Solar-Powered Cold Storage System for Horticultural Crops

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Abstract A solar photovoltaic-powered cold storage system has been developed for storage of fresh horticultural produce (6–7 tonne capacity) at Central Institute of Agricultural Engineering, Bhopal. Temperature and relative humidity controllers are fitted in the cold storage chamber to maintain desired room temperature (5–15 °C) and relative humidity (65–95%) for storage of horticultural produce. The battery backup was used for storage of solar power for operation of the cold storage system during night and cloudy weather. The shelf-life of fresh unripe mature mango (Dashari) was increased by 15 days in the cold storage as compared to 4 days at ambient storage during June month. Energy output from the solar power plant ranged from 67 to 110 kWh/day on sunny days in different months, which was sufficient to operate the cold storage unit.

Introduction

India is the second largest producer of horticultural commodities in the world with 88.977 million MT of fruits and 162.887 million MT of vegetables during the year 2013–14 (Indian Horticultural Data base 2014). A large variety of fruits are grown in India, of which mainly banana (33.4%), mango (20.7%), citrus (12.5%), papaya (6.3%), guava (4.1%), grape (2.9%), apple (2.8%), sapota (2.0%), pomegranate (1.5%), litchi (0.7%), etc. are the major ones (Fig. 1). Similarly, the major vegetable crops grown in India are potato (25.5%), tomato (11.3%), onion (11.9%), brinjal (8.3%), cabbage (5.5%), cauliflower (5.3%), okra (3.9%), pea (2.4%), etc. (Fig. 2). In the country, per capita availability of fruits and vegetables is quite low because of post-harvest losses due to poor and inadequate storage infrastructure for perishable products. The Associated Chambers of Commerce and Industry of India reported that about 30% of vegetables and fruit are lost after harvest, worth a total of over

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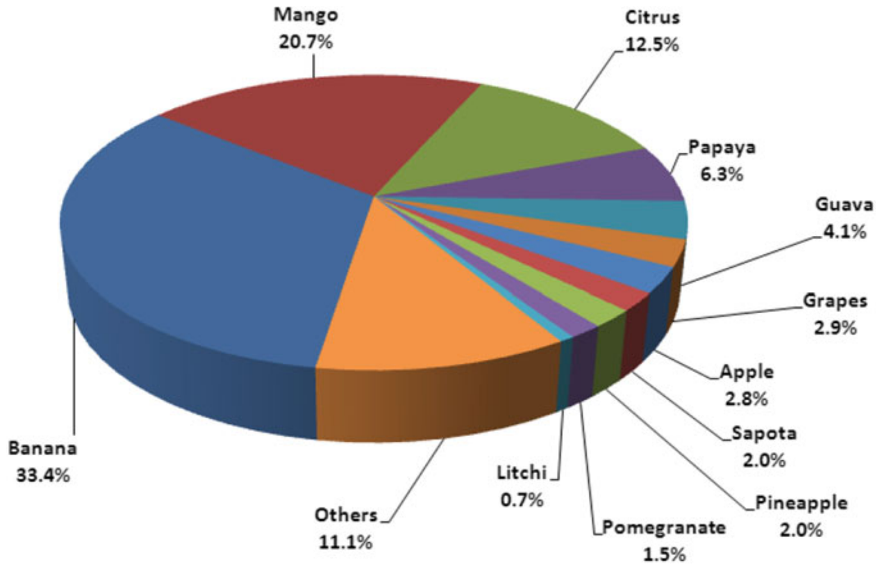

Fig. 1 Production share of major fruits crops in India during 2013–14

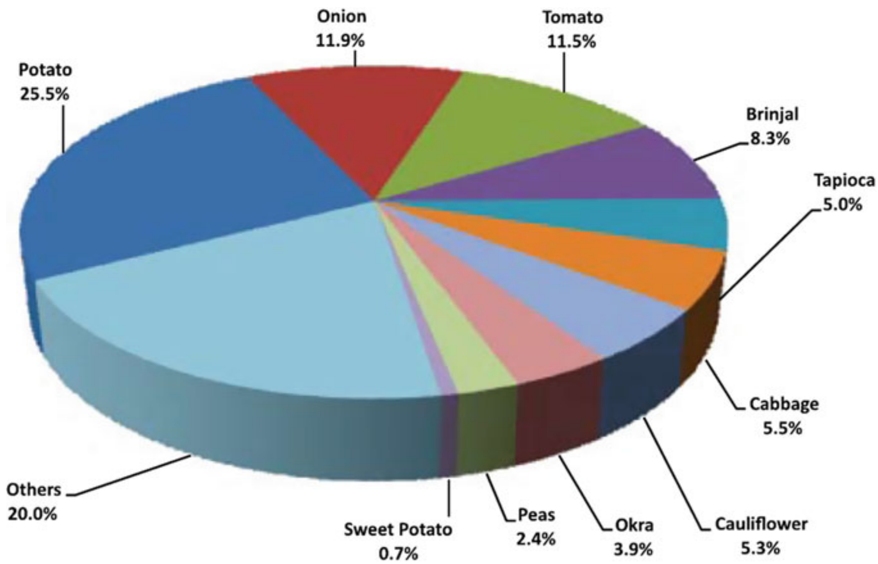

Fig. 2 Production share of major vegetable crops in India during 2013–14

2 trillion INR per year (over 33 billion USD) due to lack of storage and processing facilities and indifferent attitudes towards tackling the problem (ASSOCHAM 2013). Among the states, post-harvest losses are highest in West Bengal (over 136.6 billion INR), followed by Gujarat (114 billion INR), Bihar (107 billion INR) and Uttar Pradesh (103 billion INR). A sizable quantity of produce also deteriorates by the time it reaches the consumer. To enhance shelf life and maintain the quality of perishable products, cold chain arrangement is required if consumption is not meant immediately after harvest. Most of the horticultural produce required cooling temperature between 0 and 15 °C for safe storage and transient purposes. In the absence of a cold storage and related cold chain facilities, the farmers are being forced to sell their produce immediately after harvest which results in glut situations and low price realization. Cold chain infrastructure for fruits and vegetables can improve quality and enhance shelf life of the product. Robust farm-to-retail cold chain solution is required to sustain the growing domestic and export demand. Apart from the large cold storage structures for long-term storage, cooling system is also required for on-farm or in-production catchment for horticultural crops, so that produce get cooled during short-term storage and at the same time it can be loaded in the transportation vehicle in cool condition to maintain the quality and minimize the wastage during transportation.

In conventional cold storage systems used in India, the electrical energy expenses account 28–30% of total expenses (Energetica India 2012). Solar-based refrigeration system is very relevant to India as the running cost reduced by use of solar power. India is blessed with good amount of solar energy in most part of the country throughout the year. The mean annual solar radiation is varied between 4.6 and 6.6 kWh/m^2/day in different parts of the country. Grid power availability in the rural areas is very poor with respect to its supply and quality. The solar power is one of the best solutions for operating small cold storage system in rural areas due to the above reasons. In rural India, at place the large size cold storage facilities are available and being used for potato storage. These cold storages are run by electricity or fossil fuels. However, in the absence of small cold storage facilities in the catchment area, farmers are forced to sell the horticultural produce in the local mandies at prevailing rate. Many times the prevailing rate is quite low in local mandies. Hence, farmers incur the loss. The horticultural produce such as mango, tomato, papaya, pomegranate, etc. are transported to long distances in hot climate without pre-cooling and the cold chain arrangement. It results quality deterioration of the product and heavy spoilage.

Solar PV Powered Refrigeration System

A cold storage facility for storage of fresh horticultural produce (6–7 tonne), powered by solar photovoltaic with battery backup has been developed at CIAE, Bhopal (Fig. 3). It consisted of PV power plant (25 kW$_p$ capacity) with battery

Fig. 3 A view of solar PV panel (*left*) and mango loading in the cold storage chamber (*right*)

bank (240 V, 900 AH) and puff insulated cold storage chamber (5 m×4.4 m×3 m) fitted with vapour compression refrigeration system (2.5 TR capacity) and a humidifier. The power conditioning unit/inverter of the solar power plant converts the DC power produced from the solar panel into three-phase AC electricity (415–420 V) for operating the cold storage unit. Temperature and relative humidity (RH) controllers were fitted in the cold storage chamber to maintain desired room temperature (5–25 °C) and relative humidity (65–95%) for storage of horticultural produce.

The detail of the system is given below.

Solar Photovoltaic (SPV) Panel System

Capacity of the SPV panel: 25 kW_p
No. of PV modules: 250 $W_p \times$ 100 nos
Type of PV module: Poly crystalline silicon solar cell module (as per IEC-61215 standard).

Power Conditioning Unit (PCU)

Capacity: 25 KVA.
Inverter: AC output voltage: 415 V, 3-PH, 50 Hz, Inverter output capacity: 25 KVA, Output wave shape: Sine wave, Efficiency (at 30 °C): 85% or above
Solar charge controller: Capacity: 25 kW, Cooling: Temperature controlled fan forced cooling.
Ambient temperature range: 0–50 °C, Ambient humidity range: up to 90% condensing.

Battery Bank

Total capacity of battery bank: 900 AH at 240 V
Type of battery: Tubular lead acid solar battery,
No. of battery: 100 nos (180 AH, 12 V each), Make: Luminous.

Sensor for Temperature and RH Controller in Cold Storage

RTD sensor based temperature controller,
Temperature Range: 0–50 °C
Humidity sensor range: 0–95%.

Materials and Methods

The solar-powered cold storage system was evaluated by storage of the horticultural crop such as unripe fresh mango. The recommended temperature for mango storage is 10–13 °C (13 °C for mature green and 10 °C for partially ripe mango) and relative humidity 90–95% for maintaining post-harvest qualities by UCDAVIS Post-Harvest Technology, University of California (2014). The shelf life of the fresh matured unripe mango (Dashari varieties) was studied by storing the mango in the cold storage chamber at 12 ± 1 °C temperature and 90 ± 2% relative humidity and compared with the mango stored at ambient condition in the June month. The quality parameters such as total soluble solids (TSS), titratable acidity, firmness, physiological loss in weight of the mangoes were measured regularly during storage. Titratable acidity (TA) was determined by direct titration with 0.1 N NaOH solutions and was expressed as per cent Citric acid. The TSS values were measured by a hand refractometer and expressed as °Brix. The firmness of mango was measured with help of texture analyzer machine. The physiological loss in weight (PLW) was measured by weighing the samples regularly during the storage. The solar radiation was measured with help of the pyranometer. The energy required for operating the cold storage and energy generated from the solar power plant was measured in different months with help of the energy meters.

Results and Discussion

The average initial temperature of mango during loading was 34 °C. Temperature of the mango was slowly reduced and stabilized at about 12 °C in about 13 h. Based on the different physico-chemical parameters, it was found that Dashari

Table 1 Physico-chemical parameters of unripe mature mango during cold storage (stored at 12 ± 1 °C, and RH: 90 ± 2%)

Parameters		Dashari in cold storage	Dashari in ambient storage (control)
Safe storage life, days		15	4
Increase in total soluble solid (TSS), °Brix	At initial	8.8	8.8
	After storage	13.0	16.2
Decrease in firmness, kgf	At initial	31.6	31.6
	After storage	9.7	4.4
Decrease in titratable acidity, % citric acid	At initial	2.25	2.25
	After storage	1.0	0.92
Physiological loss in weight (wb),%		3.1	14.5%

mango stored in the cold storage (at 12 ± 1 °C temperature and RH 90 ± 2%) could be safely stored up to 15 days as compared to 4 days at ambient storage (Table 1). The ambient temperature and humidity varied between 27 and 40 °C and 40–55% respectively during the study period. The total soluble solid (TSS) of Dashari mango increased from initial values of 8.8–13.0 during the cold storage period. The TSS values indicate the development of soluble sugars in the fruits as the ripening progresses. As the fruits ripen, more carbohydrates/starches are converted into simple sugars and the TSS values increases. The loss in weight of Dashari mangoes was 3.1% in cold storage as compared to 14.5% in case of storage at ambient condition. As per some literatures, a physiological loss in weight (PLW) value of more than 10% resulted in severe shrinkage in the fruit skin that decreases its acceptance level and hence indicates the end of shelf life of the products. The cold storage was effective in maintaining the fruit firmness for a much longer period than the control ambient storage. Firmness of the mangoes was decreased from 31.6 to 9.7 kgf in the cold storage. The control samples started to ripen and softening after 2 days of storage and their firmness values decreased to 4.4 kgf 4 days of storage. The energy output from the solar PV power plant was 67–110 kWh during the sunny day in different months of the year. The average solar radiation intensity during the day (8 AM to 5 PM) varied between 366 and 712 W/m^2. The expected SPV power generation required for the cold storage unit (6–7 tonne storage capacity) was 46–68 kWh/day (depending on ambient conditions). The energy generated from the power plant was found enough to operate the cold storage system. The battery backup was used during inclement and bad weathers.

Conclusions

The solar-powered cold storage system was found suitable for storage of fresh horticultural crops for increasing shelf life of the produce. It can be a part of the cold chain arrangement to reduce post-harvest losses and improve the quality of the produce at end user. The energy output from the solar PV power plant (25 kW_p) was 67–110 kWh during the sunny day in different months of the year which was sufficient to operate the cold storage systems.

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