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Research Article

Studies of Solar Refrigerated Vegetable Vending Cart for Retaining Freshness and Nutrition of Vegetables

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Abstract: An attempt of developing a mobile vegetable vending cart with a solar powered refrigerated chamber for short period (4-7 days) storage of vegetables is made. In order to retain the freshness of the horticultural produce and to fetch a good market value among the vendors, various chemicals are usually sprayed on the vegetables which are not only unhygienic but also pollute the environment by emitting different greenhouse gases. The vendors are forced to follow this practice in order to keep the produce in saleable form for a short period and to get a good market price. There is, therefore, the necessity of a small scale cooling device which could be reliable, environment-friendly and be used at individual level for short-term storage of vegetables without depending upon the community based cool chain facilities which are located far away from the production area and are very limited in number. The solar refrigerator was designed and fabricated in the Dept. of Farm Machinery and Power, OUAT, Bhubaneswar, Odisha along with a matching tri-cycle and its performance was evaluated for studying the storability of vegetables during peak summer period i.e. April-May 2016. Provision was also made to mount and fix the refrigerator on a tri-cycle to make it mobile for the convenience of vegetable vendor. It was found that the shelf-life of tomato was enhanced to 12 days during summer season by maintaining temperatures in the range of 14-16 ^{0}C and humidity in the range of 83-94 % in the cool chamber (solar refrigerator) developed for the study.

Keywords: Solar refrigerator, Vegetable cart, storage of horticultural produces, Solar photovoltaic system, Shelf-life of vegetables.

INTRODUCTION

The combination of higher humidity and lower temperature facilitates extended shelf life. High humidity and low temperature inside the storage chamber can be maintained by using both active evaporative cooler and mechanical refrigeration system. The power requirement to operate such type of system is now-a-days a major constraint looking into the reliability, availability, environmental impact and cost of the conventional source of power (Tom et al 1991). Hence, it is proposed to develop a solar powered cool chamber incorporating both vapour compression refrigeration system and active evaporative cooler as solar electricity appears to be an attractive and viable proposition because of the abundant and free availability of sun shine in tropical areas (Sharma and Samuel 2014). Of the various solar technologies available, solar photo voltaic (SPV) systems for solar electricity generation have found widespread application because they are simple, compact and have high power-to weight ratio (Modi et al 2009). Also, the SPV system has no moving parts and in the field, SPV systems do not always require the assistance of skilled labour to install and maintain, making them well suited for village power systems. A small capacity solar powered cool chamber may therefore be useful for the small and marginal farmers in on- farm storage of their produce for a short period at individual level so that they can accumulate their harvested produce over a few days and take it to the market for getting a reasonable price by avoiding distress sales as well as retaining the freshness of vegetables among the vendors for selling to the consumers (Eltawil and Samuel 2007). It may

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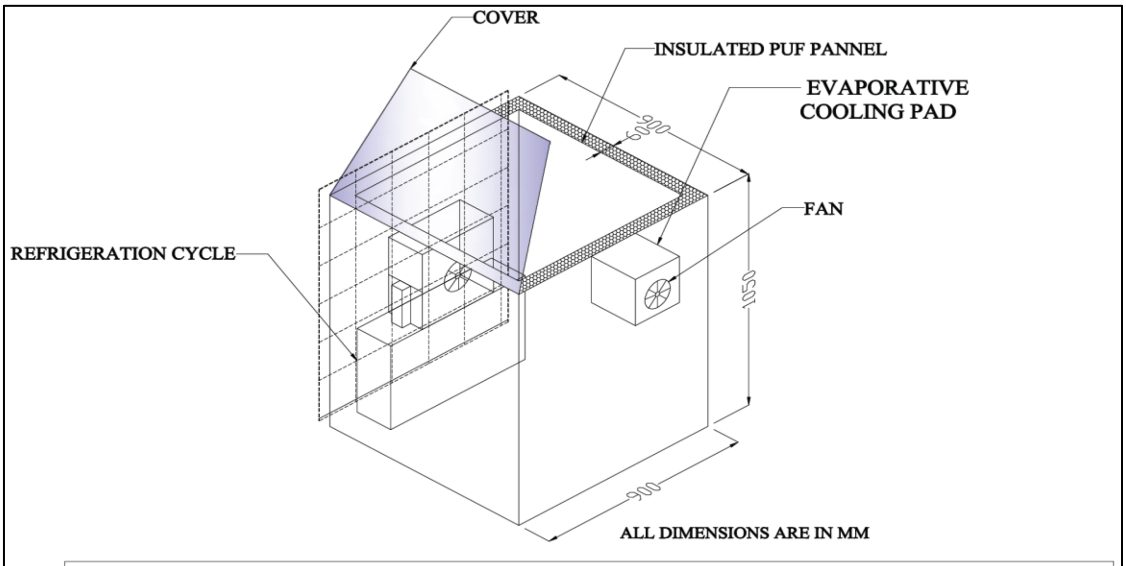
also ensure the economic sustainability and betterment of the livelihood of cultivators, vendors as well as availability of fresh produces for the consumers (Navigant 2006). The total post-harvest losses are as high as 40 % due to inadequate post-harvest handling, safe transportation and storage facilities (Anonymous 2013). Avoidance of distress sales favours selling the stored produce by the growers at their own level in the local market and keeping the interference of middle man away from picking up the freshly harvested on-farm vegetables at a much lower rate. Considering the present circumstances, development and popularization of any storage technology of both stationary and mobile type which would be cheaper and would not depend on non renewable energy sources and high technologies, could largely benefit the small and marginal farmers in on-farm storage of their produce for a shorter period and for the requirements of vendors and consumers. An attempt is therefore made in this study to develop a mobile vegetable vending cart with a solar powered refrigerated chamber for short period (4-7 days) storage of vegetables. The objective of the present study is thus the development and performance studies of an environment-friendly and affordable solar powered refrigeration system integrated with a tri-cycle mounted mobile vending unit for short term storage of vegetables considering the necessities of growers, vendors and consumers together.

MATERIALS AND METHODS

The experiments were carried out in the premises of College of Agricultural Engineering and Technology, OUAT, Bhubaneswar, Odisha during 2015-2016, which lies at the latitude of $20^{0} 15'$ N and longitude of $85^{0} 52'$ E and coming under warm and humid climatic condition. Studies on SPV powered cooling system for storage of vegetables are based on the sizing and installation of solar photovoltaic modules, power conversion (power conditioning) unit, battery, cooling system, storage structure and storability of tomato. The cool chamber was fabricated in the Workshop of College of Agricultural Engineering and Technology, OUAT, Bhubaneswar and placed in the experimental site. The dimensions of the cool chamber are as follows (Fig. 1).

- Outside dimension of about 0.9 m length X 0.9 width X 1.05 m height.
- Inside dimensions of about 0.78 m length X 0.78 m width X 0.93 m height.
- Square shape and white surface walls.

Insulation: Polyurethane foam (PUF) of 60 mm thickness was attached to all the walls, ceiling (roof) and base, because it is light in weight, low thermal conductivity, non-hygroscopic, high strength and high resistance to fire. Dark condition was maintained in the cool chamber (without diffused light) to avoid additional thermal energy gain.



EXPERIMENTAL COOLING CHAMBER FOR 100 KG. STORAGE CAPACITY

The schematic diagram of the developed set up is given below.

Solar Refrigerator Mounted on Tri-cycle

Quality Parameters Study of Stored Vegetable

The following physical parameters were tested during the experiment.

Firmness Test

Ripening of fruits and vegetables has a direct relationship with their firmness and since respiration continues even after harvest, the fruits have the tendency of becoming over-ripen. As a result of continued chemical activity within the fruits tissues even after harvest, it becomes over-ripen and soft. It is therefore required to slow down the rate of respiration and will ultimately reduce the fruit firmness change. This may be possible by storing the harvested vegetables at low temperature. The firmness of the stored vegetables is determined by a vegetable firmness tester in the unit of kg/cm^2. The firmness index of vegetables is determined by the extent of their softening stages on the basis of visual observation and is scored as follows;

Slightly softened = 1, Moderately softened = 2, Advanced softened = 3 and Fully softened = 4 where slightly softened indicates just ripen, not edible and good condition, moderately softened indicates ripen, edible and good condition, advanced softened indicates edible and over ripening starts and fully softened indicates not edible and rotten.

Physiological Loss in Weight (PLW)

Percent PLW = $(w_1-w_2) / (w_1) \times 100$

Where w_1 = weight of vegetable before storage; w_2 = weight after storage in certain days interval of storage. For good and edible condition, physiological loss in weight is up to 10 percent. For the present study, the observations were recorded at two days interval for each treatment of physiological loss in weight.

Moisture Content (MC)

The moisture content of a product is the amount of moisture present in it on weight basis and is usually expressed in percent. It is represented by two methods, wet basis and dry basis.

Wet Basis: (Weight of water in product / Weight of product sample) × 100

Dry Basis: (Weight of water in product / weight of dry matter of product sample) × 100

Experimental Results

The variety Utkal Kumari (BT-10) which is at present the most prevailing variety of tomato in Odisha was taken for the study. To start with the work, a small capacity (100 kg) cool chamber was fabricated and fitted with solar powered vapour compression refrigeration system and an active evaporative cooler. The performance of the developed solar powered cool chamber was evaluated with respect to physiological weight loss, rotten percentage, colour change and firmness condition during the storage of tomato both in winter and summer period. The freshly harvested tomato was stored in the cool chamber by keeping them in the perforated polythene packet. The physiological weight loss in the range of 10-15 percent and rotten percentage to be in the range of 20-30 are allowable for maintaining the freshness and marketability of vegetables (Olosunde 2006). The data regarding percentage physiological loss in weight, rotten percentage, prevailing temperatures, relative humidity in the cool chamber and in the ambient condition along with the shelf-life of tomato under the present investigation were recorded both during peak winter and summer period and are presented in the tables 1-4.

Table 1 Experimental observation of temperature and relative humidity in ambient condition and inside developed cool chamber with stored tomato during a winter day

Date:11-1-15 Time ↓	Ambient		Developed cool chamber		Solar Radiation
	Temp (^{0}C)	*Rh (%)*	*Temp (^{0}C)*	*Rh (%)*	*(w/m^2)*
6 am	16.3	82	12.2	93	0
8 am	19.7	80	12.2	91	181
10 am	23.7	78	12.6	91	630
12 noon	25.6	75	13.9	89	731
2 pm	26.5	73	14.7	86	590
4 pm	20.4	77	14.7	87	184
6 pm	18.4	80	14.6	88	0
8 pm	17.9	81	14.5	89	0
10 pm	15.6	85	14.5	90	0
12 mid night	15.4	86	13.3	92	0

Table 2 Experimental observations of temperature and relative humidity in ambient condition and inside developed cool chamber with stored tomato uring a summer day.

Date:6-5-15 Time ↓	Ambient		Developed cool chamber		Solar Radiation
	Temp (^{0}C)	*Rh (%)*	*Temp (^{0}C)*	*Rh (%)*	*(W/m^2)*
6 am	28.3	75	14.3	91	28
8 am	29.1	71	14.5	88	408
10 am	33.8	41	14.5	85	871
12 noon	35.5	36	14.7	85	922
2 pm	39.6	32	15.9	83	882
4 pm	36.8	40	15.5	86	414
6 pm	31.8	48	15.0	86	0
8 pm	31.4	59	14.8	87	0
10 pm	30.0	67	14.6	90	0
12 mid night	26.6	73	14.5	94	0

From Table-1, it was observed that the temperature and relative humidity variations in the solar cool chamber were in the range of 12.2-14.7 ^{0}C and 86-93 % respectively in a winter day. The decrease of temperature and increase of relative humidity were found to be in the range of about 4-12 ^{0}C and 5-12 % respectively compared to the ambient conditions. This may be due to the lower rate of evaporation of the ambient air with more relative humidity in winter days. Similarly, from Table-2, it was found that in a summer day, the temperatures and relative humidity variations in the solar cool chamber were in the range of 14.3-15.9 ^{0}C and 83-94 % respectively. The decrease of temperature and increase of relative humidity were found to be in the range of about 12-16 ^{0}C and 16-49 % respectively compared to the ambient conditions. This may be due to the higher rate of evaporation of the prevailing dry ambient air in summer days.

Table 3 Quality analysis of storage of tomato in developed cool chamber during winter period (initial moisture content 88 %)

Date	Storage (days)	% Physiological Weight Loss	Rotten/Unmarketable (%)	Colour Change	Firmness Condition (kg/cm^2)
3-1-15	Initial (0)	--	--	1	4.3
5-1-15	2	---	---	1	4.0
7-1-15	4	2.6	---	1	3.8
9-1-15	6	4.8	---	2	3.4
11-1-15	8	6.2	3.8	2	3.2
13-1-15	10	8.8	7.5	3	3.0
15-1-15	12	10.2	9.5	3	2.8
17-1-15	14	13.5	15.8	3	2.5
19-1-15	16	15.8	19.8	3	2.3
20-1-15	17	17.4	20.8	3	2.0
21-1-15	18	Spoiled	30.8	4	1.4

Table 4 Quality analysis of storage of tomato in developed cool chamber during summer period (initial mc 92 %)

Date	Storage (days)	% Physiological Weight Loss	Rotten/Unmarketable (%)	Colour Change	Firmness Condition (kg/cm^2)
4-5-15	Initial (0)	--	--	1	3.9
6-5-15	2	2.4	---	1	3.7
8-5-15	4	3.6	---	2	3.4
10-5-15	6	5.8	4.5	2	3.1
12-5-15	8	7.2	6.8	3	2.7
14-5-15	10	10.8	9.5	3	2.4
16-5-15	12	17.3	10.5	3	2.1
18-5-15	14	Spoiled	30.8	4	1.3

Considering the allowable physiological weight loss in the range of 10-15 percent and rotten percentage to be in the range of 20-30 for the vegetables (Olosunde 2006), it was found from Tables-3 and 4 that the tomato was safely stored up to 17 days and 12 days respectively in winter and summer period. The score for colour index is given on the basis of visual observations. The rating of colour index is defined as, Yellow = 1, Yellowish red = 2, Red = 3 and Dark red = 4. Where yellow indicates just harvested, not edible and good condition. Yellowish red indicates just ripen, not edible and good in condition. Red indicates ripen, edible and good condition. Dark red indicates not edible, over ripen and rotten. The score of colour index for 17 and 12 days of storage in winter and summer days was given 3 for tomato from visual observations which was in the ripen, edible and in good conditions. Hence, from the data collected in the storability of tomatoes in the solar cool chamber under study during the course of the research work, the following conclusions have been drawn.

- The shelf life of tomato in the developed cool chamber was found to be 12 and 17 days respectively during summer and winter period when it was covered with the perforated polythene packet and then stored inside the cool chamber.
- The shelf life of tomato in the developed cool chamber was found to be 11 and 14 days respectively during summer and winter period when it was not covered with the perorated polythene packet and kept in exposed condition in the crates during storage inside the cool chamber.
- The shelf life of tomato when covered with perforated polythene packet during storage inside the various cooling devices under study was observed to be 2-4 days more than without polythene cover both during summer and winter period.
- The average efficiency of module for the experimental solar PV system was found to be 12 % as against 15.7 % under standard condition, mentioned by the manufacturer.
- The temperatures and relative humidity were maintained in the range of 14-16 ^{0}C and 83-94 % respectively during summer period inside the developed cool chamber as against the recommended values for storage of tomato to be 10-15 ^{0}C and 85-95 %.

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