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Mini cold storage using the parabolic solar trough: An appropriate technology for perishable agricultural product

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This article contributes to:

Highlights:

- Harnessing solar energy in a vapor absorption system to supply the energy for mini cold storage was reported
- Using this mini cold storage, the preservation time increased significantly from a few days to a few weeks
- The concept of this novel is appropriate to be applied on a domestic scale

Abstract
Limited storage of perishable agricultural products is a common problem for small-scale farmers. Therefore, our approach for this problem is to develop a low operating cost mini cold storage using solar energy. The integration of solar thermal energy with vapor absorption refrigeration systems was studied. In vapor absorption systems, heat energy is taken as the source of input energy and the performance characteristics depend on heat energy supplied and pump work used. The novelty of our project is that it uses a parabolic solar heat collector to run a vapor absorption refrigeration system using heat energy extracted from solar energy. In this cyclic process, the refrigerating effect is produced. By utilizing this mini cold storage system, tomatoes can be stored for four weeks whereas, with room temperature storage, it only lasts one week. This appropriate technology promises small-scale farmers to keep their perishable agricultural products for several weeks without additional storage costs.

Keywords: Solar energy, Parabolic trough, Vapour absorption, Mini cold storage

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1. Introduction

India is the third country in terms of tons of food wastage. The main reasons behind this wastage include the unutilized scientific methods while harvesting and improper utilization of the cold chain [1]. So, a large amount of food is wasted due to the lack of underutilization of cold storage. Hence, to overcome this problem, we focussed on a sustainable and cost-effective solution of harnessing solar energy in producing the refrigerating effect and trying them in the storage of tomatoes. Tomatoes are perishable agricultural products that are most susceptible to atmospheric conditions [2].

The classification of vegetable crops was studied by Dhaliwal [3]. He classified the vegetables as per various parameters like botanical, hardness or temperature, usage of a plant part, culture, and life cycle. Click et al. [4] described good revolution to be the next big thing on earth. Individual description of food wastage gives more quantities than a whole was the conclusion made by them. Martindale [5] studied food preservation and its impact on reducing the wastage of food. Antonio Raffo et al. [6] evaluated the tomatoes eating quality with that of refrigerated tomatoes using the passive refrigeration system. They stated that chilling induced loss of taste but the skin layer remained the same even after seven days. Seng et al. [7] in their paper “Low-cost cold storage of tomato in modified atmosphere packaging” compared the fruit quality by storing under refrigerated source and under ambient conditions. The results proved the existence of freshness even after a month which was stored under refrigeration and the fruit kept under atmospheric conditions lost its ripening property and became soft within 12 days of storage. Kumar et al. [8] in their paper, described cold storage for storing fruits and vegetables. Initially, they classified the perishable products as not sensitive, moderately sensitive, and very sensitive to cold as per the temperature dependence like (0-4) °C, (4-8) °C, above 8 °C. The items included in the list were apples, onion, carrot, and grapes as not sensitive to cold; potato, orange, tomato, and mango as moderately sensitive; and pumpkin, okra, pineapple, and banana as sensitive to cold. For these various items, the design of cold storage was made.

Resources from Indiagronet [9] stated the various factors affecting the storage of tomatoes and Singh [10] describe various preservation technologies for fresh fruits and vegetables. The findings stated the review from various sources about reducing the post-harvest losses using various methods like modified atmospheric packaging. Velledenrian et al. [11] describe using ultraviolet and modified atmospheric conditions to preserve the life of fresh-cut fruits. Then, Ji et al. [12] in their work stated some modern and chemical methods can be used to keep the nutritional values and the flavor in a proper state.

However, perishable food storage technology in the form of cold storage increases product costs to compensate for electricity or fuel, depending on the refrigeration system used [13]. Therefore, low-cost, or even no-cost refrigeration systems need to be developed to help store perishable agricultural products for domestic farmers. The absorption refrigeration system was chosen by utilizing sunlight as a heat supplier. In order to generate sufficient heat, a parabolic trougt is applied to collect solar energy as a heat supply for the system.

2. Material and Methods

2.1. Description of vapor absorption system

Figure 1 shows the line diagram for a single effect vapor absorption refrigeration system. In a vapor absorption system, two fluids are used which are the absorbent and refrigerant. An absorbent is a substance that absorbs the refrigerant causing the pressure to reduce. As the refrigerant vapor gets absorbed the temperature of the refrigerant gets reduced due to the vaporization of the refrigerant. This basic process causes the refrigerating effect. As this occurs the absorbent becomes more and more diluted due to refrigerant getting absorbed into it and hence to separate this again heating is used to bring the absorber back to its normal state. Hence, by the process of supplying heat energy, the refrigerating effect is produced in a cyclic process.

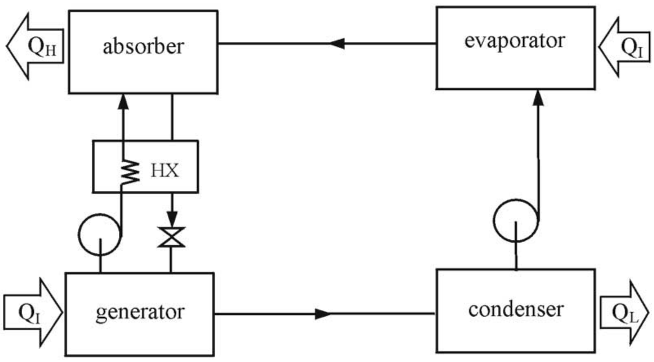

Figure 1. Working Process of Vapor Absorption System

2.2. Vapor absorption cooling system equipments

a. **Condenser:** The condenser converts the refrigerant vapor into liquid refrigerant. Here an Air-cooled Fin type Condenser is used for getting the required heat transfer in the process. The refrigerant used here (Ammonia) enters as vapor and exits at the outlet as liquid refrigerant.
b. **Expansion Valve:** The high-pressure liquid refrigerant leaving the condenser enters the expansion valve and reduces the pressure as it leaves out of the system. A capillary tube is used here as an expansion valve which brings the down the pressure in the system.
c. **Evaporator:** This low-pressure low temperature liquid refrigerant enters the Evaporator whose function is to absorb the heat in the refrigerated space and produce the required refrigerating effect of the system. The refrigerant enters as liquid condition in evaporator and leaves as vapor or superheated vapor from the evaporator.
d. **Absorber:** The function of an absorber is to gulp the refrigerant formed in the evaporator. It absorbs the vapor refrigerant coming out of the evaporator and forms a solution in the absorber system. Here, Liquid water is used as an absorbent as water has great affinity towards Ammonia vapors.

e. **Generator:** The generator is used to separate this solution formed in the absorber into their original forms of refrigerant and absorbent. The generator takes heat as the source and separates the solution into refrigerant and absorbent and helps it to flow back into the condenser and completes the cycle.

2.3. Solar parabolic trough collector

Solar parabolic consists of a solar collector shaped like a parabola for obtaining the maximum concentration of solar radiation. Here, the parabolic solar trough collector was fabricated using aluminum plates on plywood. Initially, plywood is set up, on which aluminum sheets are pasted. The final view of the parabolic solar collector is shown in **Figure 2**. A pipe is situated at the focus of the parabola so that the solar radiation on the collector will be concentrated on it and the refrigerant flowing inside the pipe gets heated. Here, this works as a generator for separating the refrigerant and absorbent. All the connected parts like the parabolic trough collector and cold storage box are shown in **Figure 3**. The experiment was conducted. All the equipment was purchased and connected in a cyclic manner. Once the equipment was ready, the refrigerant was filled in the condenser under the supervision of a local refrigerant technician. The refrigerant absorber was filled in the ratio of 70:30. The experimental setup was ready, and it was connected to the parabolic collector fabricated earlier. Once this entire setup was ready, we started with the experiment and took the values of temperatures by using digital thermocouples at various required connections of the condenser, generator, and evaporator. Based on these values of temperature readings we found the coefficient of performance at various timings of the day as per the availability of solar energy during the day. On completion of it, we collected the values of temperatures for a week, and the average instantaneous Coefficient of performance was found which came to be 1.602.

Based on this working of parabolic solar refrigeration system, we did a sampling analysis by taking 2 kg of unripe tomatoes and checked the loss in weight daily and weekly basis or four weeks. The final view of the equipment is shown in **Figure 2**. The refrigerated tomatoes were checked daily three times a day at 7:00 AM, 12:00 PM & 5:00 PM and the overall weight was checked at these times. Similarly, 2 kg of tomatoes were checked at room temperatures for their freshness and loss in weight. After a week the entire sample was shriveled hence after a week we stopped checking it at room temperature. The values are shown in the results section.

Figure 2. Final view of the set up

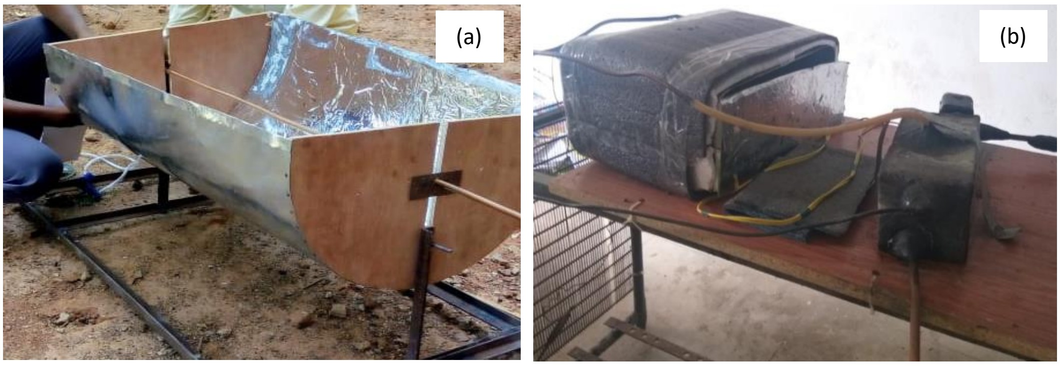

Figure 3. (a) Fabrication of Solar Parabolic Trough Collector; (b) View of Condenser, Cold storage box and Absorber Unit

3. Results and Discussion

During the experiment, the weight of tomatoes was noted every day at three different timings of 7:00 AM, 12:00 PM & 5:00 PM and was represented as the following. On the first day, the weights of tomatoes remained to be fresh intact and weighed 2 kg when refrigerated. This trend followed up till five days of the first week and for the entire five days, it weighed 2 kg with freshness intact. On the sixth day, the reduction in weight was found to be 20 g. On the seventh day, it weighed 1968 g which showed a reduction of 32 g.

On the contrary, without refrigeration and it was left in the open atmosphere, a drastic change in weight took place by the end of the first week and the entire tomatoes got shriveled and a foul smell was released. The weights displayed during this period were on day-1 at 5:00 PM of 2000 g, day-2 of 1971g, day-3 of 1888.33 g, day-4 of 1758 g, day-5 of 1637, day-6 of 1525 g, and day-7 of 1363.33 g. Hence, after the end of the first week, we stopped weighing the tomatoes kept at room temperature and the leftover stock was disbursed.

The weight of refrigerated tomatoes was also noted down similarly at three times a day which came to be 1968, 1968, 1948, 1925, 1911, 1875, and 1875 g for the second week; 1830, 1830, 1792, 1788.66, 1776, 1776, 1748 g for the third week; and 1748, 1748, 1748, 1692, 1692, 1692, 1692 g for the fourth week, respectively. Hence, based on the average values for each week after refrigeration the values of weights were stated to be 1992.571 gms at the end of the first week, 1924 g at the end of the second week, 1791 g at the end of the third week and 1716 g by the end of the fourth week. **Figure 4**, **Figure 6**, and **Figure 6** describe the results of the average tomatoes weight at 07.00 AM, 12.00 PM, and 05 PM, respectively. Meanwhile, **Figure 7** shows the average weight loss in tomatoes for week -1 at room temperature.

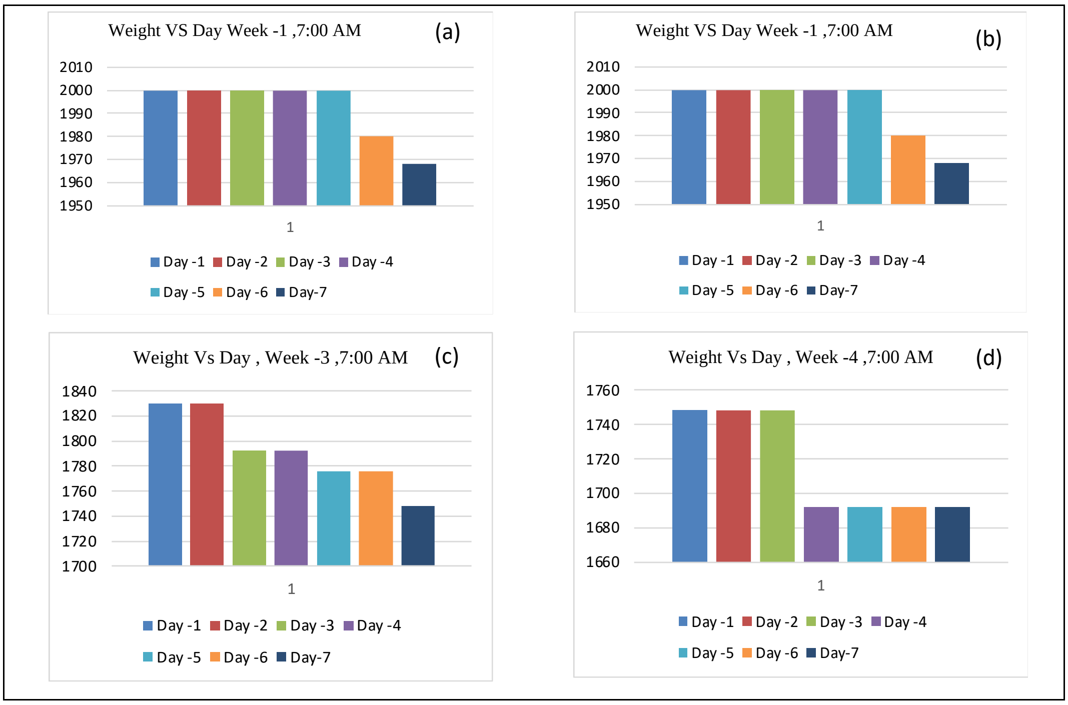

Figure 4. Average weight loss in tomatoes for 7 AM: (a) week 1; (b) week 2; (c) week 3; and (d) week 4

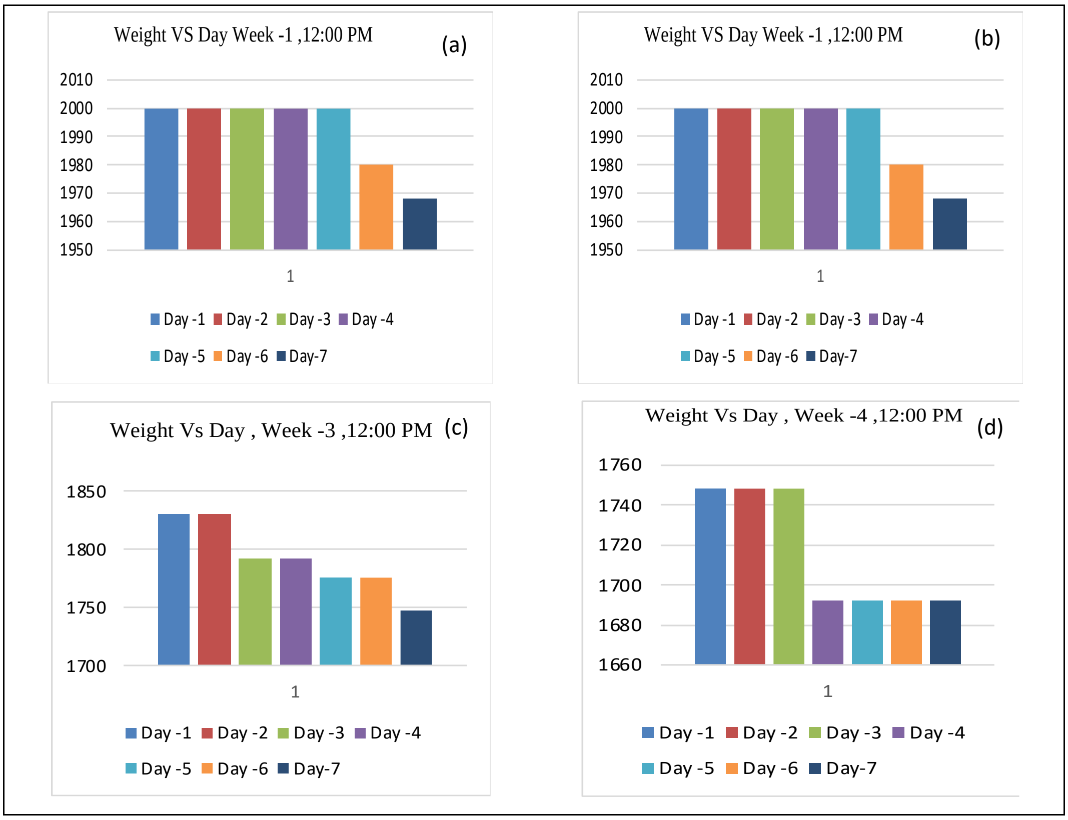

Figure 5. Average weight loss in tomatoes for 12 PM: (a) week 1; (b) week 2; (c) week 3; and (d) week 4

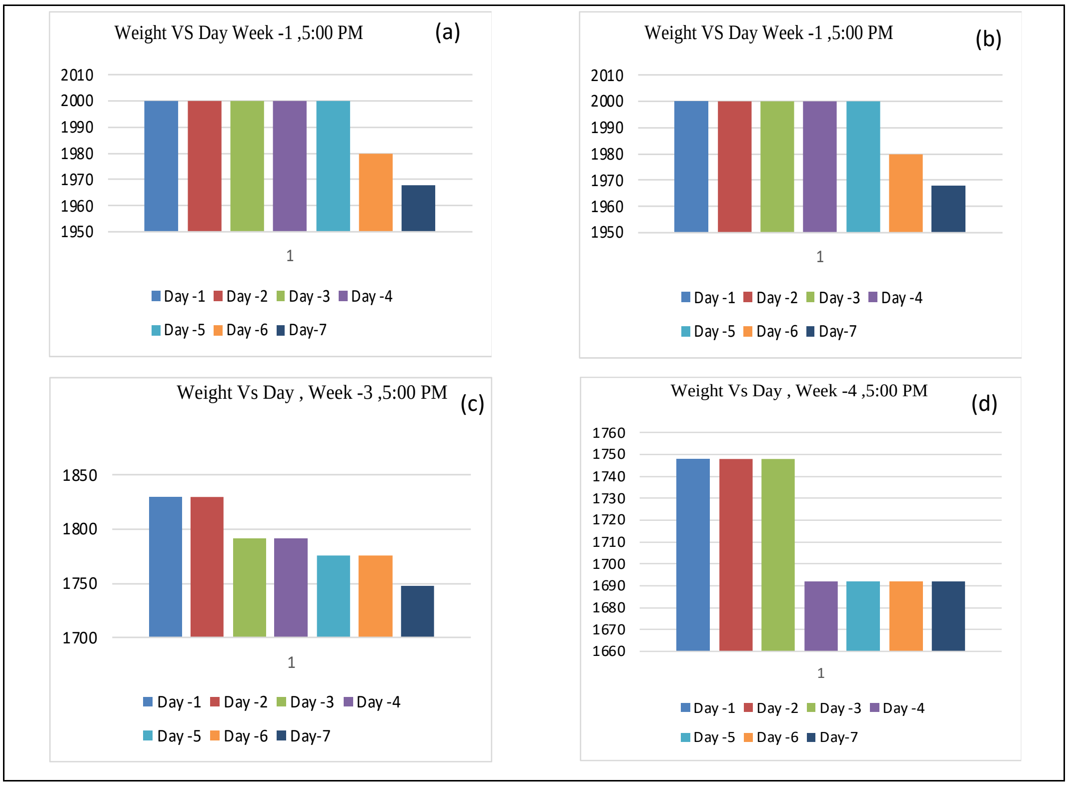

Figure 6. Average weight loss in tomatoes for 5 PM: (a) week 1; (b) week 2; (c) week 3; and (d) week 4

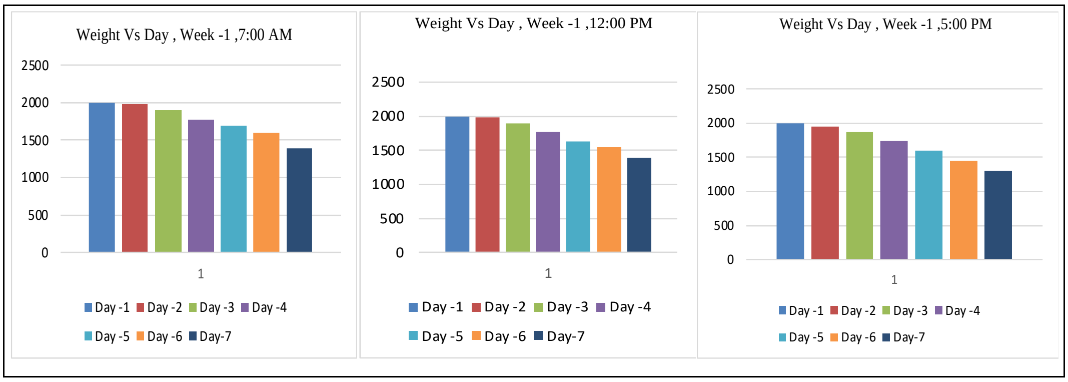

Figure 7. Average weight loss in tomatoes for week 1 (at room temperature)

Without refrigeration treatment, by the end of the first week, there was a decrease of 636.7 g and the entire lot was spoilt. By refrigerating, even after a month, the spoilt lot was 284 g only. On a minuscule scale, we are saving almost 65% of cultivation which could have been wasted if not refrigerated. Hence, by utilizing this wastage of cultivated food is reduced to a large extent with the scope of utilization being spread even to small-scale farmers with reduced power consumption due to very less moving parts available in the system.

Since tomatoes are one of the most important vegetable crops in the world for both fresh and processed markets due to their health and economic importance [14], keeping them fresh is crucial. Tomatoes have been reported to have the highest antioxidant values, including lycopene, carotenoids, vitamin C, and minerals, which can help to prevent the development of a variety of human diseases, including prostate, colon, and breast cancer [15]. Furthermore, 100 g of tomatoes can provide the human body with 40% of the recommended daily dose of vitamin C, which can help to strengthen the immune system, lower blood pressure, and lower cholesterol [16]. As is well known, postharvest factors such as transportation and storage have a significant impact on tomato quality [17]. Several postharvest applications, such as hydrogen sulfide [18], chitosan coating [19], abscisic acid [20], and essential oils [21], have previously been used to extend the shelf life of tomatoes during storage. $CaCl_2$ has been shown in previous studies to reduce fruit decay ratios and increase tissue and cell wall hardness [22]. Therefore, the appropriate technology that we have developed is expected to be a new insight in perishable agricultural product storage technology, in addition to maintaining tomato freshness, it can also improve farmers' welfare. Currently, we report only a small-scale prototype, but in the future, compact arrays could be developed on a larger scale.

4. Conclusion

The utilization of cold storage is limited to large warehouses and also limited to cultivators producing tonnes of vegetation. Our novelty is to guide the small cultivators with a mini cold storage concept on a domestic level. If the habit of waste reducting is improved on small cultivators, then a humongous effect can be generated where the minimization of post-harvesting due to lack of preservation can be improved. As an outcome, the freshness of tomatoes could be retained for a longer time without the consumption of large power required by a vapor compression operated cold storage. As a future work if the nutritional values of the food stored are tested and given a go then this might prove to be a great contribution to the small-sized cultivators whose whole dependence is on the vegetables which they grow which earn them a livelihood.

Authors' Declaration

Authors' contributions and responsibilities - The authors made substantial contributions to the conception and design of the study. The authors took responsibility for data analysis, interpretation, and discussion of results. The authors read and approved the final manuscript.

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