International Journal of Advances in Engineering and Management (IJAEM)
Volume 8, Issue 01 Jan. 2026, pp: 01-07 www.ijaem.net ISSN: 2395-5252

Solar Refrigeration for Food Security: A Study on Nutrient Retention in Vegetables Stored with DC Solar-Powered Cooling Technology

Abdulkadir Z. A[1], Jimoh A. A.[2], Muktar A[3], Sanni M. A[4], Bello B. A[5], Abdullahi K. A[6], and Ambali A. O[7]

[1,2,3,4,5,6,7]*Department of Electrical and Electronics Engineering, Institute of Technology, Kwara State Polytechnic, Ilorin*

Date of Submission: 01-01-2026 Date of Acceptance: 08-01-2026

ABSTRACT

Access to reliable refrigeration is a critical factor in reducing post-harvest losses and ensuring food security, especially in off-grid and rural communities. This research investigates the preservation capabilities of a DC solar-powered refrigerator system in preserving the nutritional quality of selected vegetables over days. A solar-powered DC refrigeration unit was designed and implemented for this study. Commonly consumed vegetables and fruits, including spinach, oranges, and apples, were selected for analysis. Their nutritional content, specifically Vitamin C, beta-carotene, and moisture content, was assessed before storage and then monitored daily during refrigeration until the values declined below acceptable thresholds for human consumption (25%). The temperature and humidity of the refrigerator were continuously logged to ensure a stable environment for preservation. The study aims to determine the duration of nutrient viability in solar-cooled storage compared to natural degradation rates in ambient conditions. Results from the study show that apples and oranges were well above the nutritional contents' threshold values throughout the days of the experiment, while spinach fell below the nutritional contents threshold values within day 4 of the study for preservation under room temperature, and is at nutritional threshold point at day 6 for spinach preserved using the DC solar-powered refrigerator's systems. This study, therefore, supports the broader goal of integrating affordable, off-grid refrigeration into sustainable agricultural and nutritional strategies. The outcome of this research is projected to influence policy and technology adoption in food security initiatives across energy-deprived regions.

Keywords: Solar Refrigeration, Food Security, Nutritional threshold point, Human Consumption, and Ambient Temperature.

I. INTRODUCTION

Food spoilage and nutrient loss remain significant challenges in ensuring food security, especially in developing regions where access to electricity is unreliable. Vegetables, being highly perishable and rich in water-soluble vitamins and minerals, require proper storage to preserve their nutritional value(Khama, 2024). Refrigeration slows down enzymatic and microbial activities that lead to degradation; however, conventional refrigeration systems are often inaccessible in off-grid rural areas due to inconsistent power supply. This challenge calls for the integration of renewable energy into food preservation strategies(Chang and Wu, 2011). Solar-powered direct current (DC) refrigeration presents a viable solution to post-harvest losses. It operates independently of the national grid and is environmentally friendly(Arafat et al., 2024). This study explores the efficacy of a locally constructed DC solar-powered refrigerator in preserving the nutritional value of vegetables by analyzing the nutritional content of selected vegetables before and during refrigeration(Singh and Pradhan, 2024).

The research seeks to evaluate how long nutrients can be retained under solar-powered cooling, thereby addressing both technological and nutritional dimensions of food security. Despite the growing popularity of solar-powered refrigeration systems in rural and off-grid locations, there is

International Journal of Advances in Engineering and Management (IJAEM)
Volume 8, Issue 01 Jan. 2026, pp: 01-07 www.ijaem.net ISSN: 2395-5252

limited empirical data on their effectiveness in preserving the nutritional quality of stored vegetables. Traditional storage methods often lead to rapid nutrient degradation, contributing to food waste and nutritional deficiencies(Amit et al., 2017). A clear knowledge gap exists in determining whether solar-powered DC refrigerators can offer comparable nutrient-preserving capabilities to conventional systems, particularly in hot climates where spoilage rates are high(Buckow and Bull, 2013). This research, therefore, aims to investigate the effectiveness of a solar-powered DC refrigerator in preserving the nutritional value of selected vegetables during storage by analyzing the initial nutritional content of selected vegetables before refrigeration, and monitoring changes in key nutritional parameters of vegetables stored in a DC solar-powered refrigerator over time, determining the storage duration at which the vegetables remain nutritionally viable. assess the temperature and humidity stability of the solar-powered DC refrigerator during storage and evaluate the potential of the refrigerator system in enhancing food security in energy-deprived communities.

This study provides scientific evidence on the performance of solar-powered refrigeration in preserving food nutrients, particularly in areas where food loss due to spoilage is prevalent. The findings will support innovations that bridge the gap between renewable energy technology and food nutrition, contributing to rural development, public health, and sustainable agriculture, and the remaining sections of this article are sectioned into an overview of solar-powered refrigeration system in section 2, the research design is presented in section 3 with subsections A, B, C, and D to highlights on selection and preparation of vegetables, pre-storage nutritional analysis, storage procedure, and nutritional degradation assessment respectively. The results and discussions of the research were discussed in section 4, and section 5 gave the conclusions and recommendations.

II. OVERVIEW OF SOLAR-POWERED REFRIGERATION AND FOOD PRESERVATION SYSTEMS

Food security is directly linked to food availability, accessibility, and utilization, making food preservation just as important as food production itself. Unpreserved or poorly stored food often leads to spoilage, nutrient loss, and in severe cases, health risks. Traditionally, preservation techniques such as sun drying, earthen storage, and smoke-drying were widely used, but these methods frequently cause undesirable chemical and physical changes that compromise food quality(Khama, 2024). With the advancement of modern technology, refrigeration has become the most effective method of preservation(Christopher et al., 2023). However, in many rural and off-grid communities, unreliable electricity supply has limited the use of conventional refrigeration systems. This challenge has stimulated the development of solar-powered DC refrigeration, which operates efficiently without dependence on the national grid and is well-suited for energy-deprived regions. Typically, a DC solar refrigeration system includes solar panels, a charge controller, a battery bank, and a DC compressor. Advances in low-energy compressors and improved insulation have made these systems increasingly practical for rural deployment (Salilih and Birhane, 2019).

Vegetables and fruits are highly perishable due to their water content and metabolic activity, and their nutritional quality is strongly influenced by storage conditions. Nutrients such as Vitamin C and beta-carotene are especially sensitive to temperature, oxygen, and light. Studies have shown that poor storage conditions accelerate enzymatic reactions, oxidation, and microbial activity, leading to rapid nutrient degradation (Nasrullahet al., 2020; Xiaohongai, 2024). Vitamin C, for instance, deteriorates quickly when stored above 10 °C, making temperature control a critical factor in vegetable preservation. According to Kader (2005), keeping vegetables between 4–8 °C can significantly reduce spoilage and extend shelf life, thereby retaining nutritional quality. Leafy vegetables such as spinach tend to lose their nutrients more quickly than fruits like oranges and apples because of their higher water activity and faster metabolic rate. These findings highlight why effective refrigeration solutions are essential not only for maintaining freshness but also for safeguarding the nutritional value of perishable produce(Hu and Yue, 2021).

Alternative preservation strategies have also been explored, particularly for communities where refrigeration may not always be affordable or feasible. Evaporative cooling methods, such as the zero-energy cool chamber, can lower storage temperatures by several degrees and help extend shelf life in arid climates, though their effectiveness is limited in humid regions. Modified atmosphere packaging (MAP) has been used to reduce oxygen and elevate carbon dioxide around produce, slowing respiration and nutrient degradation. Similarly, edible coatings made of polysaccharides or lipids act as semi-permeable barriers that reduce

International Journal of Advances in Engineering and Management (IJAEM)
Volume 8, Issue 01 Jan. 2026, pp: 01-07 www.ijaem.net ISSN: 2395-5252

moisture loss and microbial activity. While these methods provide some preservation benefits, they are often more effective when used in combination with refrigeration (Tavman et al., 2019). Comparative studies consistently show that stable refrigeration remains the most reliable and efficient technique for preserving both the physical attributes and nutritional quality of perishable produce. Against this background, DC solar-powered refrigeration offers a distinct advantage by providing consistent low-temperature storage in off-grid communities. It not only reduces post-harvest losses but also enhances nutritional retention, thereby bridging renewable energy technology with food security and public health outcomes.

III. RESEARCH METHODS AND DESIGN

The research employs an experimental design involving nutritional analysis of selected vegetables stored under controlled conditions in a solar-powered DC refrigerator. The design enables repeated sampling and monitoring over time to assess nutrient retention and degradation patterns.

A. Selection and preparation of vegetables

Three commonly consumed vegetables with varying nutrient sensitivities, Spinach (leafy), Apple and Orange (fruit) were selected. The vegetables were fresh from local markets and cleaned with distilled water. Each type was divided into equal sample sets for daily testing.

B. Pre-storage nutritional analysis

Initial (Day 0) nutrient content was determined through laboratory analysis. Parameters assessed include vitamin C content (using the titrimetric method), beta-carotene levels (spectrophotometry), and moisture content (oven drying method). These baseline values serve as control data for comparison throughout the storage period(Tavman et al., 2019).

C.Storage procedure

Vegetables were placed in the DC solar-powered refrigerator as depicted in the experimental setup of Figure 1, which operated continuously over a 10 – 14-day observation period. One sample from each vegetable group was removed daily for nutrient analysis. Temperature and humidity data were logged every hour using digital sensors.

Figure 1: The Experimental Setup

D. Nutritional degradation assessment

Daily samples were analyzed for the same parameters as the baseline. Nutrient loss over time was recorded and plotted to determine the rate of degradation, nutrient retention per day, and the threshold point at which nutrient levels fall below recommended dietary levels, as expressed in equations 1 to 3.

i. Rate of degradation $\{R_d\} = \frac{C_0 - C_t}{t}$ (1)

ii. Nutritional retention per day{%} $= \frac{C_t}{C_0} \times 100$ (2)

iii. Threshold point of nutrient level= $C_0 \times 50\%$ (3)

where C_0 is the initial nutrient concentration (day 0), C_t is the nutrient concentration at time t, and t is the number of storage days(Pandya, 2024).

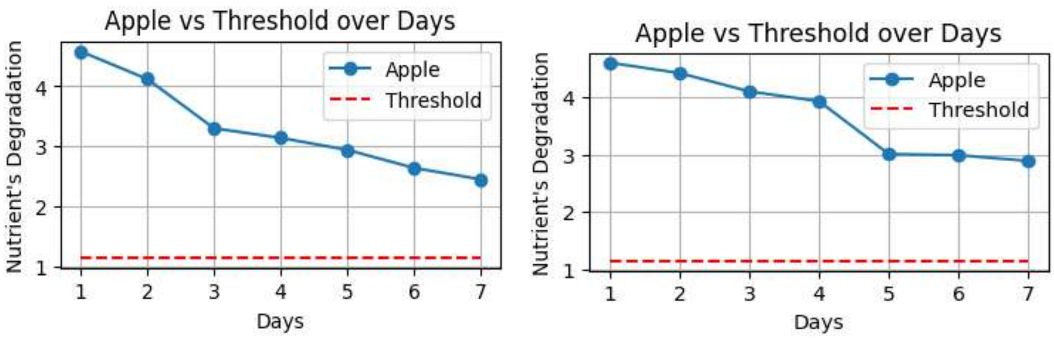
International Journal of Advances in Engineering and Management (IJAEM)
Volume 8, Issue 01 Jan. 2026, pp: 01-07 www.ijaem.net ISSN: 2395-5252

IV. RESULTS AND DISCUSSIONS

Table 1: Pre-Preservation Content Profile

Specimens	Vitamin C (mg)	Water (%)
Apple	4.6	85.60
Orange	69.70	88.00
Spinach	28.1	91.00

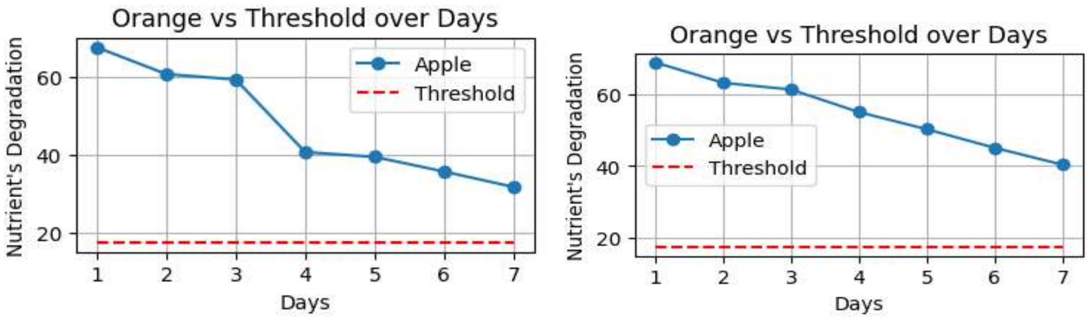
Table 1 presents the laboratory results showing vitamin C content (mg) and water percentage for each specimen analyzed. Among the samples, apple exhibited the lowest vitamin C concentration, while spinach contained the highest water percentage. These findings were obtained from laboratory analysis of 100g portions of each specimen prior to subjecting them to preservation. The data provides the baseline nutritional values necessary for assessing changes during preservation.



(a) (b)

Figure 2: Post-Preservation Content Profile for Apple at (a) Room Temperature (b) controlled DC Solar-powered Refrigerator Systems.

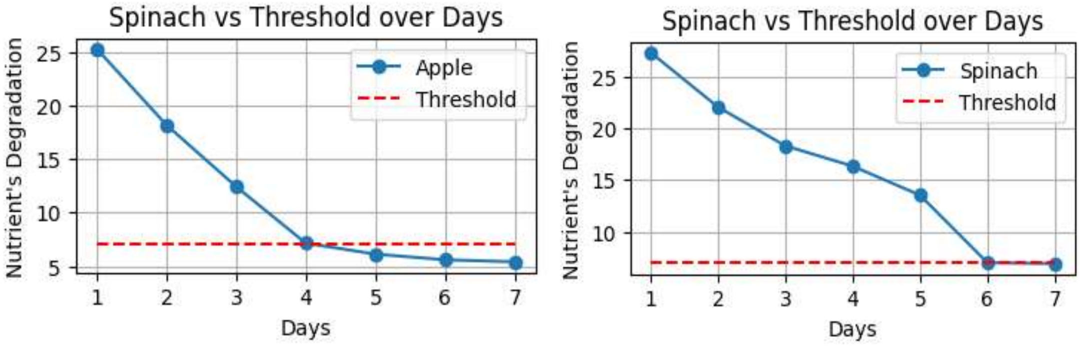
Both preservation methods maintained the apple's nutrient levels above the threshold throughout the seven days. The DC solar-powered refrigerator system slowed nutrient degradation, showing stability between days 3 and 4, as well as days 5 to 7. However, a noticeable decline occurred between days 4 and 5, indicating that while overall retention was effective, variations in nutrient stability were evident during preservation.



(a) (b)

Figure 3: Post-Preservation Content Profile for Orange at (a) Room Temperature (b) Controlled DC Solar-powered Refrigerator Systems.

Figure 3 illustrates the rate of nutrient degradation in orange during preservation. The graph indicates that the fruit remains suitable for consumption after day 7. Oranges stored in the DC solar-powered refrigerator system retained their nutrients more effectively compared to those kept at room temperature, highlighting the efficiency of solar refrigeration in slowing nutrient loss and maintaining fruit quality over the preservation period.



(a) (b)

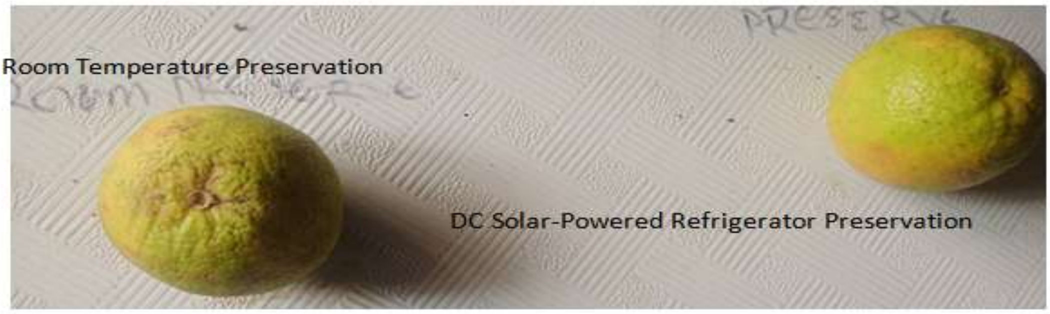
Figure 4: Post-Preservation Content Profile for Spinach at (a) Room Temperature (b) Controlled DC Solar-powered Refrigerator Systems.

In contrast to the preservation outcomes of apples and oranges, the graphical representation in Figure 4 reveals that spinach could not be effectively preserved beyond day 7 of the study. This limitation is likely attributable to its high-water content. Notably, spinach stored at room temperature reached the threshold point as early as day 4, whereas the sample preserved in the controlled DC solar-powered refrigerator system retained its nutrients longer, surviving until day 6 of the experimental investigation before significant degradation occurred.

(a) (b)

Figure 5: Post-Preservation Close Look Examination for Apples at (a) Room Temperature (b) Controlled DC Solar-powered Refrigerator Systems.

Figure 5 shows the physical examination of apples retrieved from room temperature and the DC solar-powered refrigerator system. Both apples retained their freshness after preservation. However, the apple stored in the DC solar-powered refrigerator exhibited noticeable wetness, suggesting the cooling environment influenced its surface condition, while the room temperature sample remained dry but equally fresh.



(a) (b)

Figure 6: Post-Preservation Close Look Examination for Oranges at (a) Room Temperature (b) Controlled DC Solar-powered Refrigerator Systems.

International Journal of Advances in Engineering and Management (IJAEM)
Volume 8, Issue 01 Jan. 2026, pp: 01-07 www.ijaem.net ISSN: 2395-5252

Similarly, the orange stored at room temperature exhibited a noticeable loss of freshness, characterized by a dry and slightly rough peel. In contrast, the orange preserved in the DC solar-powered refrigerator retained a moist peel, giving it a fresher and more appealing appearance. This observation highlights the effectiveness of the solar-powered refrigeration system in maintaining fruit quality compared to ordinary room temperature preservation.

Figure 7: Post-Preservation Close Look Examination for Oranges at (a) Controlled DC Solar-powered Refrigerator Systems (b) Room Temperature

Figure 7 presents the close physical examination of spinach samples after preservation. The spinach stored in the DC solar-powered refrigerator system maintained fresher, greener, and firmer leaves compared to the specimen preserved at room temperature, which showed early signs of wilting and dryness. This result underscores the superior preservation capacity of the solar-powered system in retaining the freshness and overall quality of spinach over the room temperature storage method.

V. CONCLUSIONS AND RECOMMENDATIONS

This study shows clearly that DC solar-powered refrigeration is much better than room temperature storage in keeping fruits and vegetables fresh and nutritious. Apples and oranges kept most of their vitamins for more than seven days, while spinach, which spoils faster, lasted only four days at room temperature but up to six days when stored in the solar refrigerator. This means solar-powered cooling can slow down spoilage, reduce food waste, and make food safer for longer periods. The research also has wider meaning for agriculture and community development. It provides strong evidence that governments and policymakers can use to support the adoption of renewable energy for food storage. By giving farmers access to solar refrigerators through subsidies, cooperative loans, or rural extension services, post-harvest losses can be reduced, the incomes of small farmers can improve, and families can have better nutrition. This directly supports important United Nations goals like Zero Hunger (SDG 2)**,** Affordable and Clean Energy (SDG 7)**,** andResponsible Consumption and Production (SDG 12)**,** while also helping withClimate Action (SDG 13) by reducing the use of fossil fuel cooling. Based on these results, future studies should include more types of crops and test the system under different weather conditions. Government should also support local training and production of solar refrigerators so that rural communities can use and maintain them. With these steps, solar refrigeration can become an affordable and sustainable solution for food security in places with weak or no electricity supply.

REFERENCES

[1]. Nasrullahi N, Iqbal, R., & Aslam, M. (2020). Food Science and Nutrition Technology: Conventional and Modern Methods of Preservation of Foods. Journal of Food Science and Nutrition, 4. https://doi.org/10.23880/fsnt-16000193

[2]. Amit, S. K., Uddin, M. M., Rahman, R., Islam, S. M. R., & Khan, M. S. (2017). A review on mechanisms and commercial aspects of food preservation and processing. Agriculture & Food Security, 6(1), 1–22.

https://doi.org/10.1186/s40066-017-0130-8

[3]. Arafat, M. Y., Hossain, M. J., & Alam, M. M. (2024). Machine learning scopes on microgrid predictive maintenance: Potential frameworks, challenges, and prospects. Renewable and Sustainable Energy Reviews, 190, 114088. https://doi.org/10.1016/j.rser.2023.114088

[4]. Buckow, R., & Bull, M. (2013). Advanced Food Preservation Technologies. Microbiology Australia, 34, 108–111. https://doi.org/10.1071/MA13037

[5]. Chang, L., & Wu, Z. (2011). Performance and reliability of electrical power grids under cascading failures. International Journal of Electrical Power & Energy Systems, 33(8), 1410–1419. https://doi.org/10.1016/j.ijepes.2011.06.021

[6]. Christopher, S. S., Thakur, A. K., Hazra, S. K., Sharshir, S. W., Pandey, A. K., Rahman, S., Singh, P., Sunder, L. S., Raj, A. K., Dhivagar, R., & Sathyamurthy, R. (2023). Performance evaluation of external compound parabolic concentrator integrated with thermal storage tank for domestic solar refrigeration system. Environmental Science and Pollution Research, 30(22), 62137–62150. https://doi.org/10.1007/s11356-023-26399-2

[7]. Hu, T., & Yue, Z. (2021). Potential applications of solar refrigeration systems for permafrost cooling in embankment engineering. Case Studies in Thermal Engineering, 26, 101086. https://doi.org/10.1016/j.csite.2021.101086

[8]. Khama, R. (2024). Advancements in food preservation technologies: Enhancing food quality, safety, and sustainability. Brazilian Journal of Technology, 7(4), e76174. https://doi.org/10.38152/bjtv7n4-045

[9]. Pandya, U. (2024). Food Preservation: Techniques and Importance for Food Security. African Journal of Food Science and Technology, 1–3.

[10]. Salilih, E. M., & Birhane, Y. T. (2019). Modelling and performance analysis of directly coupled vapor compression solar refrigeration system. Solar Energy, 190, 228–238. https://doi.org/10.1016/j.solener.2019.08.017

[11]. Singh Tomar, M., & Pradhan, R. C. (2024). Recent developments in solar-powered refrigeration systems and energy storage methods for on-farm preservation of fruits and vegetables. Sustainable Energy Technologies and Assessments, 72, 104032. https://doi.org/10.1016/j.seta.2024.104032

[12]. Tavman, S., Otles, S., Glaue, S., & Gogus, N. (2019). Food preservation technologies. In Saving Food (pp. 117–140). Elsevier. https://doi.org/10.1016/B978-0-12-815357-4.00004-3

[13]. Xiaohongai, S. (2024). Food Preservation: Ensuring Safety, Quality, and Longevity. African Journal of Food Science and Technology, 1–3.