Design and test of an affordable Cold Room powered by solar for improving storage quality and reducing wastage of horticulture produce.

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EXECUTIVE SUMMARY

Climate change is making it more difficult to grow enough food for an ever-growing population in Africa. Moreover, post-harvest losses are huge; leading to 50% loss of the food produced on the continent. At EcoLife, we believe sustainable supply of food will hinge on inclusive agricultural innovations.

Ecolife foods is a limited liability social enterprise that is focused on serving communities through innovation. We are promoting agriculture through scientific research and technology development. We are a multi-disciplinary team working with researchers, farmers and youth agripreneurs to solve farm challenges. In that regard, we design sustainable technologies to better agriculture while creating employment opportunities in Uganda. Since 2015, Ecolife has designed and developed technologies that tackle various challenges in the agricultural sector.

Among these is the eco cold room designed to reduce food losses that occur during periods of bumper harvest. The solar dehydrator to preserve food in the dry form for longer storage. Research on organic pesticides and fertilizers to enhance production while conserving the environment is on going. All the work is done with the involvement of communities and farmers whose ideas, knowledge and skills are the basis of most of our research. Farmers are consulted in development of the technologies that solve challenges directly affecting them. Once the technologies are out and working, the farmers are then trained on their application. Our main goal is to use locally available materials and/or made out of local resources by local inhabitants according to their technical skills training; to solve local problems.

The eco cold room is one technology that has gone through the design process to a working prototype. The performance of the cold room was validated with the beyond wireless technology provided by CLASP through the Off-Grid Cold Chain Challenge (OGCCC).

ACKNOWLEDGEMENTS

Ecolife has worked with different partners who have supported our journey; to whom we are greatly indebted. Among these is ICCO cooperation, who is our very first granter. ICCO helped us with the seed grant that has seen us implement our idea to reality. ResilientAfrica Network (RAN) at Makerere University School of public health is another partner that pushed us from where ICCO left us. We worked with RAN for two years and developed our prototype further. CLASP has worked with us on the validation of the performance of the Eco cold room. Other partners such as Makerere University Kampala, Oregon State University and Massachusetts Institute of Technology (MIT), among others have trained and equipped us with knowledge and skills to build our capacity to work with the farmers effectively in designing the various technologies.

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1 BACKGROUND

In developing countries, food crises are often caused by an inability to preserve food surpluses rather than low food production (Wandra, 2014; Chua and Chou, 2003). There is always an excess of fruits and vegetables produced during the rainy season; much of which goes to waste due to lack of preservation. This results in huge post-harvest losses leading to 50% loss of the food produced (Wandra, 2014). Horticultural produce requires a cooling temperature between 0°C to 15°C for safe storage and transient purposes (Kader, 1992). In the absence of preservation technologies such as solar drying, cold storage and related cold chain facilities, small scale farmers are forced to sell their produce immediately after harvest resulting in surpluses and low-price realization in the market. Fruits and vegetables contain a high moisture content and are therefore highly susceptible to rapid quality degradation, if not kept in thermally controlled storage facilities. Therefore, besides employing reliable storage systems, postharvest methods such as drying and cooling can be implemented hand-in-hand to convert the perishable produce into more stabilized products that can be kept for an extended period.

Ecolife cooler (Eco cold room®) is a new innovative cold storage facility for storing fresh produce. It is ideal for rural areas where there is a certain limit of power load. Solar energy-based refrigeration system is relevant to Ugandan weather because it is blessed with a good amount of solar energy in most parts of the country, throughout the year. The Eco cold room is a Hybrid Cold Room designed for use throughout the year. It can be used with the alternate power source during the absence of sunlight i.e. DG Power. The Cold Room is constructed using existing materials and structures e.g bricks and cement. Ecolife is using plastic waste insulation (re-use of polyethylene terephthalate (PET) bottles) in the cold room. Studies on the use PET bottle to produce economically feasible insulation product, have be done (Xanthos et al., 2001); polyethylene terephthalate (PET) foam is used in composite sandwich panels in construction industry with multiple advantages (Garrido et al., 2015). Additionally, the maintenance is very low and there is no running cost while operating through solar energy. These characteristics make the low-tech Ecolife Cooler best suited and affordable for horticulture farmers in Uganda. The cold room has gained continuous appreciation from the users (farmers) and prime organizations. This has encouraged Ecolife to launch it in rural collection centers to improve storage quality and reduce wastage of horticulture produce. Our goal is to reduce post-harvest losses of fresh produce using cold rooms and sustainably supply the growing population with clean, fresh produce throughout the year.

2 STATEMENT OF THE PROBLEM

Agricultural losses and waste from poor postharvest handling (Figure 2-1) are common in Uganda. This is even more pronounced in rural areas, which suffer excessive fresh produce loss due to lack of good storage facilities. The available stores and markets have no cooling facilities resulting in many produces rotting on shelf. Most food industries dealing with commercial products employ state-of-the-art cooling equipment such as freezers and fridges. The prices of such coolers are significantly high and only commercial companies generating substantial revenues can afford them. Therefore, because of the high initial capital costs, most of the small-scale companies and farmers cannot afford them. Instead cheaper, easy-to-use and practical cooling facilities become appealing to such companies and even to the rural farmers. Importantly, many farming areas in Uganda have an abundance of natural building materials but literacy in science and technological use of such materials is limited. Ecolife uses her upper hand in scientific research and technology to use the existing materials to design technologies relevant to the farmers. The Eco cold room is one such technology designed to reduce losses and increase incomes for the farmers and traders.

Figure 2-1: Horticultural farm waste

3 STATUS OF COLD STORAGE IN UGANDA

Although, there is a vast scope for increasing the fruit and vegetable production as a means of youth employment, fighting poverty and malnutrition at household level; the lack of cold storage and cold chain facilities is a major bottleneck in tapping this potential. The cold storage facilities now available are very expensive and mostly for exported/imported commodity like potato, orange, apple, grapes, flowers, etc. Most storage facilities located at Entebbe International Airport are operated and developed by private investors e.g. Fresh Handling Services Ltd, Entebbe Handling Services (ENHAS), and Roka Bonds Ltd. These handle all fresh produce from fish to vegetables for export (Ssemwanga, 2012). There are no cold storage facilities at border crossings. KK foods is the only company directly engaged in coldstorage of fresh produce for export purposes. There are no available coldstore facilities for direct use by farmers or traders on the local market.

4 OUR APPROACH

We focus on agricultural led development interventions, and work with farming communities to create affordable technological solutions to the farmers' local challenges and generate income. Using a step by step methodology of the design process and a human-centered design; we have developed, built, and tested an energy-efficient and cost-effective solar powered cold room. In building the first prototype, we worked with community members to identify the problem through a needs assessment study. We looked at various options and agreed to design and develop the cold room. We involved students from Universities, farmers and community members in doing all the research and design work. The PET bottles used as insulation (Figure *6-1*) were collected by community members from schools, parties and other functions where bottled water was consumed or even those littered around the community. We aligned these bottles between two walls to act as the insulation and testing of the cold room with produce was done. All the produce used in the testing was got from the farmers, who were allowed to participate in the loading of the produce in the coldroom and in the inspection and assessment of the produce after the test days. The produce tested was passion fruits, mangoes, traditional leafy vegetables, tomatoes and cabbage. We obtained feedback from the farmers and community on the performance and application of the cold room. Following that feedback, we developed the second prototype which is the focus of this report.

5 Product Features

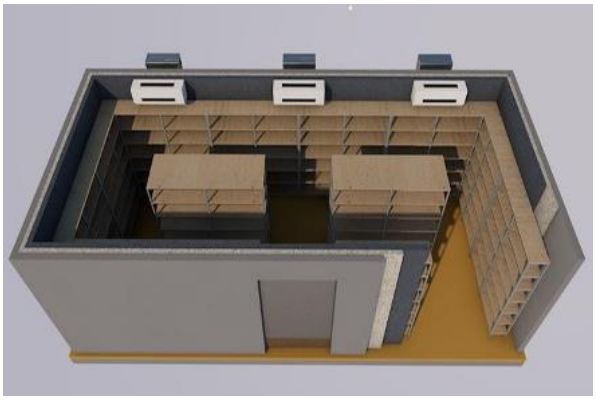

Figure 5-1 Archtectural design of the cold room

5.1 The standard features include

- Cold room size (LxWxH): 20 m^3
- PET insulation material: 100 mm
- Product capacity: 4 to 5 MT
- Loading rate: 10%
- Backup:
  - 14 hours with 10% loading and less times door opening condition
  - Temperature range: 5˚C to 10˚C
- Low voltage and over voltage protection
- Mono-crystal or poly-crystal solar panels
- Batteries require no maintenance
- Solar Panel: 3.0 kW

5.2 Unique Feature:

- Thermal Energy Storage system to provide backup during night and cloudy weather
- Solar powered
- DG set system
- Ecofriendly insulation material
- Low maintenance
- No running cost on solar supply

6 DESIGN CONSIDERATIONS AND CRITERIA

6.1 Affordable Insulation Board

When the problem of cold storage was identified, we listed the main considerations to resolve the need for good insulation. We identified and evaluated different designs to choose the best according to the most relevant design for our purpose.

Design factors for affordable insulation material:

1. Be locally available or made out of local resources by local inhabitants according to their technical skills training.
2. A high R-value
3. Able to trap air in as part of its structure, in order to increase the R-value,
4. Water resistant.
5. Be low cost as possible.

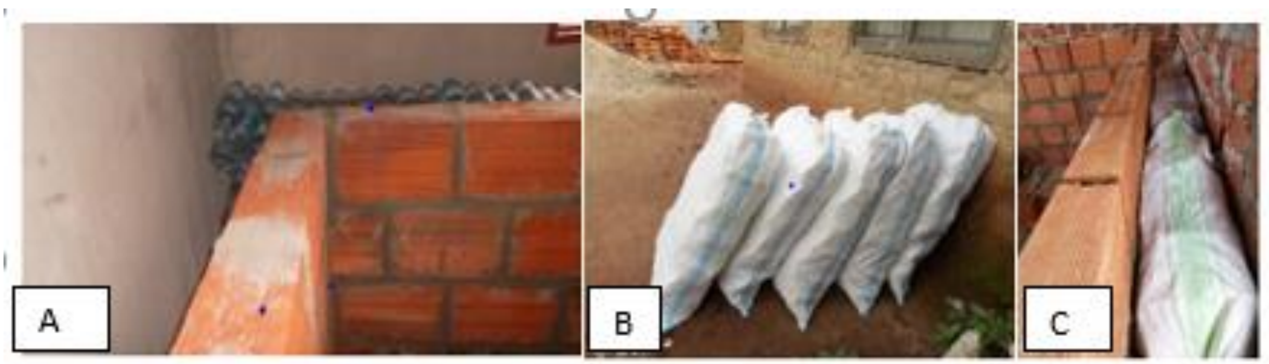

Figure 6-1: **A-** Insulation used in the 1st prototype, **B&C**-Insulation board used in second prototype

PET bottles can be used as a low cost filler alternative foam instead of the costly foam core (Xanthos et al., 2001). The insulation board has a long life time, does not degrade or deteriorate and can be recovered in later days, for example, by adding it back into new insulation or molding it into new applications. The impact of this insulation system is, not only based on energy consumption and GHG emissions, but also on further environmental issues such as waste management and circular economy in developing countries. This insulation was used in Eco cold rooms connected to a solar hybrid system to cool internal temperature between 5 to 10^{o}C. Produce stored included tomatoes, passion fruits, green pepper, mangoes, traditional leafy vegetables and cabbage. The data provided in this report is that for mangoes because they were tested when we had equipment from CLASP to take note of the differences in temperature inside and outside of the cold room.

6.2 Air vents in the Attic (roof ventilation).

This is the space at the top of the building under the roof (Figure *6-2*). To keep heat out of the structure and improve circulation. Exhaust vents and intake vents were added to enhance roof ventilation, hence allow hot air to esacape during the hot hours of the day. This was done on the second prototype to reduce the supper heated air that gets trapped in the attic increasing attic temperature thus affecting the cold room temperature.

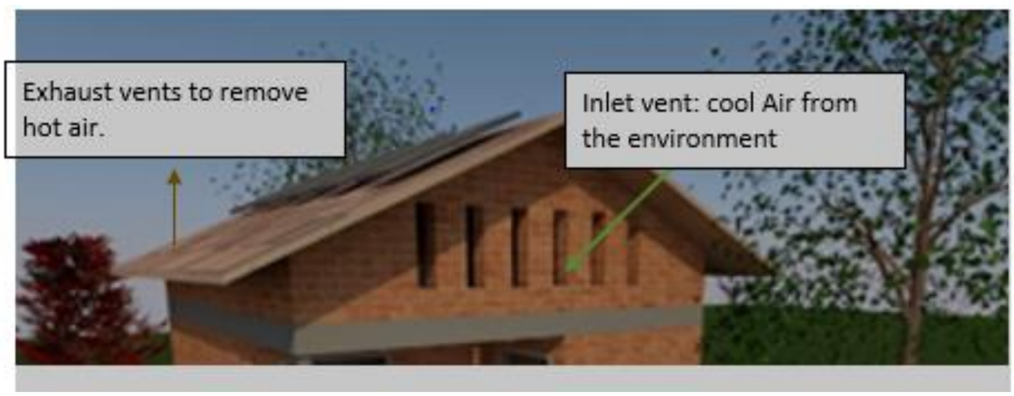

Figure 6-2: Attic with air vents.

6.3 Diesel engine to run the cooling units during low or no sunshine days.

A diesel engine combined with the alternator (Figure *6-3*) was present in the system. A three-phase generator was available from 10 kVA onward. It was an over design in the system, and as well as it creates financial burden to the system. A simple single phase 3.5 kVA alternator was used to supply energy during rainy/cloudy days when sunlight was limited. We work with farmers who still rely on rain fed agriculture when solar production is always low, yet surpluses that need to be stored occur then, hence the need for the diesel power.

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Figure 6-3: Affordable diesel engine with an alternator.

6.4 Inverter for the AC supply

An inverter was used to harvest maximum power from the solar panel and make it usable for the single-phase compressor motor. The main feature of this inverter was to convert DC input to AC output.

Figure 6-4: Inverter used in the Eco cold room

6.5 Modified Split AC Fans

A local fabricator was used to make fans for the cold room. We converted the existing air conditioners into efficient blowing fans for the cold room (Figure *6-5*).

Figure 6-5: Modified Split AC units - locally fabricated fans to blow cool air

6.6 Automated Data recording system

We are transforming the agriculture setor through knowledge sharing and capacity building. An automatic data recording system was installed to record temperature and humidity of both the cold room and ambient environment. This digital recording system helped us to review storage conditions on a daily basis (Figure *6-6*). This allowed us to identify any faults or shortcomings in performance of the coldroom. We were therefore able to schedule maitanence and effectively collect data on the different aspects e.g. relative humidity and temperature of the cold room.

Figure 6-6: An automatic data recording system

7 TEST RUN OF THE COLD STORAGE, FINAL TECHNICAL DATA, AND ITS ANALYSIS

A test run of the cold room was performed. First without produce to determine if the device meets the target temperature of 5°C inside the Eco cold room. Farmers from Luwero provided mango fruits harvested at hard green physiological stage of maturity. The mangoes were used to test the performance of the cold room. Mangoes were stored in cold storage (test) and ambient temperature (control) to investigate the effect of temperature on the shelf life of mangoes. They were stored in the cold room at 8°C - 10 °C for 12 days. The fruits were subjected to ripening assessment on the 12^{th}, 13^{th} and 14^{th} day. The quality assessment was done two times by carefully observing the fruits immediately after removal from cold room and after ripening in the subsequent two days in ambient conditions. The cold room was in operation 24hours/day.

7.1 Testing with no Produce

The first test was performed without any produce stored to see if it functions correctly before the actual food preservation test. The minimum temperature recorded was 6.6°C and maximum was 20.6°C for the cold store. The maximum atmospheric temperature being 32. 5°C. The mean temperature of the sensors (A1, A2, A3, A4 and A5) per hour were consistent for 17 test hours irrespective of the rises in ambient temperature (Figure *7-1*). The sensors were in different positions of the cold room i.e. at the door, and the four walls of the cold room.

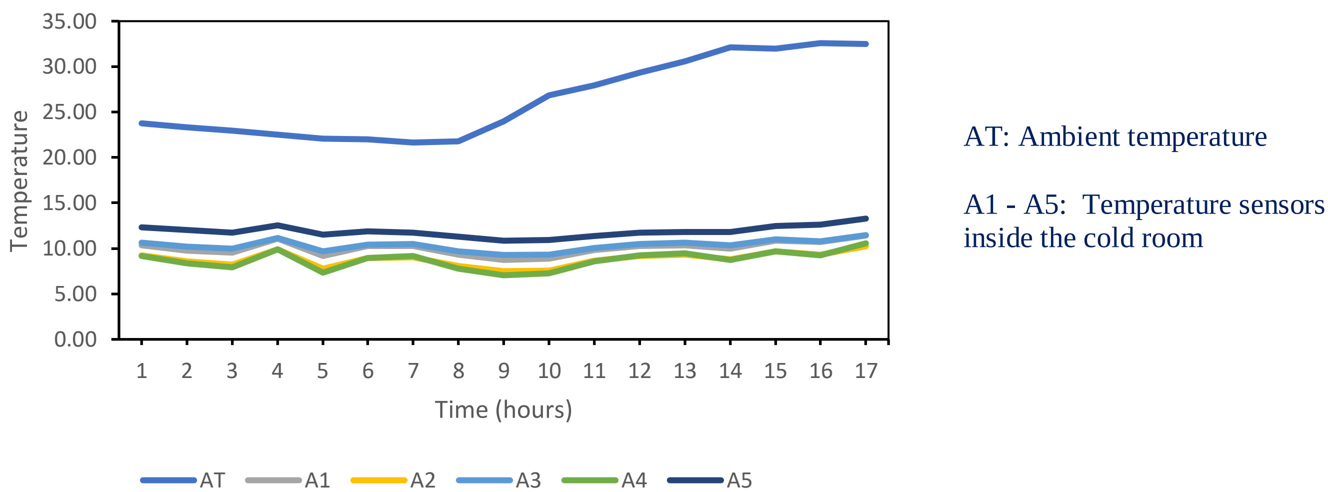
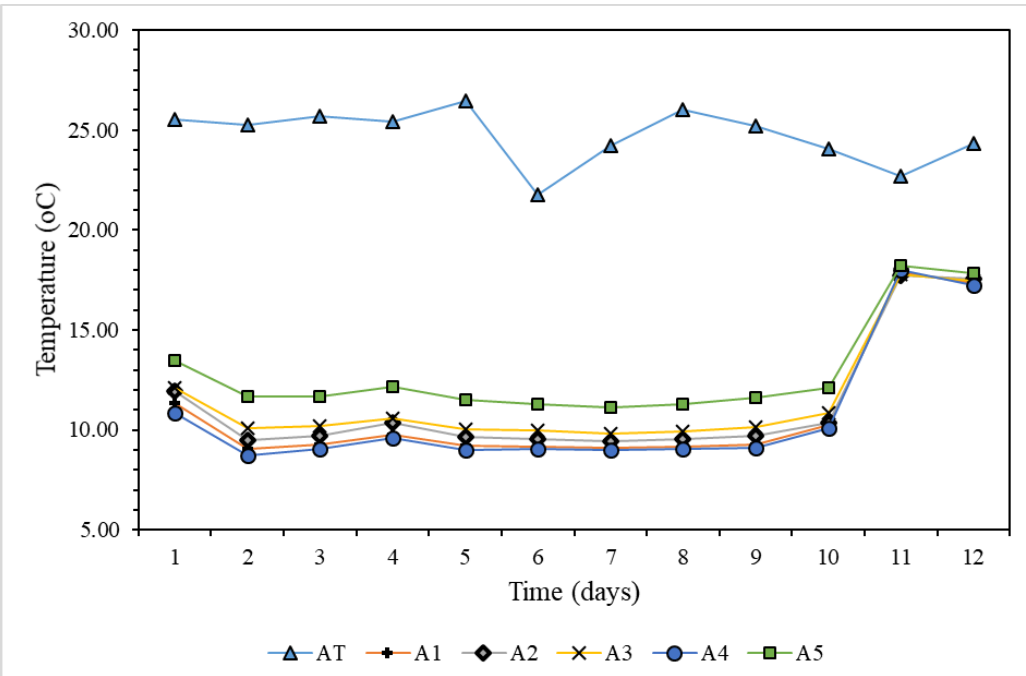


Figure 7-1: Temperature varriations with out fresh produce.

7.2 Testing with produce

Temperature as reflected by different sensors (A1-A5) in Figure *7-2* was recorded. The minimum temperature of the cold storage was 7.5°C. The system was maintained at a temperature range of 8-10°C necessary for storage of mangoes. At this temperature the system automatically stops its compressor. The compressor goes on an off depending on the temperature inside the cold room. The unit was operated in a sunny day, in a partial sunny day and at night. Using the automatic data recording system temperature and humidity of both the cold room and ambient environment were recorded.



AT: Ambient temperature

A1 - A5: Temperature sensors inside the cold room

Figure 7-2: Temperature inside the cold storage as a function of time

The Slope from day one to day two indicates the fall of temperature inside the cold storage. And the rising slope indicates the increment in temperature inside the cold storage during off time. The shelf life of mango fruits stored in the cold room was extended compared to mangoes stored at room temperature. This is due to the reduction in field heat in shortest possible time, lower moisture loss, inhibition in water loss and reduction in ethylene production in fruits (Kader, 1992)

Mangoes received from the market were too ripe (Figure *11-6*). Cold storage maintained the quality of the mangoes compared to room temperature samples (Figure *11-9*; Figure *11-10*). There was less spoilage of produce received from farmers compared to those bought from market collection centre. This was asscociated with the poor post harvest handling technologies/transportation from farm to market. Cooling injury (Figure *11-11*) was observed in samples received from the market collection ceter. Therefore, low temperature storage reduced quality parameters such as peel color, for cold stored fruits as compared to mangoes stored at room temperature (Figure 11-7 and Figure *11-8*). Chilling injury was observed and it was progressive with storage duration especially with magoes received from market traders

7.3 Testing the on/off of the compressor

The slope below indicates the changes in temperature inside the cold storage (from 10°C to 8°C). the temperature on average oscilated between 8 and 10°C for 10 minutes hence saving energy.

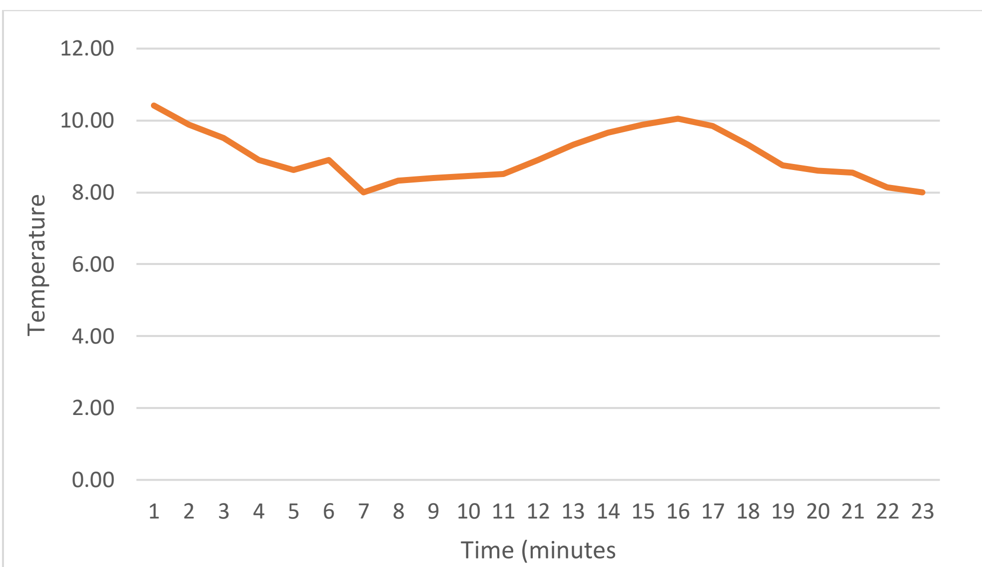


Figure 7-3 Temperature changes inside the cold room

8 CONCLUSION

Our test results showed that the designed low cost cold room powered by solar can extend shelf life of fruits and vegetables. This will therefore increase the revenue period for smallholder farmers as well as their bargaining power in the market place. Despite the fact that we used local materials for construction, and the insulation of the cold room was locally designed, we saw a significant difference in the shelf life of the test and control produce. Testing with different energy systems (Solar and Diesel) allowed us to profile an affordable cold storage for rural communities in Uganda for use during wet (low solar energy /no electricity) and dry seasons (high solar energy/no agricultural produce). At ambient temperatures, shelf life of mango fruit is shorter. The quality and shelf life of mangoes was maintained throughout the test period in the cold room. The shelf life was increased with a decrease in temperature. Further investigation might be needed for determining the critical temperature for chilling injury of the fruits.

9 RECOMMENDATION

The testing revealed that reusing plastic waste PET bottles filled with air as insulation material for cold rooms can save energy, a good innovation for developing countries in the climate change error. The first order for sustainable approach would be to create a completely standardized procedure for recycling waste PET bottles into PET foam as an alternative material for making sandwich panels for cold rooms in Sub-Sahara Africa. It is also important to have quality technological solar supply and equipment for sufficient energy supply in the cold rooms. We recommend establishing cold rooms at collection centres for both food self-sufficiency and considerable progress towards goals of zero food loss and human nutrition in Africa.

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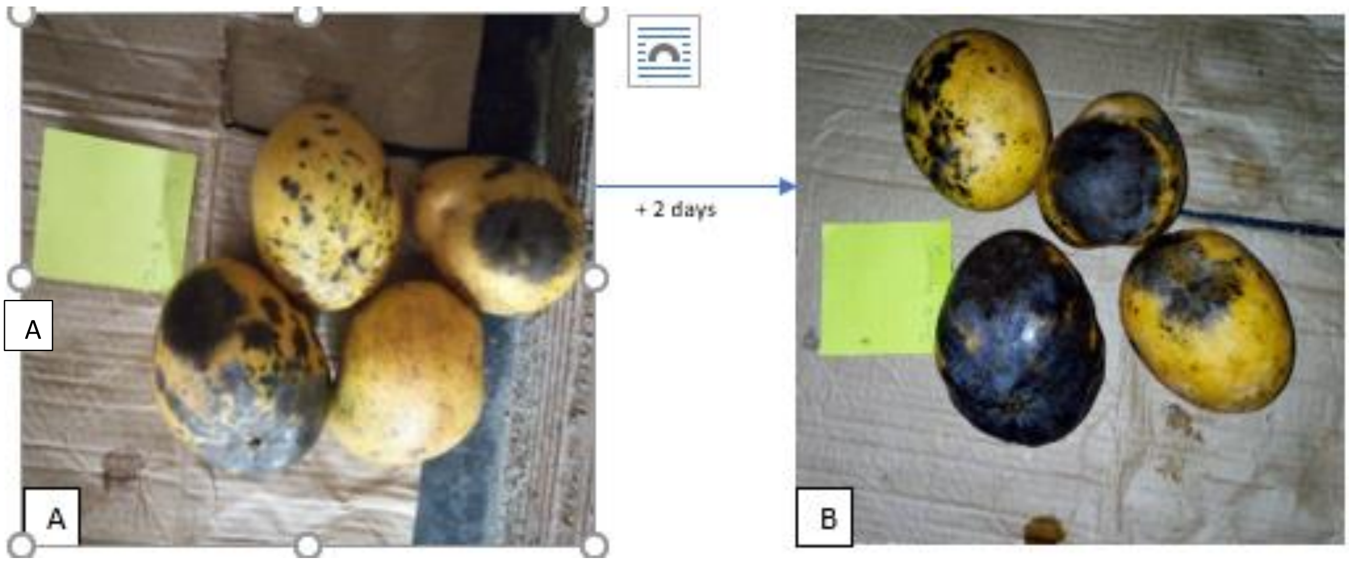

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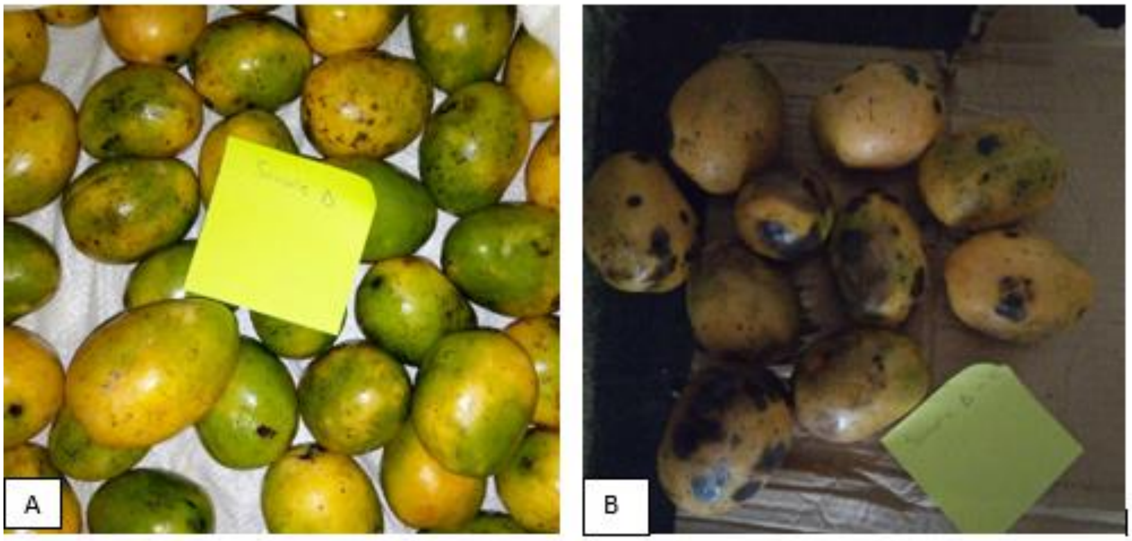

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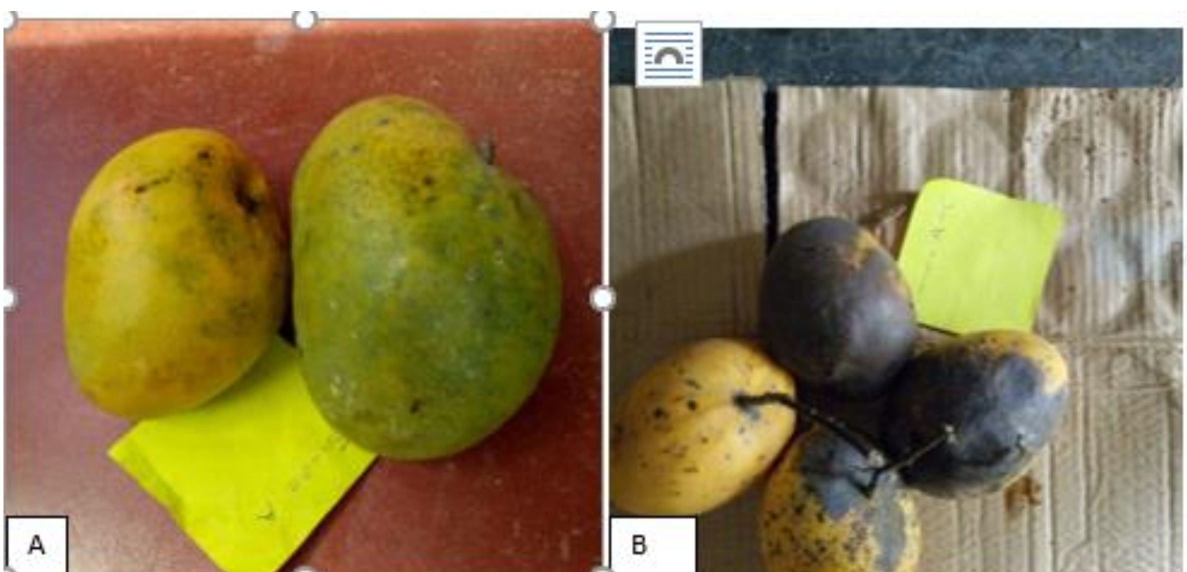

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