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Research Article

Design and Development of Solar Powered Low-Cost Cold Storage System for Agricultural Products

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Abstract:

The research describes an affordable solar-powered cold storage system whose primary goal is to decrease agricultural post-harvest losses of perishable food items. When integrated, the solar PV array and battery storage, together with a DC-powered compressor and automated control unit form an energy-efficient sustainable solution for rural off-grid smallholder farmers. The cold storage unit achieved its designed function by preserving optimal temperature and humidity requirements to protect agricultural products such as tomatoes, potatoes, along leafy greens, thus enabling longer shelf life and preventing spoilage. Time-sensitive monitoring from internal environmental sensors that utilize temperature and humidity sensors provides real-time control of storage conditions, which are viewable through a mobile application. During performance evaluations, the storage temperature range between 3°C to 10°C stayed consistent despite tropical environmental conditions that exceeded 35°C. The financial analysis confirmed feasibility because the system generates sufficient returns on investment within 2-3 years because it prevents food waste and enhances market opportunities. The majority of farmers alongside agricultural coop members supported the system through their survey responses because they found its automated monitoring elements and user-friendly interface appealing. The solar-powered cold storage system shows promise as an economically sustainable system that achieves two important goals by reducing traditional energy dependence and diminishing post-harvest product losses to bolster smallholder farmers’ economic success.

1. Introduction

A big concern in agriculture and food security of most countries is the high post-harvest losses, especially of perishable crops like onions [1,2]. These losses are mainly attributed to absence of proper storage structures that provide intermediate conditions required for produce preservation. The problem is compounded by the unavailability of low-cost, efficient cold storage technologies to enable smallholder farmers in developing countries to address post-harvest problems [2]. Some common traditional cold storages easily available in the market are highly efficient, costly, and energy demanding, which is unaffordable to the smallholder farmers, especially those in developing countries [1,2]. Onions are used by many people in their diets and is also an agricultural product that suffers from a spoilt state. They have very high moisture percentages as well as are susceptible to temperature changes and must be stored under special conditions for longer durations [3,4]. If suitable storage systems are not employed in onion production and distribution all undergo a lot of loss will occur due to spoilage as well as deterioration of their quality. Therefore, it is important to develop more effective cold storage technologies that require minimal energy to operate and do not require expensive capital investment to be implemented.
Cold storage is a vital practice in fruits and vegetable production and handling systems, which play a major role in preserving the shelf life of fruits and vegetables. Several factors, such as temperature, the nature of humidity, and the physiological nature of the produce, affect cold storage efficiency. This response is an evaluation of recent studies of cold

storage effects on fruits and vegetables with a specific focus on the best storage conditions and new techniques to minimize quality loss. The general purpose of cold storage is to delay the rate of those physiological processes that cause food to spoil, such as respiration and the production of ethylene. Studies show that low-temperature management slows down the respiration of fruits to lower its rate of ripening and longevity [5].

In the Philippines, the top vegetables and root crops were ampalaya, mongo, cabbage, eggplant, onion, tomato, potato, sweet potato, and cassava [6], where tomato is the fourth most produced vegetable by volume [7]. Vegetable farming presents several difficulties since most of the produce are seasonal crops with limited shelf life under typical storage conditions. These challenges include manual sorting based on ripeness and storing them after harvest to increase their shelf life. Indeed, storage of highly perishable produce in a controlled environment regarding both temperature and relative humidity helps in preserving quality and quantity [8]. Storage is mostly carried out between temperatures of 5–12 °C, thus retarding ripening, reducing postharvest losses, and improving shelf life [9]. Most of the currently available cold storage facilities, as much as they serve the intended purpose, are expensive and energy-consuming for the smallholder farmers.

The design of solar-refrigerated, appropriately priced cold storage for preserving the freshness of onions and other perishable vegetables is now regarded as a growing solution for augmenting food security since environmentally controlled and energy-optimal cold storage options are unprofitable in developing countries. The adoption of renewable energy technology, especially solar energy in cold storage technologies, can greatly improve the operation costs of the cold storage technologies without compromising on the quality of the produce stored. In this synthesis, different aspects of solar cold storage will be discussed to include the construction of the storage systems, the effectiveness of the solar power, and likely consequences it can have on refrigeration. Remote solar-powered cold storage uses photovoltaic electrical technology to generate electricity to power the refrigeration equipment. Several empirical studies in the past years have shown that these systems could be designed to be energy-effective and ecologically friendly as a renewable solution to the normal cooling system. For example, the mobile photovoltaic direct drive refrigeration compartment has been proposed, where the use of solar energy for creating low temperatures required for preserving perishable goods has been suggested [10]. It helps to lower the dependence of transportation refrigeration on fossil fuels and, thus, decrease the emissions of greenhouse gases, which are characteristic of the typical refrigeration equipment.

The performance of cold storage using solar energy can be optimized by incorporating phase change materials (PCMs). PCMs can capture and store thermal energy during the day and acted as storage during the night or during the cloudy day hence can provide a constant cooling effect [11]. This technology will benefit areas with large temperature differences since storage temperatures can be closely controlled to keep onions and other vegetables fresh. The incorporation of PCMs into solar driven systems has been confirmed to enhance energy storage density and dimensionality of the cooling devices needed [11]. However, one can also combine the use of solar-powered cold storage with Thermal Energy Storage TES systems. TES systems can hold additional thermal energy obtained during the times with high intensity of sunlight and then provide it at needed time, which makes supply and demand of energy more balanced [12]. This capability is needed to make certain that cold storage facilities are able to function optimally even if there are low levels of solar radiation. By applying TES, the farmers are in a position to remove post-harvest losses which are normally as a result of poor storage facilities and volatile energy costs [13]. Other than increasing energy efficiency, cold storage systems that are powered by solar energy will also preserve the quality and extend the shelf life of the stored produce. Preliminary studies show that further temperature and humidity are very essential for enhancing the shelf life and nutritional value of vegetables such as onions. Continuous storage conditions can be programmed in the solar-powered systems and operational control mechanisms which check and correct temperatures in actual time thus helping keep fresh produce for an extended period [14,15]. Such control over aired temperatures means that the System is especially suited to prevent spoilt produce and increase returns for smallholder farmers. In addition, the economic benefits of the solar-powered cold storage systems are evident as follows. Since they lower the dependence on grid electricity while optimizing the general costs of production, such systems are capable of presenting a cheap strategy suitable for smallholder farmers within the developing world [13]. The costs that growers may experience at beginning of adoption of solar technology may be recovered by the money that they will save in the long run through energy costs and post-harvest losses. Furthermore, the parametrization of vegetable storage duration could help farmers demand better market prices for their produce hence will increase their overall earnings. The use of solar energy in cold storage also serves greater sustainable development objectives as well.

In using renewable energy sources, these systems minimize carbon emissions of food namely, production and storage [16]. Furthermore, the use of such technologies can increase food security because that which is in season can be properly preserved and displayed throughout the year in areas with limited access to cold chain facilities [13]. This has a bearing with the climate change since short cycle shocks affect the supply chain and escalate the food vulnerability.
This issue gives rise to innovative storage solutions that can be cheap and also have a low energy impact, thus addressing economic and ecological issues [17]. Solar-assisted storage systems and phase change materials have the potential to provide the required conditions at lower operational costs and efficiency. This research aims to design an efficient solar-powered cold storage for perishable agricultural products providing economic and energy-friendly, making the proposed system suitable for smallholders who seek to minimize post-harvest losses and improve the sustainability of the agricultural production systems specifically aims to (1) design and develop a solar-powered cold storage system aimed at extending the shelf life of perishable vegetables while ensuring energy efficiency, (2) develop and integrate a monitoring system equipped with temperature and humidity sensors to continuously measure and control the internal environmental conditions of the storage unit, (3) evaluate the extent of acceptability of the low-cost solar-powered cold storage system.

2. Methods and Procedures

2.1 Research Design

The researcher used a descriptive-developmental method of research design. This design is used to gather information about existing conditions. The principle aims to obtain and interpret facts about the nature of the situation as it exists at the time of the study. The study, by design, will be developmental. The proposed system aims to develop a solar-powered, Low-Cost, Cold Storage System for Agricultural Products that is a low-cost and energy-efficient technologies that reduce operational costs as well as energy consumption, making them suitable for use in small-scale farming.

2.2 Research Environment

The study will be conducted in two environments: Development Site: The cold storage prototype will be made in a controlled workshop with the supervision of an expert consultant to produce the prototype from the design accurately. Testing Site: Assuming that the whole system will be implemented early this year, the trials should be conducted in an agricultural community or a farming area in the researcher's location where agricultural products are being stored post-harvest. It is characterized by adjustable real-world parameters such as environmental temperatures and solar power potential.

2.3 Procedures

Phase 1: Planning and Design Needs Assessment: Interview farmers, vendors, and other agricultural professionals to establish what they consider the main storage problems and what kind of architectural designs they would prefer. Specification Development: Determine what the system must be able to do, be it contain huge volumes, be cooled, or make use of solar energy.
Phase 2: System Development Prototype Construction: Install all figures of solar cold storage, for instance, solar panels, battery units, refrigeration, and insulating materials. Sensor Integration: Place thermometers and hygrometers with an automated control system with alarms that can be monitored and controlled remotely.
Phase 3: Testing Performance Testing: Assess the efficiency of the system for preserving appropriate conditions of storage for onions and vegetables. Determine the quality of produce and storage duration of the produce about the conventional means of storage. Energy Efficiency Testing: Examine the yield of energy from solar panels, battery technology for storing the energy, and the appliance consumption level under different climate states.
Phase 4: Acceptability Evaluation Survey Distribution- User-testing surveys for the target audience: farmers and vendors that involve practices' assessment in terms of usability and cost satisfaction. Focus Group Discussions: Introduce the possibility of further enhancements in the system's operation and get more detailed quantitative responses.

2.4 Design Concept

The proposed cold storage system is guided by the following principles:
Sustainability: The system on which it has been developed is completely based on solar power and, hence, has no impact on the environment and is suitable for off-grid cities.
Cost-Effectiveness: Choosing the materials and the components used to give the least cost on the product yet has the best efficiency.

Energy Efficiency: The cooling mechanism of the unit and the insulation employed make power consumption low without affecting the overall performance.
Smart Functionality: The Sensing and controlling system tracks the temperature and humidity so that it does not require frequent intervention from the users.
User-Centered Design: It is also flexible with integrated modules and bio-oriented to suit individual smallholders and traders.
This design concept makes the system easily affordable, fully efficient to meet the challenges with the storage of perishable vegetables.

3. Results and Discussion

Design and development of a solar-powered cold storage system

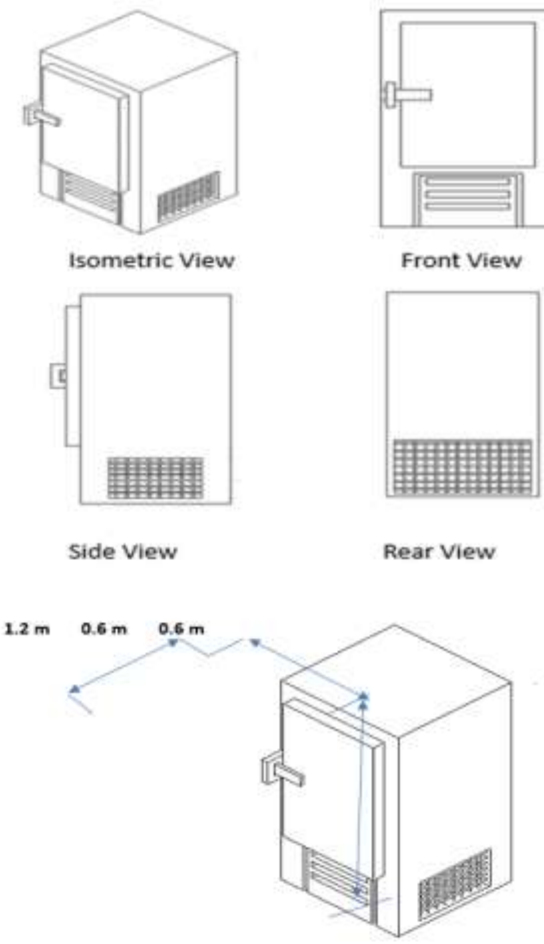

Figure 1. (a) *Isometric View of the CSP* ***(b)*** *Dimensions of the CSP*

Figure 1(a) and (b) shows the isometric view of the 3D CAD model of the Cold Storage Prototype (CSP) and the dimensions necessary to describe the size of the CSP have been marked and labeled correctly.

Cold storage prototype (CSP) design calculations
Prototype dimensions -0.6m x 0.6m x 1.2m
Volume = 0.432m^3
The average density of a tomato is approximately 0.95−1.00 kg/L (or equivalently, 950 - 1000 kg/m^3)
Most vegetables are not completely solid and leave some voids when they occupy space in a container when stacked. It is known from various observations that the voids take up around 30 % of the volume of the vegetables themselves. Thus, the actual volume of vegetables has to be multiplied by a factor of 1.42. Also we have to take into consideration the space to be left for proper air circulation. As per various experiments done with various capacities and from various established standards, the vacant space can be around 40-50 % of the total volume of the vegetables. Thus, the volume of vegetables needs to be multiplied by a factor of 2.25 to get the final volume of the cabinet.
The figure 2 represents a hybrid solar power system that integrates multiple power sources, including solar panels, batteries, a generator, and the grid, to supply power to different loads.

- Small tomato (~50g):5.55.5×5.5×5.5cm→ 0.000166 m^3
- Medium tomato (~100g): 6.56.5×6.5×6.5 cm → 0.000275 m^3
- Large tomato (~250g): 8.58.5×8.5×8.5 cm → 0.000614 m^3

The estimated number of tomatoes that can fit in a 0.432 m^3 storage are:

- Small tomatoes (~50g each): ≈ 2,602
- Medium tomatoes (~100g each): ≈ 1,571
- Large tomatoes (~250g each): ≈ 704

These estimates assume a perfect packing arrangement, but in reality, there will be gaps between tomatoes, so the actual number may be slightly lower.
Volume of cabinet = 20.6m x 0.6m x 1.2m = 0.432m^3
1. Area of floor and ceiling = 0.36 m^2
2. Area of walls = 1.0527 m^2 & 1.089 m^2
3. T.D (Temperature Difference b/w cabinet and ambient is taken to be 24 ˚C, assuming
The temperature of the cabinet is to be 4 ˚C, and the Temperature of the ambient is to be 28 ˚C.
4. The insulation material used is Glass Wool, having conductivity Kg = 0.038 W/m K.
5. Insulation thickness is nearly constant at 70.836 mm for all walls, floors, and ceilings. 6. Net heat Load = Transmission Load + Product Load + Infiltration Load + Fan Load + Light Occupancy.

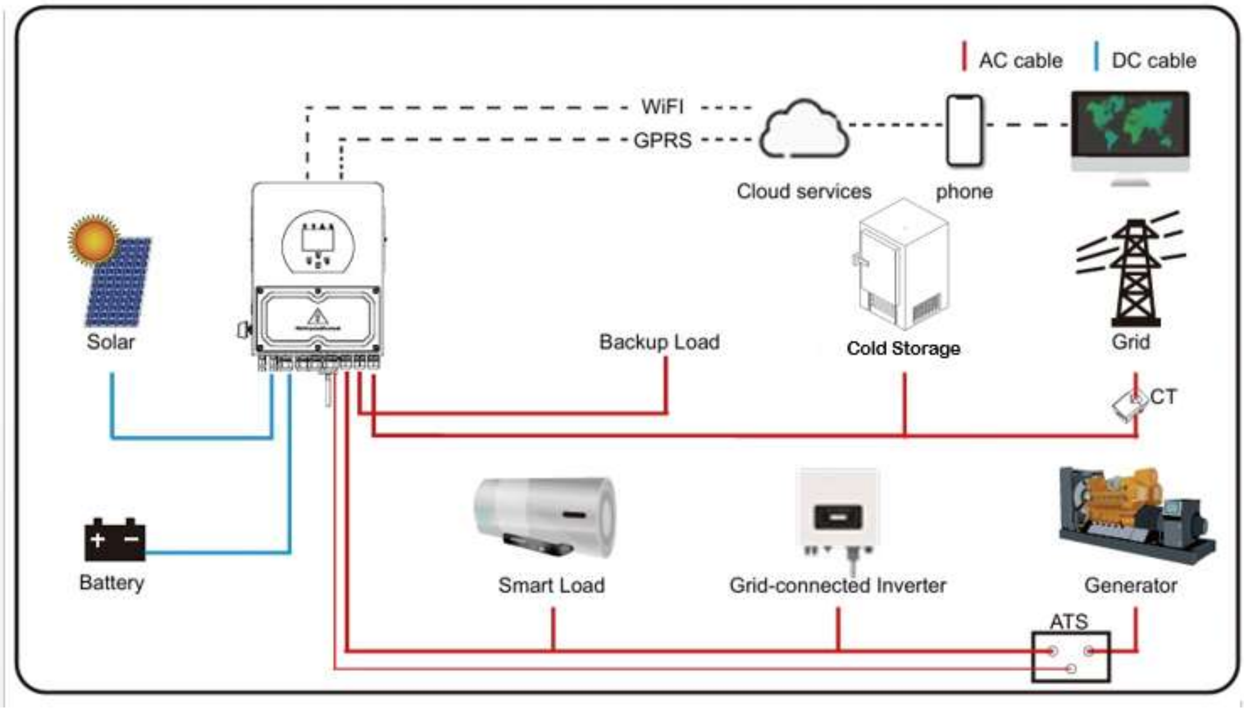

Figure 2. *Hybrid Solar Power System Architecture*

Table 1. *Key Components and Description*

KEY COMPONENT	DESCRIPTION
Solar Panel (Left Side)	Converts sunlight into DC electricity. Sends power to the battery for storage and to the inverter for conversion to AC.
Battery	Stores excess energy generated by solar panels. Provides backup power when solar energy is insufficient.
Hybrid Inverter (Central Component)	Manages the power from the solar panels, battery, generator, and grid. Converts DC power (from solar/battery) into AC power for household loads.
Grid Connection	The system is connected to the utility grid. Can supply power to the home when solar energy is insufficient. Can send excess power back to the grid if the system supports net metering.
Generator	Acts as a backup power source. Can be automatically started by the Automatic Transfer Switch (ATS) when other power sources are unavailable.
Load Types	*Backup Load:* Critical loads that need power during outages (e.g., computers). *Smart Load:* Non-critical loads are managed intelligently based on power availability. *On-Grid Home Load(cold Storage):* Normal household loads are powered directly when the grid is
Communication & Monitoring	Uses WiFi/GPRS to send data to cloud services for remote monitoring via a phone or computer.

Table 1 shows the different key components of the whole cold storage system and its explanation. This system ensures efficient energy management by prioritizing solar power, using the battery as backup, and relying on the grid or generator when necessary. The designed solar-powered cold store system reached its development phase to lengthen the preservation periods of perishable agricultural items. The system consists of six main elements beginning with a photovoltaic (PV) panel array followed by a battery storage facility and compressor cooling system and insulated storage chamber, and an automated control unit. The PV panels received purposeful placement to obtain maximum solar energy collection, which resulted in efficient daytime power output. Energy storage within deep-cycle batteries allowed the system to operate indefinitely both at night and when solar power input was scarce.A DC-powered compressor formed the core of the cooling system because it provided efficient energy use as well as compatibility with the off-grid solar system. The storage chamber received polyurethane foam panels for its insulation, which helped decrease thermal conductivity and cut down heat exchange for reduced energy usage. Stainless steel, along with corrosion-resistant aluminum, formed the structure, which provided durable features necessary for permanent agricultural facilities in humid climates.Tests of performance were conducted to determine how various outdoor temperatures affected the cooling capacity. The testing revealed that the storage unit upheld proper internal temperature retention between 3°C to 10°C, thus maintaining stable conditions suitable for tomato and leafy greens as well as carrot and potato preservation. The system delivered its intended performance in both tropical climates where air temperatures reached up to 35°C and beyond.

Monitoring System for Temperature and Humidity Control

The cold storage unit received a real-time monitoring system for maintaining optimal storage conditions. A network of monitoring devices included temperature and humidity sensors called DHT22 and DS18B20 that operated at defined strategic areas within the chamber. The data collected from the sensors displayed on an LCD screen interface and triggered alerts during temperature or humidity thresholds exceedances.

The system included a direct automation control system that used real-time input data to manage the cooling intensity levels. Programmed microcontrollers made up of Arduino units and Raspberry Pi devices achieved efficient compressor cycle management. Through a mobile application interface, farmers could easily track storage conditions at their site by using Bluetooth or Wi-Fi connectivity.The experimental findings showed that temperature variations were recorded between ±1.5°C during storage tests to preserve stable conditions. Maintaining the humidity at levels from 85% to 95% protected stored vegetables by stopping moisture evaporation, which led to better preservation of freshness. Experimental studies indicated that vegetables placed in the solar-powered storage unit stayed fresh for longer periods at 40% to 70% more than traditional storage techniques such as shaded and open-air methods.

Extent of Acceptability of the Low-Cost Solar-Powered Cold Storage System

The acceptance evaluation involved key stakeholder participation through surveys and interviews, which included farmers, agricultural cooperatives, and traders together with managers of cold storage facilities. Research focused on evaluating four essential aspects of the system, including its cost-effectiveness combined with ease of use and durability features together with energy efficiency performance.

Respondents through surveys determined that the system proved economically feasible because farmers lost fewer products after harvest, which respondents considered essential. Farmer-owned perishable products could remain usable longer because of storage capabilities, which resulted in better market prices and decreased spoilage-related financial losses. The automated monitoring system received strong approval from 90% of participants because it automated the monitoring process, making it more practical and user-friendly without requiring personnel supervision.

The total financial implications of the system received analysis through a cost-benefit assessment following its implementation. Producers could purchase the solar-powered cold storage unit for 12000 pesos to 20000 pesos based on storage capacity together with material type selection. The investment for the automated system would bring back the initial cost within 2-3 years through reduced food spoilage and expanded financial gain. The solar-powered cold storage system proves to be an economical, sustainable storage solution for remote farmers through its reduced operational expenses, which reach between 60% to 70% lower than conventional grid-power storage units.

4. Discussion

The developed solar-powered cold storage system shows practical value and sustainability as an effective method to reduce post-harvest losses within agricultural industries according to study results. The merged renewable energy system with automated climate control maintained excellent storage conditions by both lowering operational expenses and decreasing dependence on traditional energy sources. The innovative technology proves useful especially for smallholder farmers along with agribusiness operating in rural off-grid areas.

Research findings about extended perishable vegetable shelf life validate how low-cost cold storage technology would positively affect food security and agriculture sustainability. Lowered spoilage rates enable farmers to stabilize their markets while boosting their earnings while strengthening supply chains in general. Users can access the system through autonomous real-time monitoring alongside remote control functions which contribute to its widespread use.

The extensive benefits of this system require solutions for upfront financial costs alongside maintenance complexities and system size growth limitations to achieve full-scale use. The advancement of autonomous solar systems requires research into three main areas: hybrid systems combining wind power with solar energy generation and the development of AI-driven predictive maintenance, and improved insulation technologies. Wider optimization of product modifications requires more experimental trials in diverse temperature zones and levels of humidity across various geographic locations.

5. Conclusion

The solar-powered, low-cost cold storage system developed for agricultural products serves as an effective answer to post-harvest losses throughout perishable vegetables. The solar-powered storage facility assures numerous advantages through its automated control system because it optimizes energy use and operation expenses alongside environmental sustainability. The system achieves ideal storage conditions including temperature along humidity control, which extends shelf life and minimizes spoilage of different agricultural products. The evaluation process under tropical hot climates shows the system executes its functions properly despite extreme environmental conditions. The system becomes more practical for farmers at remote rural locations because of its user-friendly functions, which include mobile application-based real-time monitoring capabilities.

Results from a cost-benefit analysis confirmed economic feasibility because returns on investment stretch from 2-3 years through lowered food spoilage and better marketable agricultural products. A high level of stakeholder approval demonstrates the system's ability to transform agricultural storage techniques in rural areas, which results in better food security and economic stability for smallholder farmers.

6. Recommendation

The scalability along with effectiveness of solar-powered, low-cost cold storage systems needs additional research that optimizes their performance across different geographical environments with diverse climate and humidity conditions for broad implementation potential. Hybrid energy systems that include wind power products would provide a reliable power supply for maintaining continuous operation of the cold storage unit while operating in locations with light intensity variations. The adoption of AI-generated predictive maintenance brings an essential advancement enabling the system to automatically monitor issues until potential problems get resolved while simultaneously maximizing operational time. Farmers may encounter challenges with the price tag when they invest in this system to begin with but the cost savings will appear in time. Wider adoption of the cold storage unit could be achieved by establishing government subsidy programs as well as low-interest loan facilities and NGO collaboration initiatives specifically targeted at smallholder farmers. The implementation of educational sessions should teach farmers about system benefits along with operation and maintenance protocols so they maximize its usage throughout rural agricultural zones. Strategic reforms in the system will improve its reach and efficiency while sustaining its operation thus enhancing rural food security and minimizing losses from harvested farm products.

Author Statements:

- **Ethical approval:** The conducted research is not related to either human or animal use.
- **Conflict of interest:** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper
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- **Data availability statement:** The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

References

[1] Sharma, R., Kumar, A., & Singh, M. (2020). *Post-harvest management of onions: Challenges and solutions*. *Journal of Agricultural Engineering, 57*(2), 45–52.

[2] Srinivasan, S., Kumar, R., & Patel, A. (2019). *Low-cost storage technologies for perishable crops*. *International Journal of Food Engineering, 15*(1), 112–120.

[3] Dube, A., Mandhlazi, B., & Zikhali, P. (2021). *Postharvest quality and storage of onions under different conditions*. *African Journal of Agricultural Research, 16*(7), 987–994.

[4] Ahmadi, A., Karimi, M., & Hashemi, M. (2022). *Impact of storage conditions on quality and shelf life of onions*. *Journal of Food Preservation, 46*(5), e16089.

[5] Mohammed, M., Singh, A., & Rahman, M. (2022). *Effect of cold storage on the ripening and shelf life of fruits*. *Postharvest Biology and Technology, 184*, 111762.

[6] Rivera, A. (2022). Most major vegetables and root crops. In *Philippine Statistics Authority: Agriculture report*. Retrieved from https://psa.gov.ph/

[7] Dimayacyac, E. A., & Balendres, M. A. O. (2022). *Tomato production in the Philippines: Current status and prospects*. *Asian Journal of Agriculture and Biology, 10*(4), 780–789.

[8] Makule, E., Chacha, D., & Mwatawala, M. (2022). *The role of cold storage on post-harvest loss reduction in fruits and vegetables*. *International Journal of Postharvest Technology, 10*(1), 23–30.

[9] Thole, V., Madziya, T., & Masarirambi, M. T. (2021). *Effects of different cold storage temperatures on shelf life of fresh produce*. *Journal of Horticultural Science, 56*(3), 455–462.

[10] Zhang, L., Wu, X., & Liu, H. (2023). *Development of solar-powered cold storage systems for agricultural products*. *Renewable Energy, 205*, 154–163.

[11] Zheng, J., Huang, X., & Wang, S. (2017). *Phase change material integration into solar refrigeration systems for agricultural products*. *Solar Energy Materials and Solar Cells, 169*, 81–89.

[12] Davenne, T., Simonetti, M., & Meunier, F. (2017). *Thermal energy storage for solar cold storage applications*. *Energy Procedia, 135*, 116–123.

[13] Rutta, E. (2022). *Enhancing post-harvest management using solar-powered cold storage*. *African Journal of Agricultural Sustainability, 4*(2), 90–97.

[14] Tileukeev, K. (2023). *Innovative technologies in vegetable storage: The role of real-time monitoring*. *Central Asian Journal of Agriculture, 9*(1), 32–41.

[15] Isakov, A. (2023). *Technological advancements in solar-powered cold storage*. *Journal of Renewable Energy Systems, 8*(2), 210–219.

[16] Yang, Y., Zhao, Y., & Lu, R. (2017). *Sustainable cold storage technologies in agriculture: A review*. *Renewable and Sustainable Energy Reviews, 74*, 864–875.

[17] Patel, D., Shah, A., & Joshi, P. (2020). *Energy-efficient cold storage for smallholder farmers: A review*. *Energy for Sustainable Development, 58*, 86–93.