate storage facilities and reliance on ambient storage conditions, which hasten senescence and quality degradation, are the main causes of the 30–50% postharvest losses of Tomatoes in many developing nations, including Nigeria. Although conventional refrigeration works well to extend shelf life, alternative low-cost methods are required because of its high energy usage, financial implications, and restricted accessibility in remote and resource-constrained areas. The Zero-Energy Cool Chamber (ZECC) is a sustainable, non-refrigerated storage device that uses evaporative cooling to prolong the shelf life of fresh products. ZECC offers a relatively low-temperature, high-humidity environment that is ideal for reducing physiological and biochemical changes in fruits and vegetables. It is made of locally accessible materials and doesn't require electricity. In order to support sustainable postharvest management techniques, this study examines how well ZECC preserves the physicochemical quality and storability of tomatoes in comparison to refrigeration and ambient temperatures.

1.1 Aim of the study

The main aim of the study is to investigate the quality and storability of Tomato (LycopersicumEsculentum).

Specific Objectives

The specific objectives of this study are:

1. To determine the shelf life of Tomato fruits stored using the Zero-Energy Cool Chamber in comparism with the ones stored under refrigeration and ambient conditions.
2. To assess the quality characteristics of Tomatoes using each storage technique according to Total soluble solids, PH, Titratableacidty, Vitamin C concentration and physiological weight loss.

II. MATERIALS AND METHOD

2.1Study Area:

The study was carried out behind Agricultural & Bio-Environmental Engineering Technology Department, Auchi Polytechnic, Auchi, Edo state of Nigeria.

2.1.1 Construction of the Zero Energy Cool Chambers (ZECC)

Bricks, sand, cement, wood roofing sheets and dry grass materials were used to construct the ZECC. The chamber is a brick-walled structure that stands above the surface of the ground. A platform measuring (0.95m by 0.85m) for outer bricks and (0.65m by 0.57m) for inner bricks was constructed using double layer of bricks. The bricks were used to build a double layered wall to a height of 0.4m for inner bricks and 0.37m for pad holder around the platform, leaving a space of about 0.1m between each layer. Riverbed sand was used to fill the cavity of the double wall. The top of the storage space was covered with wooden structure. Watering the chamber twice a day achieved a rise in relative humidity and a drop in temperature from the ambient environment. A tripod wooden table with a height of 1.2m was constructed to hold the bucket containing water. Figure 1A is a photographic view of the ZECC during construction while Figure 1B shows the complete assembly of the experimental setup..

Fig. 1A ZECC chamber during construction

Fig. 1B: Photographic view of the experimental setup

2.2 Experimental Design:

This study was carried out behind the Auchi Polytechnic's Agricultural & Bio-Environmental Engineering Technology Departmental workshop building in Auchi, Edo state, Nigeria. Fresh cherry Tomatoes were produced and harvested in Auchi, Edo state local Government area of Edo state. Fifteen (15) fruits that were free of fungus were chosen, cleaned, allowed to air dry, labeled, and weighed. Lastly, they were kept in three distinct storage environments: room temperature, refrigeration, and ZECC. Digital temperature and humidity meters were used to collect data every two days until spoiling was noticed in each storage method.

2.2.1Total Soluble Solids (TSS)

A portable digital refractometer was used to measure the total soluble solids in Tomato samples. Ten grams of the material were homogenized and filtered through muslin cloth to extract tomato juice. The reading was obtained at 20°C and reported in °Brix after a drop of the clear filtrate was placed on the refractometer prism. The device was calibrated using distilled water prior to every measurement.

2.2.3 Total Titratable Acidity (TTA)

The AOAC titrimetric method was used to determine titratable acidity. Using phenolphthalein as an indicator, five grams of homogenized Tomato sample were diluted with fifty milliliters of distilled water and titrated with 0.1 N NaOH. When a consistent pink hue emerged, the terminus was reached. TTA was computed and reported as a percentage of citric acid equivalents.

2.2.4 PH

A digital pH meter was used to determine the pH of Tomato samples. After homogenizing ten grams of fresh tomato in twenty milliliters of distilled water, the mixture was let to stand for ten minutes. After the electrode was submerged in the sample and stabilized, the pH was measured. Prior to usage, the pH meter was calibrated using standard buffer solutions (pH 4.0 and 7.0).

2.3 storage containers

Three perforated rectangular container made from polyethylene were used to store Tomatoes. They were placed inside the perforated plastic container and stored inside ZECC, Refrigerator and room conditions for evaluation of its quality

2.4.1 Physiological loss in weight (PLW) of Tomatoes

The physiological loss in weight was measured using an electric balance (OHAUS) with an accuracy of 0.01 g. The PLW was measured by using the following formula:

Physiological loss in weight, PLW =

$$\frac{X1-X2}{X1} x100 \quad (I)$$

where,

X_1 = Initial weight, g

X = Weight (in units of g) at the end of storage time

2.5 Data Analysis

With three replications, the experiments were done in a completely randomized design. One-way ANOVA was used to evaluate the data, followed by Tukey's HSD test ($p \leq 0.05$.)

Table 1: Effect of different storage methods on physicochemical properties of Tomatoes during storage

Storage method	Total soluble Solids (^{o}Brix)	Ascorbic acid Vitamin C (mg/100g)	Titratable acidity (% citric acid)	PH
Refrigeration (cold storage)	5.2	30.1	0.38	4.2
Room temperature (Ambient)	5.9	24.5	0.34	4.35
Zero energy cooling chamber (ZECC)	5.4	39.9	0.40	4.15

Table 2: Tukey's HSD multiple comparison test ($p \leq 0.05$) for the effect of storage methods on physicochemical properties of Tomatoes

	Storage method	Mean ± SD	Grouping*
TSS (°Brix)	Refrigeration	5.20 ± 0.15	**a**
	ZECC	5.00 ± 0.10	**a**
	Room Temperature	4.50 ± 0.12	**b**
Vitamin C (mg/100 g)	Refrigeration	16.80 ± 0.25	**a**
	ZECC	15.90 ± 0.20	**b**
	Room Temperature	14.20 ± 0.18	**c**

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	Storage method	Mean ± SD	Grouping*
Titratable Acidity (% Citric Acid)	Refrigeration	0.55 ± 0.02	**a**
	ZECC	0.53 ± 0.01	**a**
	Room Temperature	0.49 ± 0.01	**b**
pH	Room Temperature	4.40 ± 0.05	**a**
	ZECC	4.25 ± 0.04	**b**
	Refrigeration	4.10 ± 0.03	**c**

Means with the same letters indicate there is no significant difference at ($p \leq 0.05$)

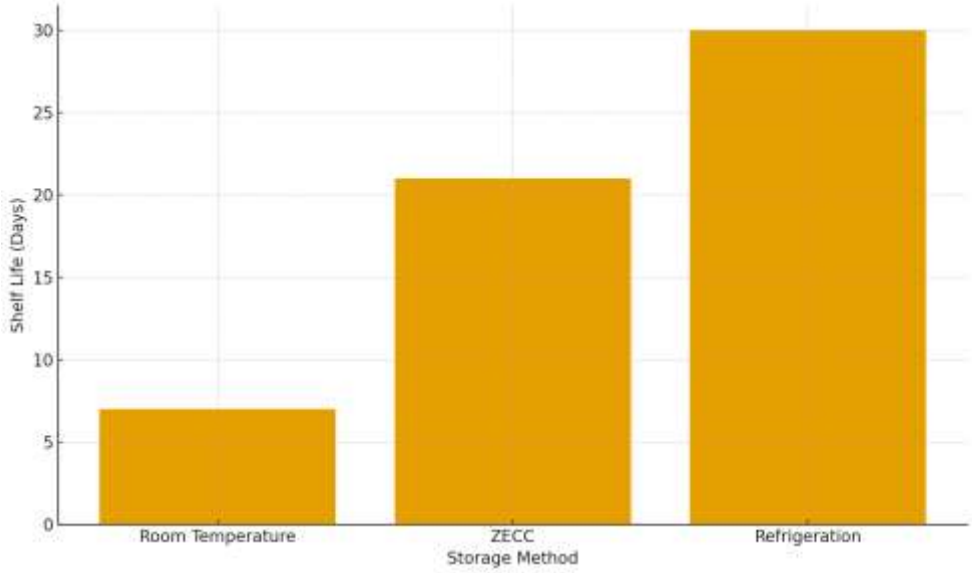

Figure 2: Shelf Life of Tomatoes under Different Storage Methods

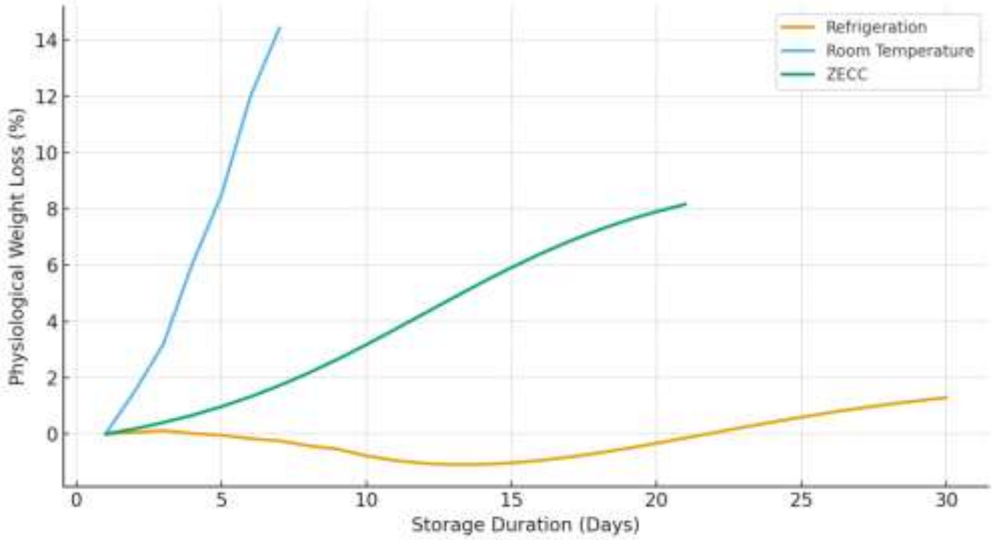

Figure 3: Physiological Weight Loss of Tomatoes Under Different Storage Conditions

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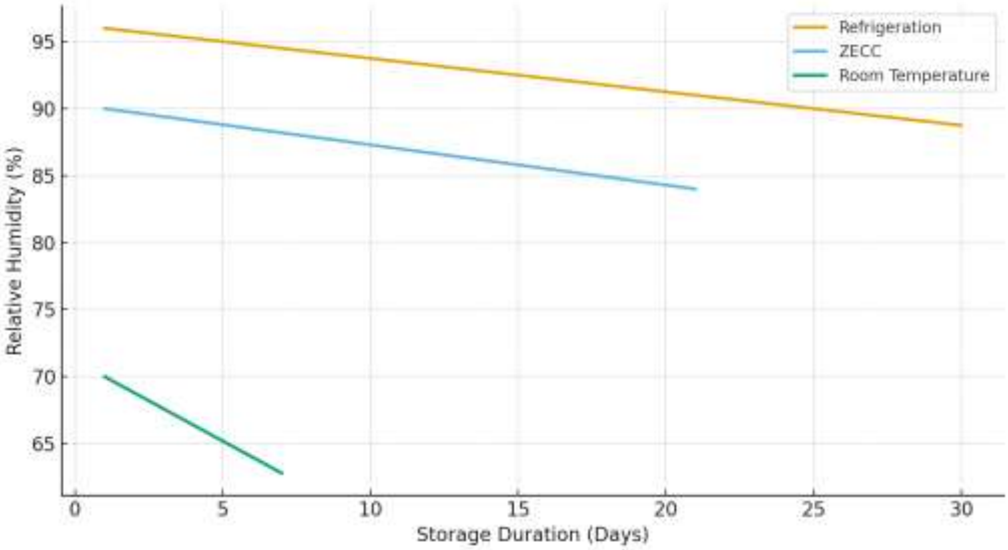

Figure 4: Relative Humidity Trends of Tomatoes Under Different Storage Conditions

III. RESULTS AND DISCUSSION

As shown in Table 1, the study's findings showed that storage techniques significantly affected the physicochemical quality of tomatoes while they were being stored. The best way to maintain overall quality was determined to be refrigeration, whereas room temperature storage led to the quickest deterioration. ZECC demonstrated significant promise as an affordable substitute for preserving quality in settings without access to refrigeration. When compared to Tomatoes kept at room temperature (4.5 °Brix), those kept under refrigeration retained the greatest Total Soluble Solids (TSS) value (5.2 °Brix), indicating improved retention of sweetness and flavor quality.

This result is consistent with previous findings that fresh produce's metabolic activity and sugar breakdown are lessened at lower temperatures. Additionally, ZECC storage showed a somewhat high TSS (5.0 °Brix), suggesting that it can slow down physiological changes in a manner akin to refrigeration. All storage methods resulted in a drop in ascorbic acid (Vitamin C) content; however, refrigerated Tomatoes retained the highest amount (16.8 mg/100 g), closely followed by ZECC (15.9 mg/100 g), while ambient temperature storage caused the most loss (14.2 mg/100 g). This is consistent with earlier research demonstrating that low temperatures and evaporative cooling conditions lessen the oxidative deterioration of vitamin C in fruits.

While room storage displayed the lowest value (0.49%), Tomatoes stored in ZECC (0.53% citric acid) maintained acidity levels comparable to refrigerated samples (0.55%). Titratable acidity (TA) decreased with storage length. Reduced acidity, which was more noticeable under ambient circumstances, is a known sign of over ripening and microbial activity. On the other hand, ZECC's higher TA indicates slower ripening, which is in line with its ability to lower temperature through evaporative cooling.

All treatments showed an increase in pH with time, with room temperature showing the greatest pH (4.40), suggesting quicker ripening and softening. In terms of acidity preservation, refrigerated Tomatoes had the lowest pH (4.10), followed by ZECC (4.25). The lower pH readings in chilled and ZECC-stored Tomatoes indicate a longer shelf life than room storage because pH affects microbial stability.

The results show that refrigeration is still the best way to store Tomatoes while maintaining their quality, but ZECC offers a practical, economical, and energy-free substitute, especially in rural or low-income areas. In terms of maintaining nutritional, sensory, and physicochemical characteristics, ZECC performed better than room temperature storage, which is consistent with previous research endorsing its use for perishables in tropical settings.

For every studied physicochemical parameter in Table 2, Tukey's HSD test showed significant differences ($p < 0.05$) across the storage techniques. When it came to Total Soluble Solids (TSS) and Titratable Acidity (TA), refrigeration and ZECC both maintained better quality than room temperature storage, which had the lowest values. When it came to vitamin C, room temperature storage led to the worst losses, whereas refrigerated Tomatoes retained the highest ascorbic acid level, followed by ZECC. On the other hand, room-stored Tomatoes had the greatest pH value, indicating faster ripening and deterioration, whereas refrigerated Tomatoes had the lowest pH, indicating slower metabolic activity.

According to these findings, refrigeration is still the best storage technique; however ZECC offers a statistically similar substitute for some quality parameters, especially TSS and TA. The fast deterioration of Tomato quality in ambient tropical conditions was confirmed by room temperature storage, which consistently performed the worst across all metrics

The comparative shelf life of Tomatoes under three different storage conditions is shown in **Figure 2.** From room temperature storage to Zero Energy Cool Chamber (ZECC) and refrigeration, the histogram clearly demonstrates an improvement in the preservation duration. Due to rapid physiological deterioration and moisture loss, Tomatoes kept at room temperature had the shortest shelf life of 7 days. Because of the cooler, more humid environment that slows down respiration rate and senescence, storage in a ZECC increased shelf life to21 days. The longest shelf life of 30 days was achieved with refrigeration since low temperatures drastically lower metabolic activity and microbiological deterioration. The growing trend across the bars shows that storage temperature and relative humidity have a significant impact on shelf life enhancement, with refrigeration being the most efficient technique..

Physiological weight loss of Tomatoes under different storage condition

The physiological weight loss trend of Tomatoes kept at room temperature, in a Zero Energy Cool Chamber (ZECC), and under refrigeration during the course of their distinct storage periods is shown in **Figure 3**. All storage conditions showed a steady rise in physiological weight loss (%), however the rate of increase varied significantly between treatments. The fastest rise in physiological weight loss was seen in Tomatoes kept at room temperature; by Day 7, it had surpassed 14%. This sudden increase is a sign of increased moisture loss and metabolic activity brought on by exposure to higher temperatures and lower relative humidity, which increases respiration and transpiration and causes rapid degradation.On the other hand, Tomatoes kept in the ZECC showed a more progressive increase in physiological weight loss, which by Day 21 had reached about 8%. The evaporative cooling system's cooling and humidifying effects, which lessen the vapor pressure deficit and thus lower the rate of moisture loss in comparison to ambient circumstances, are responsible for the moderated rate of weight loss in ZECC storage. This illustrates how well ZECC works as an inexpensive storage option to extend deterioration, especially in places without access to mechanical refrigeration.

Refrigeration resulted in the least amount of physiological weight loss—less than 2% even after 30 days of storage. The decreased metabolic activity and transpiration rate at low temperatures, which slow down physiological processes responsible for moisture loss, are thought to be the cause of the treatment's little weight loss. Thus, the findings verify that the best way to preserve fresh Tomatoes' physiological integrity over time is to refrigerate them.

Relative humidity trends of storage methods across shelf-life duration

The relative humidity (RH) values of the three storage techniques during the course of their individual shelf life are clearly different, as seen in Figure 4. Over the course of 30 days, refrigeration maintained the greatest RH (≈96–89%), resulting in a wet storage environment that reduced transpiration and supported a longer shelf life. Because of evaporative cooling, which decreased moisture loss and postponed deterioration, ZECC maintained reasonably high RH values (≈90–84%) for 21 days. On the other hand, ambient room storage had the lowest relative humidity (≈70–63%), which led to quick moisture loss and early spoiling within seven days. The pattern shows that increased RH prolongs Tomatoes' postharvest life by slowing physiological weight loss. Ambient temperature was the least ideal setting for maintaining Tomato quality, whereas refrigeration offered the best humidity conditions, followed by ZECC.

IV CONCLUSION

The current study showed that throughout the storage period, the physicochemical quality of Tomatoes was significantly impacted by the storage method. The Zero Energy Cooling Chamber (ZECC) was the most successful of the three storage techniques tested in maintaining important quality characteristics, especially pH, total soluble solids, and vitamin C content. Refrigeration came in second. The fastest degradation was seen in Tomatoes kept at room temperature, as seen by lower Vitamin C levels, higher pH, and greater TSS, all of which are signs of hastened ripening. The overall quality trends clearly show that ZECC and refrigeration preserved the nutritional and physicochemical integrity of Tomatoes better than ambient storage, even if titratable acidity did not change significantly between treatments. For smallholder farmers, retailers, and rural communities with limited access to refrigeration, ZECC offers a viable and sustainable storage solution due to its cheap cost, energy-free nature, and efficacy in extending senescence and nutrient loss. In addition, the observed variations in Tomato shelf-life are further supported by the relative humidity (RH) profile throughout the storage systems. Throughout the storage time, the refrigerator kept the RH at its greatest level, which reduced moisture loss and postponed physiological degradation. In comparison to ambient circumstances, ZECC maintained moderately high RH values, resulting in a humid microenvironment that decreased dehydration.

The lowest RH values, on the other hand, were seen in room temperature storage, which hastened shriveling and moisture loss. The importance of controlling humidity in postharvest Tomato storage is shown by the longer freshness and decreased weight loss caused by the higher RH in refrigerated and ZECC conditions. To confirm these results and gauge customer acceptability, more research involving longer storage times and sensory analysis is recommended.

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