

**DEVELOPMENT OF A SOLAR-POWERED COLD STORAGE FOR
TOMATO FRUITS PRESERVATION**

BY

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ABSTRACT

Post-harvest losses of tomato fruits present a significant challenge in agricultural production, especially in areas lacking reliable electricity. This research developed and assessed a solar-powered cold storage system designed to extend tomato shelf-life. The system featured a 4-litre insulated chamber with two Peltier modules, heat sinks, CPU fans for air circulation, a 12V-12Ah battery, a 100W solar panel, charge controller, and temperature control. Design calculations indicated a cooling power requirement of 23W with total system load of 158W. Performance evaluation indicated 67.71% cooling efficiency, decreasing chamber temperature from 31°C to 21.6°C within 60 minutes under no-load conditions, and maintaining 23.3 to 24.5°C during loaded operation. Comparative storage trials conducted over 12 days showed substantial differences between cold-stored and ambient-stored tomatoes. Cold storage prevented physiological weight loss to 3.39% compared with 26.73% for ambient storage, maintained firmness at 163.67 N/m² compared to 207.33 N/m² for controls, preserved moisture content at 11.41% against 10.07%, and minimized colour changes. Both conditions maintained stable pH values (4.1 for cold storage versus 4.0 for ambient). The research confirms that solar-powered cold storage offers a practical, sustainable solution for minimizing tomato losses in regions with inadequate grid electricity, substantially extending shelf-life while preserving marketability qualities.

Keywords: *Post-harvest losses, solar-powered system, cold storage, shelf-life extension, sustainable technology.*

1 INTRODUCTION

Fresh fruits and vegetables start to deteriorate as soon as they are harvested because they are cut off from their source of water and nutrition. They began to lose weight, texture, flavour, nutritive value, and appeal. Cooling on the other hand significantly slows down the rate of deterioration, thereby increasing the storage life of the produce. Sizeable quantity of produce deteriorates by the time it reaches the consumer due to inappropriate handling methods. This is mainly because of the perishable nature of the produce which requires a cold chain arrangement to effectively maintain the quality and extend the shelf-life (Ogunjirin *et al.*, 2024).

Commercial produce is stored at temperatures slightly above the freezing point to maximise its shelf life and ensure it can be transported over long distances.

In this situation, long storage times at very low temperatures may not be needed, and the high cost for commercial or industrial-grade cooling equipment is difficult to justify. But fresh produce will still deteriorate substantially within a day or two if it is not cooled at all from ambient conditions, especially during the hot summer months. Lower-cost cold storage options can benefit market growers by helping them to preserve produce freshness and quality for a few additional days (Sharma, 2021). Produce losses can be significantly reduced, especially for growers transitioning to a higher level of production who have excess produce to carry over from one day's market to the next. Cold storage is a critical component in the food supply chain. Without rapid cooling and appropriate storage conditions, produce deteriorates rapidly.

Nutritional losses and even spoilage of the entire crops can occur. Initial rapid cooling to extract latent field heat extends shelf life and maintains quality produce. Cold stores intended for long-term holding of produce are designed close to produce areas (Kumar *et al.*, 2021). They will source produce during harvest season and store in bulk, without undertaking any retail packaging. During off season periods, the chambers are periodically opened and product released to the market (NHB, 2015). To provide a diversity of vegetables over a long season, small-scale vegetable producers need to use energy efficient cold storage methods to reduce costs and extend the revenue period while maintaining produce quality and freshness.

Modern cooling technologies have been increasingly recognized as a promising tool to address a multitude of challenges emerging in increasingly complex food systems in developing countries, including food loss and waste, food safety, food and nutrition security; poverty, economic growth; and environmental sustainability. Cold storages have been increasingly important technologies to reduce food loss and food waste globally, including developing countries, by reducing microbial growth that causes spoilage (IFPRI 2020; Mayton, 2020; Kashyap and Agarwal 2020).

According to Natarajan *et al.* (2023), conventional cold storages typically require a reliable and consistent power supply to operate refrigeration systems and other necessary equipment. The power supply for conventional cold storage is obtained from the local electrical grid. Due to the lack of electrical power infrastructure in many rural remote agricultural areas, a diesel generator

is used to generate power to operate their refrigeration systems and other necessary equipment. While diesel generators provide a reliable source of power for cold storages system, Diesel generators emit pollutants such as nitrogen oxides (NO_x), particulate matter (PM), sulphur dioxide (SO₂), and carbon monoxide (CO) (Kumar *et al.*, 2023). These emissions contribute to air pollution and can have adverse health effects on both human beings and the environment. Researchers are looking for energy-saving and environmentally beneficial ways to keep fresh fruit in a low-temperature cold storage system because the vapour-compression refrigeration-based standard cold storage uses more energy and influences the environment globally (Natarajan *et al.*, 2023). Solar energy-based cold storage systems are now becoming technologically and economically viable alternatives to grid power and can be deployed in far-off remote places. For running solar-powered cold storage, battery backup units are provided to store solar power generated during the daytime and supply it during night-time and cloudy weather conditions. Inadequate solar Photovoltaic (PV) generation often leads to power loss in the running of cold storage units. Hence, a proper design of the system is needed to fulfil the power consumption of a cold storage unit with a correct PV size (Singh *et al.*, 2021). Moreover, the power consumption needed for the cold storage unit depends on the weather conditions at the location of its installation. Mostly, the cold storage is designed to regulate and run at a temperature range of 5 to 10 °C, depending on the requirement of different fruits and vegetables (Sharma *et al.*, 2022).

Therefore, this study aimed to develop a cold storage system for preservation of tomato fruits using locally sourced and available materials.

2. MATERIALS AND METHODS

The experiment was carried out at Agricultural Engineering Laboratory (8°10'04.3"N 4°16'09.3"E) and Food Chemistry Laboratory (8°10'04.8"N 4°16'06.9"E), LAUTECH, Ogbomoso.

2.1 Cold Storage System Components

i. Peltier module

It acts as a heat exchanger. The amount of cooling produced by the module depends on the type of the module used and how much power it is supplied. A (TEC1-12706) module with 60W capacity was used based on the amount of total cooling needed for the tomato fruits storage.



Plate 1: Peltier module

ii. Aluminum heat sink

The aluminium heat sink was used to facilitate the transfer of heat from the surface of the thermoelectric.



Plate 2: Heat sink

iii. Direct current fans

12V Central Processing Unit (CPU) fans was used for uniform air circulation inside the chamber. The fans were placed at the front centre position so that the air could come through all the sides of the pads.



Plate 3: DC fans

iv. Battery

A 12V 12Ah storage battery was selected based on capacity to keep the system working in the absence of sun light that provides power to the system.



Plate 4: Battery

v. Insulated box

A 4 litres rectangular insulated box was used as the cold storage box in which the cooling system was mounted and the tomatoes was loaded.



Plate 5: Insulated box

vi. Solar panel

A solar panel is a photovoltaic module which consists of photovoltaic (PV) cells. When this material is exposed to sunlight, it produces an electric current through a physical process known as the "photovoltaic effect". A 12V 100W solar panel was used.



Plate 6: Solar panel

vii. Charge controller

A charge controller was used to regulate the rate at which current is added to or drawn from electric batteries.



Plate 7: Charge controller

viii. Monitoring system

A digital WC3032 temperature control with NTC10K temperature probe sensor was used to monitor and regulate the temperature in the cold storage box.



Plate 8: Temperature control

2.2 Thermal Properties of Tomatoes.

Food water content has a significant impact on their thermal characteristics. Tomato specific and latent heats were determined by looking at their water content. Siebel's formula was used to express the specific temperatures of tomato. Equation 1 shows the relationship;

$$C_p, \text{ fresh} = 3.35a + 0.84 \quad 1$$

Where:

$C_p, \text{ fresh}$ is the food's specific heats before and after freezing, respectively.

a is the fraction of food's water content.

$0.84 \text{ kJ/kg } ^\circ\text{C}$. is the food's solid (non-water) portion's specific heat constant

2.3 Design Calculations

1. Cooling Power.

This is the amount of heat energy that is need to be removed in order to achieve the desired temperature, and it was calculated using Equation 2.

$$P = \frac{M \times c \times \Delta T}{t} \quad 2$$

Where:

P is the cooling power (W)

M is the mass of tomatoes (kg)

c is the Specific Heat Capacity of tomato (kJ/kg)

ΔT is the temperature difference ($^\circ\text{C}$)

t is the time of cooling (s).

2. The size of the box.

It was determined based on the volume of tomatoes to be stored. And it was determine using Equation 3.

$$V = \frac{M}{\rho} \quad 3$$

Where:

V is the volume of tomatoes (L)

M is the mass of tomatoes (kg)

ρ is the density of tomatoes (kg/L)

3. Number of Thermoelectric (TEC) required.

$$\text{No. of TEC} = \frac{\text{Cooling power}}{\text{power per module}} \quad 4$$

4. Battery capacity

$$\text{Battery capacity} = \frac{\text{Total power}}{\text{Battery voltage}} \quad 5$$

5. Cooling efficiency

$$\text{Cooling efficiency} = \frac{T_{db} - T_c}{T_{db} - T_{wb}} \times 100 \quad 6$$

Where:

T_{db} is the dry bulb temperature ($^{\circ}\text{C}$)

T_{wb} is the wet bulb temperature ($^{\circ}\text{C}$)

T_c is the cold box temperature ($^{\circ}\text{C}$)

2.4 Design Consideration

- i. A 100W solar panel was used in order to save the useful life of the battery.
- ii. The shape of the evaporative cooling system is rectangular, to provide a large surface area for air movement.
- iii. The box was wrapped with aluminium foil for good air conduction.

2.5 Statistical Analysis and Tests.

The tomatoes stored in the cold storage box and under ambient temperature (control) was subjected to some tests such as firmness test, pH test, colour change test, weight loss, and

moisture content determination. Moreover, the data collected was computed using Microsoft Excel Spreadsheet.

i. Weight loss determination

A digital weighing balance was used to determine the physiological weight loss of both the tomatoes stored under ambient temperature and the ones that was stored in the cold storage chamber.

$$\% \text{ Weight Loss} = \frac{M_1 - M_2}{M_1} \times 100 \quad 7$$

Where:

M_1 is the mass measured before.

M_2 is the mass measure after.

ii. Firmness test

The firmness of tomato was measured using penetrometer. The test was conducted on both the tomatoes stored under the ambient condition and on the one stored in the cold storage developed.

iv. pH test

Both samples of tomato stored under the ambient temperature and the one in the cold box was grinded using mortar and pestle and was diluted with 100mL of distilled water and was later filtered. The solution was tested with pH meter and the result was recorded.

iv. Color change test

The solution that contains tomato and distilled water was poured into cuvette and was placed into the colorimeter to determine the colour changes in tomato stored under ambient temperature and the one in the cold storage box respectively.

v. Moisture content

The moisture content of the tomato was determined using oven drying method. Three samples were prepared in a slurry form and placed in a petri dish with 5g mass measured from each sample of tomato stored under ambient temperature and the one stored in the cold storage box was kept in the electric oven at temperature of 60°C for about 5 hrs. The initial and final weight for each sample were recorded.

3. RESULTS AND DISCUSSION

3.1 Design and Construction.

A solar-powered cold storage system with 4 litres capacity of storage chamber consists of insulated box, cooling unit and solar unit was designed and constructed as shown in Plate 9.

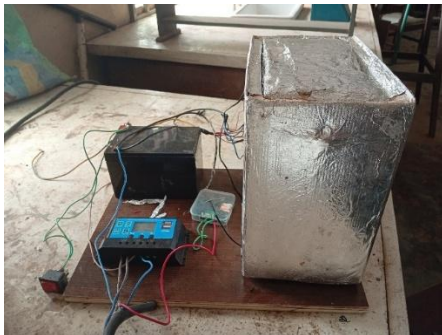


Plate 9: Full Setup of the Cold Storage System.

3.2 No-Load Test and Evaluation of the Cooling Box.

The result of the testing carried out are presented in Table 1 and 2 respectively. However, for the first trial test, the box temperature gradually decreases from about 24.5°C to around 21°C over the first hour while the ambient temperature remains constant at 28°C (Table 1). However, the

results of second test revealed that the box temperature gradually decreases from about 25°C to around 22°C for 2 hours while the ambient temperature remains constant at 26°C (Table 2).

Table 1: The result of No-load test for 1 hour.

S/N	Time (Mins)	Ambient Temperature (°C)	Box Temperature (°C)
1	0	28.0	32.0
2	1	28.0	31.0
3	3	28.0	30.0
4	3	28.0	29.0
5	6	28.0	28.0
6	11	28.0	27.0
7	14	28.0	26.0
8	18	28.0	25.0
9	22	28.0	24.0
10	40	28.0	23.0
11	47	28.0	22.0
12	60	28.0	21.6

Table 2: The Result of No-load Test for 2 hours.

S/N	Time (Mins)	Ambient Temperature (°C)	Box Temperature (°C)
1	0	26	24.5
2	4	26	24
3	11	26	23.5
4	20	26	23
5	22	26	22.5
6	26	26	22
7	32	26	21.5
8	42	26	21
9	60	26	21.4
10	84	26	22
11	120	26	22.4

3.3 Load Test and Evaluation of the Cooling Box.

The box was loaded with 1 kg of tomato. The system was observed until the cooling that is required to stored tomato was achieved. The temperature changes were recorded against the time and the result of the experiment is presented in Table 3. The box temperature steadily decreases over time from 31.2 °C to about 23.3 °C, eventually stabilizing below the ambient temperature of 30.6 °C.

Table 3: The Result of Load Test.

S/N	Time (Mins)	Ambient Temperature (°C)	Box Temperature (°C)
1	0	30.6	31.2
2	10	30.6	28.2
3	25	30.6	25.2
4	60	30.6	24.2
5	120	30.6	24.0
6	130	30.6	23.8
7	150	30.6	23.7
8	160	30.6	23.3

3.4 Effects of Storage on the Weight and Physiological Properties of Tomato.

The results after 12th day of storage show clear differences between tomatoes stored under ambient condition (control) and those stored under cooling (cold storage). Initially, both groups started with the same weight (1000 g). However, over time, the control group showed a more rapid decline in weight compared to the cooled group. By day 4, the control tomatoes had already reduced to 870 g, while cooled tomatoes maintained a higher weight of 981.5 g. This trend continued through day 8 and day 12, where control

tomatoes declined further to 792.2 g and 732.7 g respectively, whereas cooled tomatoes retained much higher weights of 970.3 g and 966.1 g.



Plate 10: The Conditions of the Tomatoes on 1st day of Storage.



Plate 11: The condition of the control sample on 12th day of Storage.



Plate 12: The condition of the cold stored sample on 12th day of Storage.

Table 4: Physiological Weight Loss of Control and Cold Stored Tomatoes for 12 Days

Day(s)	Cold stored Sample (g)	Control Sample (g)
1	1000.00	1000.00
4	981.50	870.00
8	970.30	792.80
12	966.10	732.70

This indicates that cooling significantly reduces the rate of physiological weight loss in tomatoes. The reduced weight loss can be attributed to slower respiration and transpiration rates under low temperature. Cooling minimizes water loss, delays softening, and maintains firmness for a longer period, thereby extending the shelf life of tomatoes.

In contrast, tomatoes stored under ambient conditions experience accelerated respiration and water loss, leading to greater weight reduction, faster deterioration, and reduced market quality. However, plates 10, 11 and 12 shows the conditions of the tomatoes in day one of storage and the results after 12th day of storage.

3.5 Effects of Storage on the Moisture Content of Tomato.

The percentage moisture content (MC) of tomato samples stored under ambient condition after 12th day of storage were 9.59, 9.74, and 10.87 %, with average moisture content of 10.07% while the one stored in the cold box after 12th day of storage were 11.62,

9.15, and 13.46 % with average moisture content of 11.41 %. This indicates that the tomatoes contained relatively high-water content, which is consistent with the physiological nature of fresh tomatoes as a perishable fruit. The slight variation among samples could be attributed to differences in initial ripening stage, varietal composition, and handling during storage. Generally, the average value falls within the range reported for fresh tomatoes (10 – 12%), confirming the freshness of the samples used (Bapary *et al.*, 2024).

3.6 Effects of Storage on the pH Tomato.

After the 12th day of storage, the pH values of the control samples remained constant at 4.0, while tomatoes stored in the cold chamber had a slightly higher value of 4.1. This suggests that storage temperature had a minimal effect on pH within the experimental period. Tomatoes are naturally acidic fruits with a pH range of 4.0–4.5, and the observed values align with literature reports. The slightly higher pH in stored samples may be due to reduced enzymatic and microbial activities at low temperature, thereby slowing down acid degradation.

3.7 Effects of Storage on the Firmness of Tomato.

After the 12th day of storage, control samples recorded higher firmness values (207.33 N/m²) compared to stored samples (163.67 N/m²). This implies that tomatoes stored under ambient conditions tend to soften faster due to higher rates of respiration and enzymatic activity leading to cell wall breakdown. In contrast, (Liu *et al.*, 2019) found out that cold storage significantly slowed down the softening process, thereby

maintaining firmness. This agrees with previous studies that storage at low temperature delays ripening and prolongs shelf life.

3.9 Effects of Storage on the Color Change of Tomato.

The control samples recorded slightly higher readings (0.23, 0.22, 0.24) with 0.23 average compared to the stored samples (0.21, 0.20, 0.21) with 0.21 average after the 12th day of storage. This indicates that tomatoes stored under ambient conditions experienced more rapid pigment changes (lycopene and carotenoid development) than those under cold storage. Color development in tomatoes is strongly influenced by temperature; low temperature slows down lycopene synthesis, thereby maintaining greener fruit for longer. This trend indicates that although cold storage is effective in reducing respiration and delaying ripening, moisture condensation and prolonged low temperature may have contributed to higher weight loss compared to ambient conditions. Such losses could be due to transpiration and metabolic activities occurring even at low temperature.

Table 5: Summary of the Test Results

Test	Control	Stored
Moisture content	10.07%	11.41%
pH	4.0	4.1
Firmness	207.33N/m ²	163.67N/m ²
%Weight loss	26.73%	3.39%
Color change	0.23	0.21

4 CONCLUSIONS

This study successfully achieved its aim of developing a prototype solar-powered cold storage system for tomato fruits preservation. Therefore,

- The solar-powered cold storage system was designed and constructed using locally available materials, and it operated effectively within the desired temperature range suitable for tomato preservation. This demonstrates the feasibility of renewable energy-based cold storage as an alternative to conventional grid-powered systems.
- Performance evaluation of the cold storage system showed that it significantly reduced storage temperature compared to ambient conditions. The system maintained a stable cooling environment, proving its reliability and efficiency in preserving perishable crops without dependence on unstable grid electricity.
- Comparative tests between cold-stored and ambient-stored tomatoes revealed that the developed system reduced physiological weight loss, delayed firmness deterioration, minimized colour changes, and maintained moisture content. These outcomes confirm that solar-powered cold storage extends the shelf-life and market value of tomatoes compared to ambient storage.

In conclusion, this study has addressed some Sustainable Development Goals (SDGs) such as; SDGs 2 (Zero hunger), SDGs 7 (Affordable and clean energy), SDGs 8

(Decent work and economic growth), SDGs 9 (Responsible consumption and production), SDGs 12 (Climate action), and SDGs 13 (Decent work and Economic growth) and the upscaled developed device is hereby recommended for tomatoes preservation.

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