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Application of Renewable Energies for Storage of Horticultural Produce in Marginal Areas of Kenya: *The Performance Evaluation of a Prototype Solar-Charcoal Cooler*

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Abstract:
Kenya relies heavily on agriculture for food and employment particularly in the rural areas. It is therefore of great importance that efforts resulting in high agricultural productivity be handled with all the degree of seriousness. Due to the drastic fall in world prices of coffee and tea, there has been a steady shift to horticultural crops production such that the sector is now the second foreign exchange earner after tea. Most of the produce is marketed in many developed countries including Europe and the United States of America.
There are however, some serious challenges the sector is facing including lack of ideal facilities for proper storage of perishables and semi-perishables at the farm level in Kenya particularly between harvesting and the time when the crop is accepted by the customer. This has resulted in tremendous losses and loss of morale for the farmers. Simple and effective storage systems should therefore be developed and used to minimize losses thus improving the net returns on farmers. Refrigeration plays an important role in many countries, particularly for the preservation of food, medicine and for air conditioning. Cooling can be provided in different ways. The method adopted in industrialized countries depends heavily on grid electricity, supplied continuously and reliably to every part of the country. Less than 20% of the Kenyan population has access to electricity thus making it not only impossible but also expensive to use cold storage systems at the rural level. Alternative methods are therefore necessary.
The main objective of the research was to investigate the possibility of using renewable energies for storage of horticultural produce in marginal areas of Kenya with specific objectives mainly including the development of a prototype solar-charcoal cooler and testing its performance as related to temperature, humidity and products storageability. A prototype solar-charcoal cooler was developed at the Biomechanical and Environmental Engineering Department (BEED), College of Engineering and Technology of the Jomo Kenyatta University of Agriculture and Technology (JKUAT), Kenya and performance tested. It mainly consisted of two components:
(1) A solar air drift which included a solar power driven fan to blow air through the charcoal to facilitate evaporation of water from the charcoal.
(2) A cooling chamber which was lined with an aluminium sheet on the inside, charcoal layer on the outside and a water pan at the top for water supply.
The performance of the cooler indicated positive results as regards to ideal parameters affecting produce storage. These parameters mainly included variations in temperature and humidity to levels ideal to product storage. The results also indicated that various fruits and vegetables including paw paws and spinach could be stored in the cooler for longer periods as compared to when they were under ambient conditions.

Keywords: *Renewable, Energies, Storage, Horticultural, Produce, Solar-charcoal, Cooler*

1. Introduction

As the case is with many developing countries, Kenya relies heavily on agriculture for food and employment particularly in the rural areas. Attempts in ensuring high productivity in agriculture should hence be encouraged. Horticultural crops have steadily gained importance in foreign exchange earnings such that the sector is now the second foreign exchange earner after tea. There are however, some serious challenges the sector is facing including lack of ideal facilities for proper storage of perishables and semi-perishables at the farm level in Kenya and in particular between harvesting and the time when the crop is accepted by the customer. This has resulted in tremendous losses and loss of morale for the farmers. Tables 1 and 2 show ideal storage conditions for perishables and semi-perishables and approximate figures for crop losses in developing countries respectively. Simple and effective storage systems should therefore be developed and used to minimize losses thus improving the net returns on farmers.

Commodity	Storage temperature ^{o}C	Relative humidity %	Storage life
Asparagus	0 – 2.0	95	2 – 3 weeks
Beans (green)	5.0 – 7.0	90 – 95	7 – 10 days
Carrots	0	90 - 95	2 – 5 months
Cauliflowers	0	90 - 95	2 – 4 weeks
Cucumbers	7.0 – 10.0	90 - 95	10 – 14 days
Cabbage	0	90 - 95	3 – 6 weeks
Chillies, Capsicums	7.0 - 10.0	90 - 95	2 – 3 weeks
Courgettes, Zucchini	0 - 10.0	90	5 -14 days
Eggplants, Brinjals	7.0 - 10.0	90	1 week
Melons	0 - 10.0	85 - 90	5 – 14 days
Okra, Lady fingers	7.0 - 10.0	90 - 95	7 – 10 days
Onions (dry)	0	65 - 70	1 – 8 months
Potatoes (white)	5.0 - 10.0	93	2 – 5 months
Potatoes (sweet)	12.0 - 16.0	85 - 90	4 – 6 months
Tomatoes (ripe)	7.0 - 10.0	85 - 90	4 – 7 days
Tomatoes (green)	12.0 - 20.0	85 - 90	1 – 3 weeks
Watermelons	4.4 - 10.0	90	2 – 3 weeks
Apples	1.0 - 4.4	85 - 90	3 – 8 weeks
Avocadoes	4.4 - 12.5	85 - 90	2 – 4 weeks
Mangoes	12.0	85 - 90	2 – 3 weeks
Pineapples	7.0 - 12.5	85 - 90	2 - 4 weeks
Papayas	7.0	85 - 90	1 – 3 weeks

Table 1: Ideal temperature and relative humidity and storage life for some horticultural products
Source: FAO, 1986

Crop	Approximate % losses
Apples	14
Avocadoes	43
Bananas	20 - 80
Cabbage	37
Carrots	44
Cassava	10 -25
Cauliflower	49
Citrus	20 -95
Grapes	27
Lettuce	62
Papaya	40 -100
Plantain	35 -100
Potatoes	5 – 40
Onions	16 – 35
Raisins	20 -95
Stone fruit	28
Sweet potatoes	35 -95
Tomatoes	5 -50

Table 2: Approximate figures for crop losses in developing countries
Source: Bakker-Arkema, 1999

Various methods for handling/processing farm produce are used in several parts of the world[1-15]. Refrigeration plays an important role in developing countries, particularly for the preservation of food, medicine and for air conditioning. Cooling can be provided in different ways. The method adopted in industrialized countries depends heavily on grid electricity supplied continuously and reliably to every part of the country. In contrast, refrigeration is required in developing countries to stimulate agriculture and commerce in vast areas without a reliable electricity supply. Less than 20% of the Kenyan population has access to electricity thus making it not only impossible but also expensive to use cold storage systems at the rural level. Alternative methods are therefore necessary.

Currently more effort is being directed towards the production and marketing of raw produce. However, little emphasis has been put on the storage, processing and local use of such produce[7]. Storage helps to maintain quality and is part of orderly marketing. Storage also ensures continuous supply of similar quality produce during off-season. Other reasons for storage include; handling of over-production, sustainability and continuity of farm operations[2].

The charcoal cooler has been in use for ages but its adaptability in Kenya has been poor due to lack of construction standards and scientific back-up on its performance potentials. This paper reports the performance of a solar-charcoal cooler which mainly comprised two components namely the solar air drift and a cooling chamber.

2. Materials and Methodology

The prototype solar-charcoal cooler used in this study was developed at the Biomechanical and Environmental Engineering Department, Jomo Kenyatta University of Agriculture and Technology, Nairobi, Kenya. It was made of a mild steel frame covered in wire mesh on the outside and lined with an aluminium sheet on the inside. The cooler mainly comprised of two components namely the solar air drift and a cooling chamber.

- The Solar Air Drift: The main components in this case were a solar panel and a battery to store solar energy as electricity. The electrical power was used to drive a fan which blew or drew air through the charcoal to facilitate evaporation of water from the charcoal.
- The Cooling Chamber: This was lined with aluminium sheet on the inside, charcoal layer on the outside and a water pan at the top for water supply.

Figure 1 shows a pictorial presentation of the solar-charcoal cooler.

Figure 1: The prototype solar-charcoal cooler developed for laboratory studies

Initial performance tests of the cooler involved monitoring of the temperatures and relative humidity values in and out of the cooler over a 24-hour period for about one month. Some farm produce namely paw paws, tomatoes, bananas, carrots, cabbage, kales and spinach were then stored in the cooler till the end of their shelf life and their storageability evaluated with time. The tests carried out to evaluate storageability included firmness, vitamin C (ascorbic acid), starch, colour and weight tests.

Firmness tests on the fruits and colour tests on all the products were carried out after three days' intervals for 14 days. Firmness or crispness is used as a test for suitability for consumption. It was in this case established by use of a fruit firmness tester also known as a pressure tester or penetrometer. The materials and equipment for starch tests included iodine solution, vegetable leaves to be tested, a large test tube sometimes called a boiling tube, a 250-ml glass beaker, ethanol and a teat pipette. The glass beaker was filled to half with boiling water and a large test tube which was a quarter full of ethanol added to it. The ethanol was allowed to boil. The leaf to be tested was softened in the boiling water for ten seconds and then added to the ethanol and allowed to boil for a minute until all its colour disappeared. It was then removed from the ethanol and put back in the hot water to soften for ten seconds thereafter spread on a white tile and three drops of iodine solution dropped on it to test for starch. A blue-black colour would indicate the presence of starch.

Loss of colour and shrinkage of agricultural produce plays a vital role in consumer/customer attraction and enhances product acceptability. Shrunk products with undesirable colour will not appeal to consumers. Loss of colour and shrinkage was determined by physical/visual inspection. Handling and storage are among the factors that affect vitamin C contents of fresh produce. The retention of vitamin C is often used as an estimate for the overall nutrient retention of food products because it is by far the least stable nutrient. It is highly sensitive to oxidation and leaching into water-soluble media during storage. The materials and equipment used for vitamin C tests in this study included 1% starch indicator solution, iodine solution, a graduated cylinder, 250 ml glass beaker, 100 ml conical flask and a teat pipette. The fruits were first thoroughly washed and their juices extracted by mechanical pressure. Each type of juice sample was filtered to remove pulp and seeds and placed in labeled plastic containers. The juices were then transferred into the 100-ml conical flask and ten drops of starch solution added. This was then titrated with the iodine solution until the first blue colour which persisted for about twenty seconds was observed. The initial and final volume of iodine solution required to produce the colour change at the end point was recorded. Increases in pH values of the fruit juices as time goes by is related to the deterioration of fruit characteristics. Weight tests were conducted since fresh fruits and vegetables contain a lot of water. Water loss results into loss of weight (saleable weight) and that constitutes a direct loss in marketing. Measures that minimize water loss after harvesting will thus enhance profitability. A loss of 5% of the weight will usually make products appear wilted or shriveled.

3. Results and Discussion

The observations of this study indicated that applications of biomass in this case charcoal and solar energy can yield positive results in improving storageability of horticultural produce. Improvement in temperature and relative humidity which are sensitive parameters as regards to produce storegeability was observed. This is shown on figures 2-7. The relative humidity generally increased with the use of wet charcoal. However, when the fan was used the humidity decreased implying that a combination of the charcoal wetting and fan utilization (solar energy utilization) would result in ideal storage conditions. Ambient temperatures were higher as compared to those in the charcoal cooler particularly when charcoal wetting was involved. The results did not indicate major effect on temperature when the fan was used. However, temperatures in the cooler seemed to be more uniform which might be an ideal situation for some produce stored in the cooler.

The various tests conducted to evaluate storegeability of the produce also indicated positive results when the solar-charcoal cooler technology was involved. Figures 8 and 9 show the observations for fruit firmness tests. Results for starch tests on vegetables are shown on tables 3 and 4. Again in this case, a combination of charcoal cooling and solar energy utilization result in improved performance. Results for vitamin C tests on fruits as presented on tables 5 and 6 also indicated less increases in pH values when solar energy technology was used as compared to when only charcoal was used. Increases in pH values of the fruit juices where only charcoal cooling was used was related to deterioration of fruit characteristics. Observations for weight tests as shown on tables 7 and 8 again indicated that the use of the solar technology improved storageability due to reduced water loss i.e. reduced weight losses. Results of tests carried out to investigate the effects on shrinkage and loss of colour are presented on tables 9 and 10. The use of the solar energy i.e. use of the solar power driven fan indicated some positive improvement on some produce.

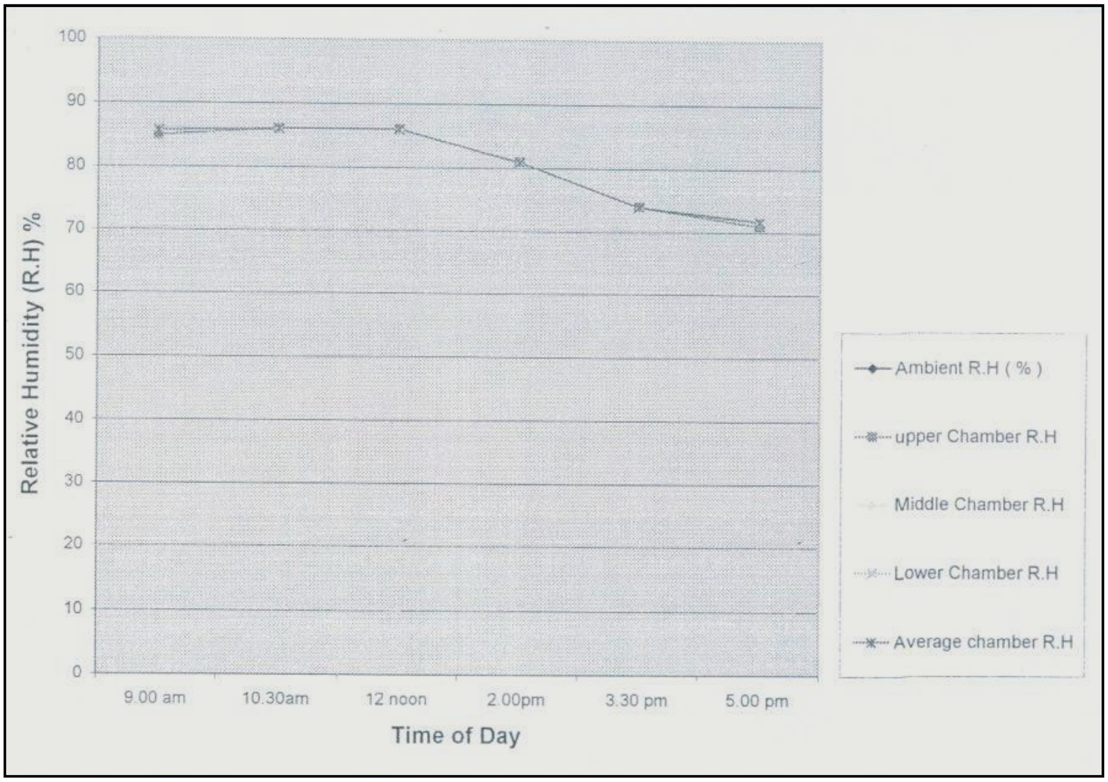

Figure 2: Relative humidity variation with time (before charcoal wetting and fan was off)

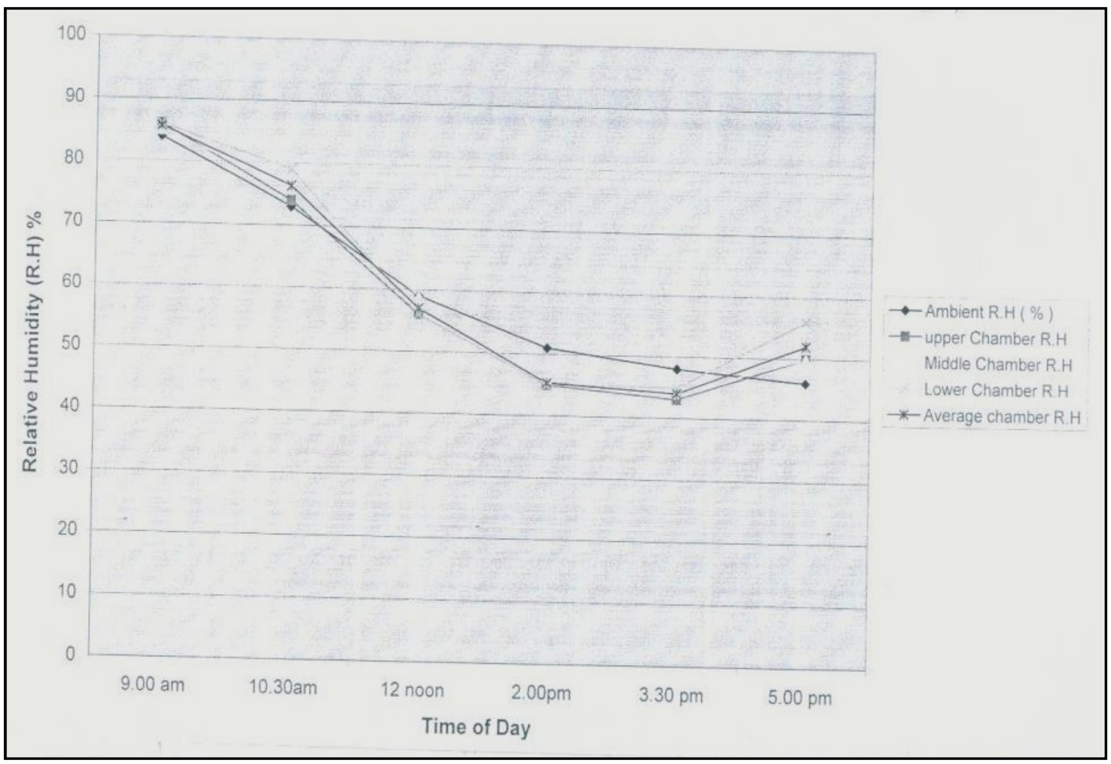

Figure 3: Relative humidity variation with time (after charcoal wetting and fan was off)

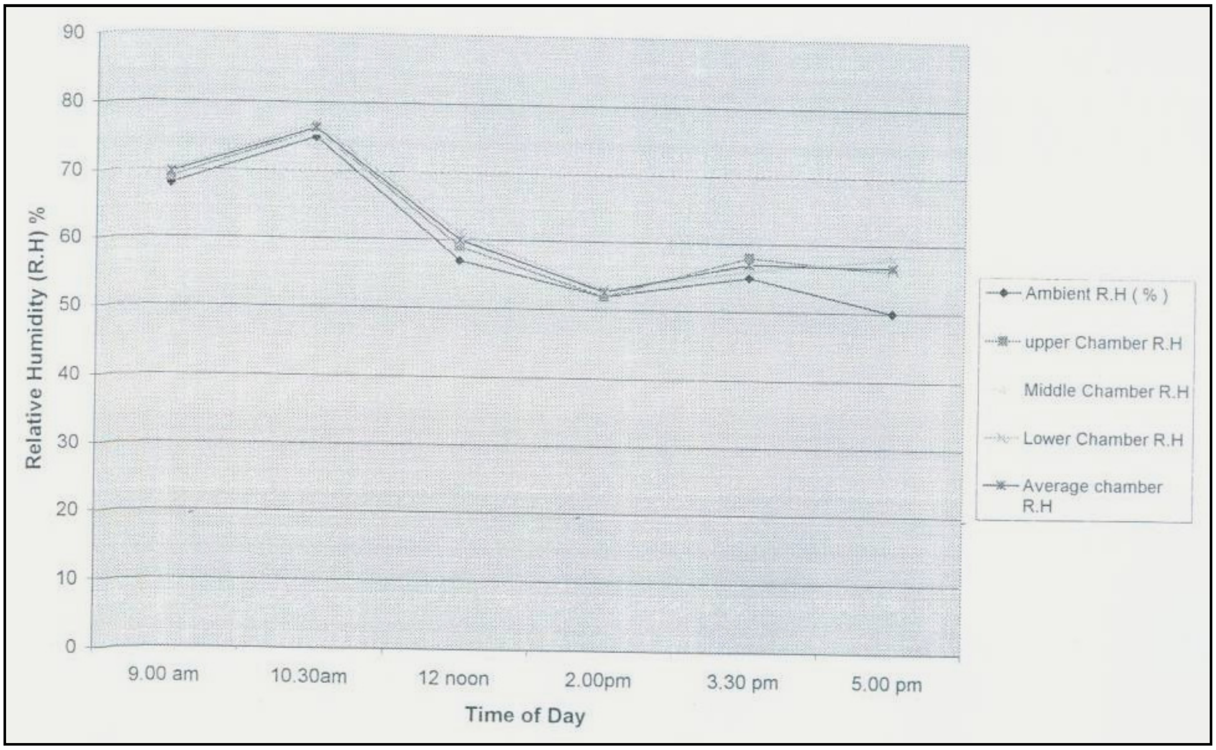

Figure 4: Relative humidity variation with time (after charcoal wetting and fan was on)

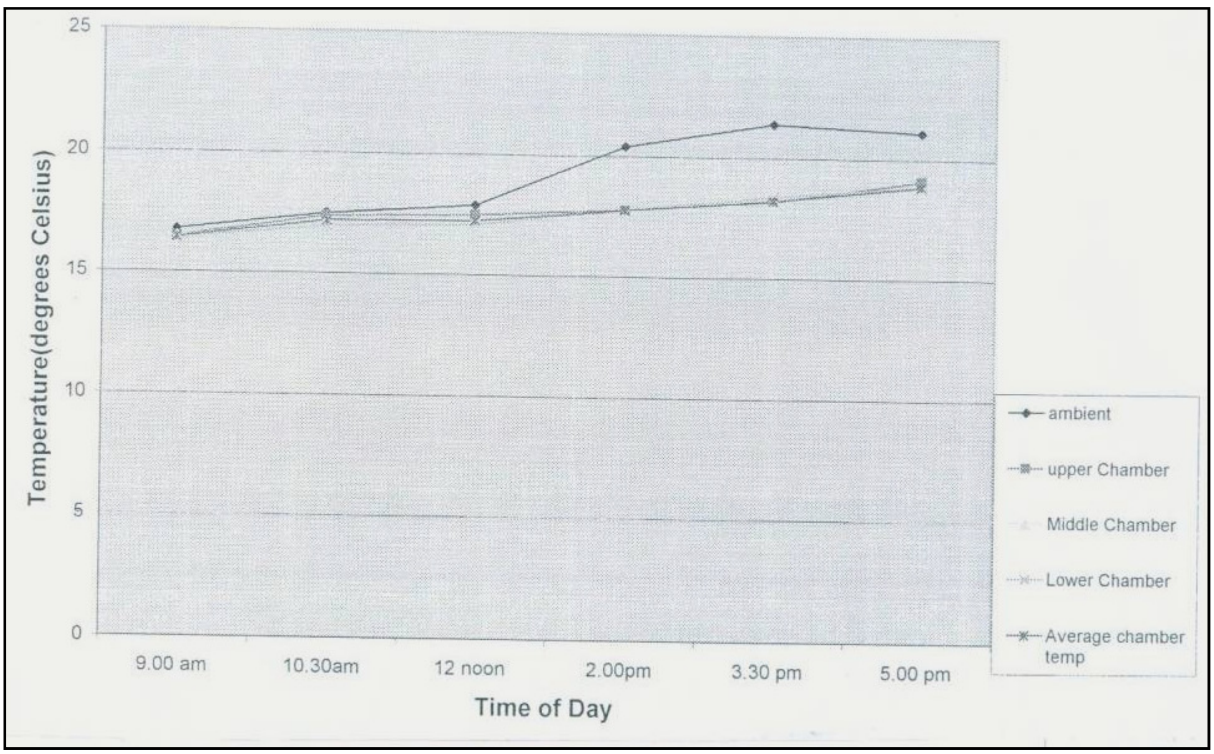

Figure 5: Temperature variation with time (before charcoal wetting and fan was off)

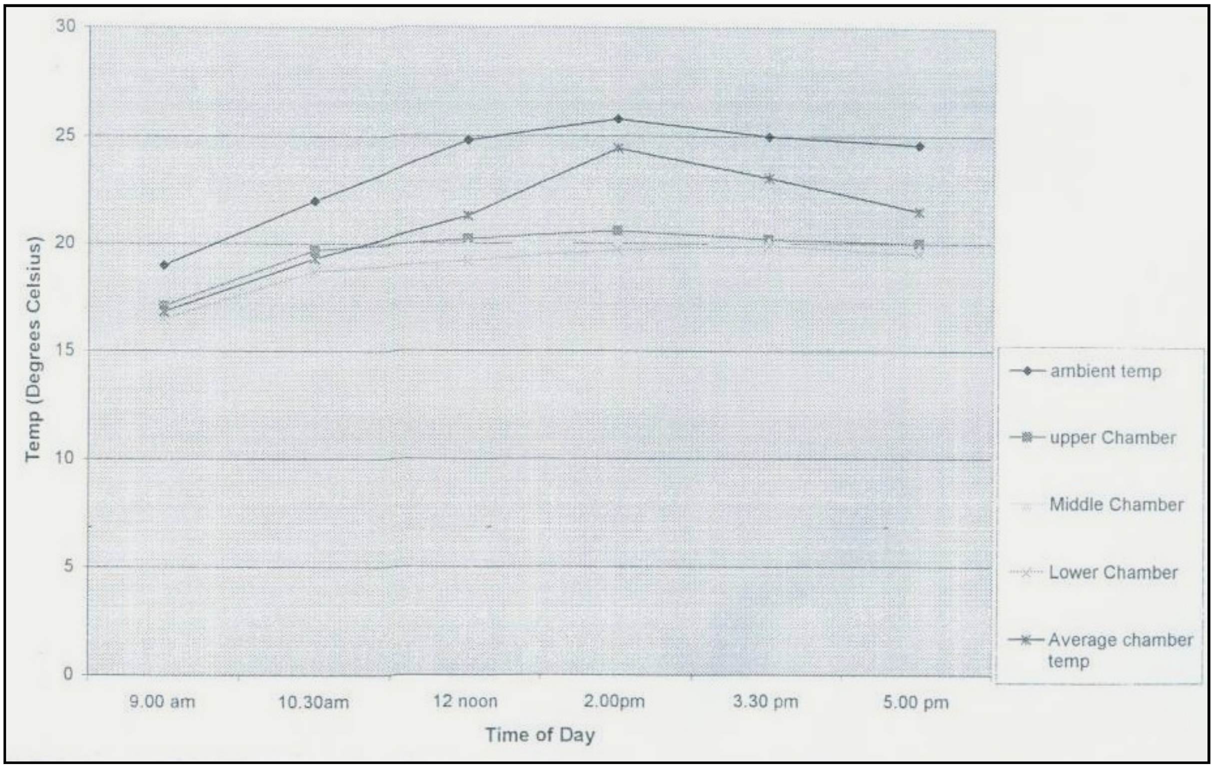

Figure 6: Temperature variation with time (after charcoal wetting and fan was off)

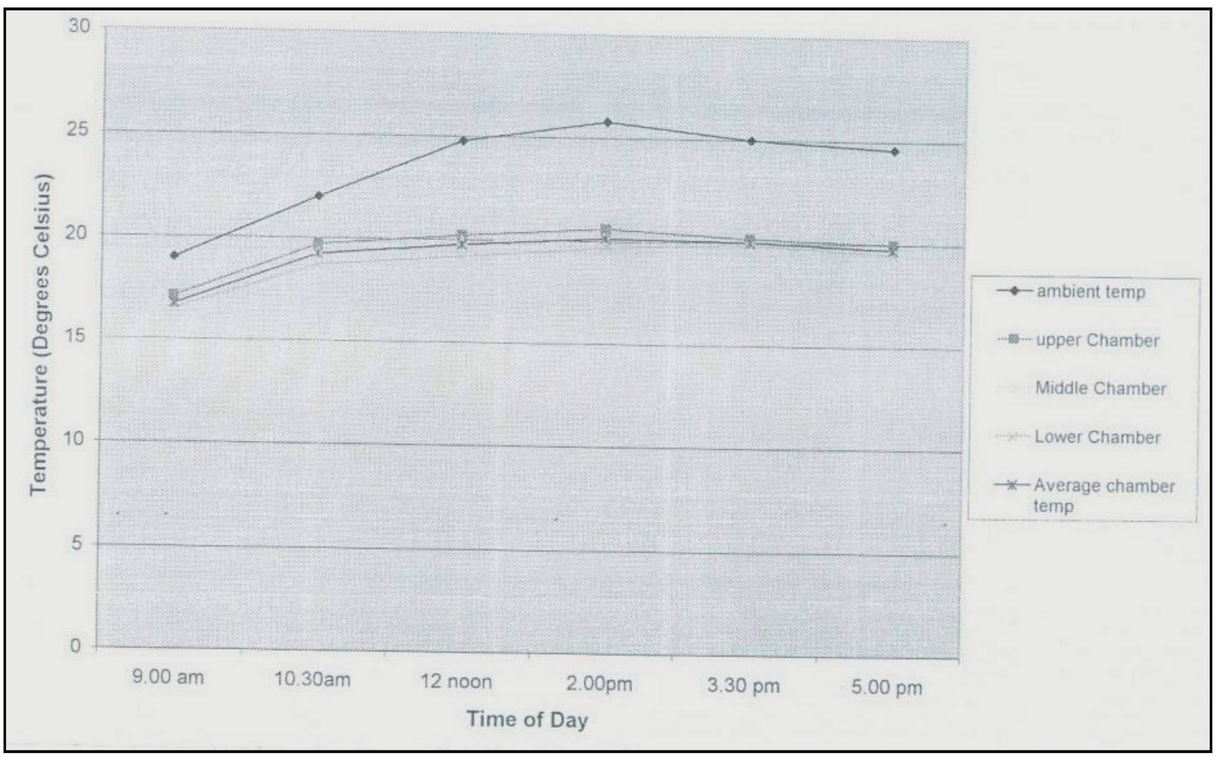

Figure 7: Temperature variation with time (after charcoal wetting and fan was on)

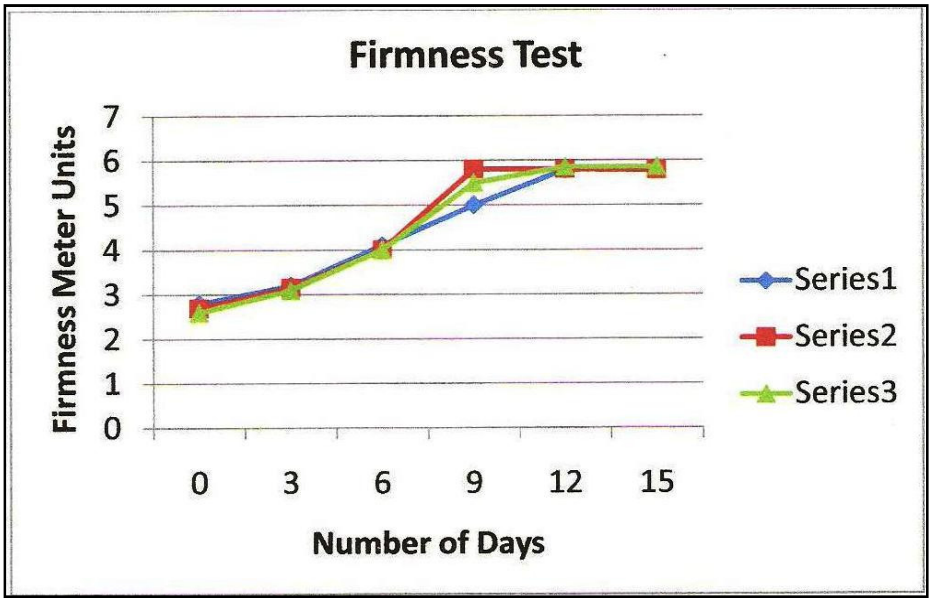

Figure 8: Charcoal cooler without solar technology.
Series 1 – pawpaw, Series 2 – tomato, Series 3 – banana

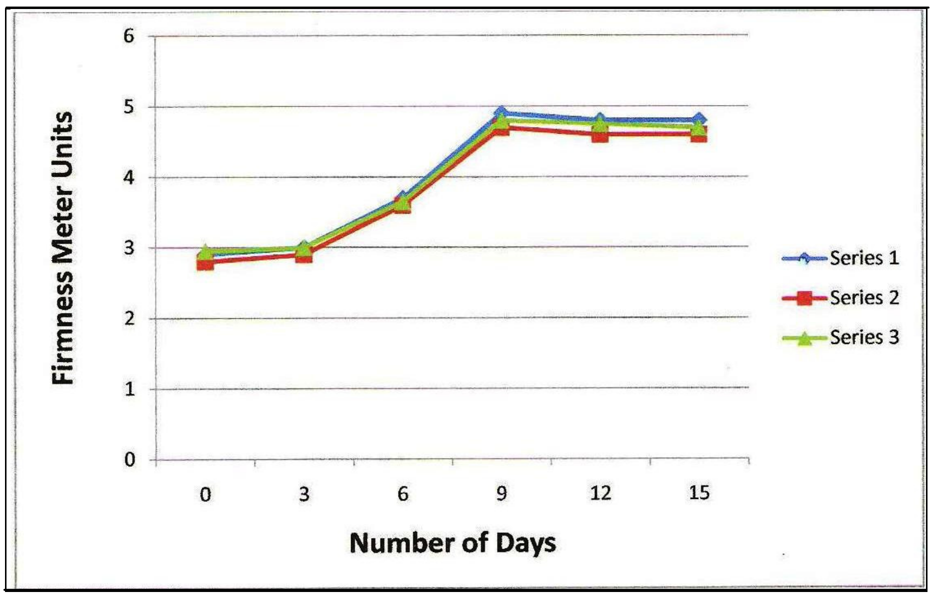

Figure 9: Charcoal cooler with solar technology.
Series 1 – tomato, Series 2 – pawpaw, Series 3 – banana

Storage time	Spinach	Kales
Fresh product	Blue-black colour	Blue-black colour
Week 1	Plain blue colour	Plain leaf with few blue traces
Week 2	Faint blue colour	Plain leaf/no trace of blue

Table 3: Starch tests on vegetables (Charcoal cooler without solar technology)

Storage time	Spinach	Kales
Fresh product	Blue-black colour	Blue-black colour
Week 1	Blue colour	Plain blue colour
Week 2	Faint blue colour	Faint blue colour

Table 4: Starch tests on vegetables (Charcoal cooler with solar technology)

Storage time	Paw paws	Carrots	Tomatoes
Fresh product	5.87	6.29	6.75
Week 1	5.88	6.48	6.85
Week 2	5.96	6.78	6.97

Table 5: Vitamin C tests on Fruits (Charcoal cooler without solar technology)

Storage time	Paw paws	Carrots	Tomatoes
Fresh product	5.85	6.27	6.76
Week 1	5.86	6.36	6.82
Week 2	5.90	6.53	6.98

Table 6: Vitamin C tests on Fruits (Charcoal cooler with solar technology)

Product	Fresh weight (g)	Weight after 14 days (g)	% water loss
Spinach	2.69	2.39	11.00
Kales	2.75	2.54	7.50
Cabbage	1133.00	1131.87	0.10
Bananas	86.00	85.91	0.10
Tomatoes	80.00	79.95	0.06
Carrots	75.00	74.78	0.30
Pawpaws	224.00	223.78	0.10

Table 7: Variation of product weight (Charcoal cooler without solar technology)

Product	Fresh weight (g)	Weight after 14 days (g)	% water loss
Spinach	2.72	2.61	4.00
Kales	2.78	2.68	3.58
Cabbage	1102.00	1101.56	0.04
Bananas	82.00	81.98	0.03
Tomatoes	78.70	78.67	0.04
Carrots	78.40	78.24	0.20
Paw paws	228.00	227.86	0.06

Table 8: Variation of product weight (Charcoal cooler with solar technology

Storage time	Kales	Spinach	Cabbages	Paw paws	Bananas	Tomatoes	Carrots
Fresh product	Green, turgid	Green turgid	Green outer leaves	Greenish yellow	Greenish yellow	Pale red, turgid.	Orange, turgid
Week1	Pale yellow, little shrunk	Black shade, wilted leaf	Outer leaves bleached along the edges.	Yellow, turgid appearance	Yellow appearance	Red coloured, turgid	Orange, traces of mould growth
Week2	Yellow, wilted / shrunk	Complete blackening , wilted leaf	Increased bleach on outer leaves	Yellow, softer, traces of mould on surface	Darker shade, shrunk.	Red, increased softness.	Orange, grey mould on surface.

Table 9: Variation of product Turgidity and Colour (Charcoal cooler without solar technology)

Storage Time	Kales	Spinach	Cabbages	Paw paws	Bananas	Tomatoes	Carrots
Fresh product	Green, turgid	Green, turgid	Green, turgid outer leaves	Greenish yellow	Greenish yellow	Pale red, turgid	Orange, turgid
Week 1	Green, leaf little shrunk	Green, wilted leaf.	Outer leaves green, little loss in turgidity	Yellow, turgid appearance	Yellow appearance	Red coloured, turgid	Orange, little loss in turgidity
Week 2	Yellowish green wilted /shrunk	Traces of black, wilted leaf	Outer leaves bleached along the edges	Yellow colour, increased softness	Darker shade, little shrunk	Red, increased softness	Orange, traces of grey mould on surface

Table 10: Variation of product Turgidity and Colour (Charcoal cooler with solar technology)

4. Conclusion and Recommendations

The results of this research have shown that incorporation of solar energy in providing power to drive a fan in this case improves the storageability of perishable agricultural produce. Leafy vegetables such as spinach and kales can be stored in the solar-charcoal cooler for up to about 11-12 days as opposed to a period of only three days where the solar powered fan is not incorporated. Fruits on the other hand can be stored in the solar-charcoal cooler for up to two weeks without losing their desired qualities. This can be attributed to their smaller surface area to volume ratio. Most fruits also possess a waxy cuticle on their surfaces. It is important that they are properly handled to avoid inflicting injuries on to the surface of these products before and during storage. The use of solar energy should be encouraged since it is one of the green/renewable sources of energy. Applications of solar energy are possible in all regions which receive sunlight and will result in savings as a result of reduced costs of electricity from the main national grid.

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