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Movable solar powered cold storage for fruits and vegetables

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ABSTRACT

A solar powered portable cold storage system was designed and developed in 2017-18 for storage of fresh fruits and vegetables to increase the shelf life. The capacity of the cooling chamber is 3.88 m^3. The cold store was operated at three temperatures 8, 12 and 16ºC, respectively for 24 h. At 8ºC, the ranges of temperature and RH inside and outside cold storage were 9.3–11ºC and 73.11–76.4% and 26.5–40.7ºC and 25.3–61%. At 12ºC, the ranges of temperature and RH inside and outside cold storage were 13–14.7 ºC and 68.2–77.7% and 28.7–42.1ºC and 26.0–45.5%. At 16ºC, the ranges of temperature and RH inside and outside cold storage were 17–18.1ºC and 72.9–79.3V and 29.5–43.9ºC and 22.2–50.1%. An average difference in temperature and RH of three setting temperatures (8, 12 and 16ºC) were 23.47, 21.94 and 18.90ºC and 33.63, 39.77 and 39.44% respectively. The average cooling efficiency of the developed cold storage for three setting temperatures was 91.26, 89.69 and 87.06 % respectively. This environment helped in keeping the vegetables fresh for significantly longer time. This cold storage structure is very useful for rural areas where there is shortage of electricity or its supply is erratic for storage of fresh fruits and vegetables.

Key words: Cold storage, Cooling efficiency, Temperature difference

Fresh fruits and vegetables start to deteriorate as soon as they are harvested because they are cut off from their source of water and nutrition. They lose weight, texture, flavour, nutritive value, and appeal. Cooling significantly slows down the rate of deterioration, thereby increasing the storage life of the produce. Commercial produce is stored at temperatures just above that which will cause freeze damage to the product so that it can have the maximum possible shelf life and be transported very long distances. Market growers those selling through farmers markets, farm stands, or community-supported agriculture typically sell their fruits and vegetables within a few days of when they were harvested. They can get premium prices for what they grow because of its "localness" and freshness. In this situation, long storage times at very low temperatures may not be needed, and the high cost for commercial or industrial-grade cooling equipment is difficult to justify. But fresh produce will still deteriorate substantially within a day or two if it is not cooled at all from ambient conditions, especially during the hot summer months. Lower-cost cold storage options can benefit market growers by helping preserve produce freshness and quality for a few additional days. Produce losses can be significantly reduced, especially for growers transitioning to a higher level of production who have excess produce to carry over from one day's market to the next (John 2009).

Cold storage is a critical component in the food supply chain. Without rapid cooling and appropriate storage conditions, produce deteriorates rapidly. Nutritional losses and even spoilage of entire crops can occur. Initial rapid cooling to extract latent field heat extends shelf life and maintains quality produce. Cold stores intended for long term holding of produce are designed close to produce areas. They will source produce during harvest season and store in bulk, without undertaking any retail packaging. During off season periods, the chambers are periodically opened and product released to market (National Horticultural Board 2015). To provide a diversity of vegetables over a long season, small-scale vegetable producers need to use energy efficient cold storage methods to reduce costs and extend the revenue period while maintaining produce quality and freshness.

MATERIALS AND METHODS

Design of one tonne capacity cold storage was done based on the crate size and its capacity. Crates of size 53.5 × 36.0 × 30.0 cm were used to keep the material. Each crate has capacity to keep 30 kg of fruits and vegetables. In single layer seven crates were placed and stacking up to five layers. A total of 35 crates or 1000 kg fruits and vegetables can be placed in the store for storage. Based on above consideration the storage structure was constructed with following specifications.

a. Outside dimension: 1.98 m length × 1.34 m width × 1.83 m height; b. Inside dimensions: 1.86 m × 1.22 m

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× 1.71 m; c. Rectangular shape; d. Insulation: 5 cm thickness of fiberglass (glass wool)

Portable cold storage unit consists of different units such as, frame, walls, floor ceiling, door, moving unit and cooling system (Fig 1). The frame of the storage unit was constructed by welding angle iron of 3 cm × 3 cm cross section to get good strength for holding one tonne capacity produce and its own dead load. Wall, floor, ceiling and door of the storage unit are 60 mm thick. It consists of three materials, such as, galvanized iron sheet, glass wool and polycarbonate sheet, respectively. The galvanized iron sheet mainly used to give strength to the storage unit, glass wool and polycarbonate sheet were used as insulating material to reduce the heat flow from outside to inside storage unit. This unit is considered as a portable cold storage by using three iron wheels having load capacity of 800 kg each. Front wheel was fixed with the angle bar to facilitate easy turning. Handle is made of iron pipe connected to the front wheel for pulling the unit

- The solar photovoltaic (SPV) system consisting of 8 solar panels of 210Wp each, one solar inverter (3000VA) and a battery bank of four heavy duty batteries of 12V/150Ah each was used to power the AC to cool the storage (S Fig 1). The electric current produced by SPV panels during daylight hours charge the batteries, and the batteries in turn supply power to the system. For maximum utilization of solar energy, the solar modules are carefully oriented so they face true south. The use of batteries with inverter gives electricity for a longer period of time by providing a consistent operating voltage and current to the system.

Total cooling load = 1.2 × Q_{total} = 1.2 × 2258.37 = 2710.04 W = 2710.04/(1.163× 60)=38.836 kcal/min=38.836/50=0.77TR (tonnes of refrigeration)

Cooling system: Based on cooling load 0.8TR standard split air conditioner can provide a low-cost cooling source. A standard air conditioner can lower the temperature up to 15-16ºC only. This limitation was overcome by using Sub-Zero controller (SZ-7510/69-E). With the help of this controller the temperature of the storage can be reduced up to 0ºC making it suitable for storage of wide range of fruits and vegetables. A smaller air conditioner may be sufficient to cool the same size room enough to take the field heat off a wide range of fruits and vegetables and significantly improve produce quality as compared to storage at ambient conditions. It should be noted that different produce has different optimum storage temperatures. Many produce items do best at very cold temperatures, just above freezing, but other produce typically handled by market growers do best at higher temperatures.

Performance of cold storage: After the development of the portable cold storage, it was tested in order to evaluate its performance. It was operated for the three set temperatures (8, 12, 16ºC), respectively for about 24 h. The system performance was evaluated at hourly interval for 24 h. Temperature and relative humidity inside cold store and corresponding observations of outside environment were recorded. Power consumption of cooling system was measured to determine energy input to the system. For tomato storage these set temperatures are used to study the shelf life of tomato.

The temperature and relative humidity were taken using two temperature-humidity data logger manufactured with sensitivity of ± 0.5ºC and ± 1% for temperature and relative humidity respectively. One kept inside the cold storage and other kept outside in shade to avoid direct radiation. Cold storage was operated for three individual temperatures for 24 h, the temperature and the relative humidity were measured. Both the temperature of the inside the cold storage and the ambient temperature were also determined. In order to determine the wet bulb, a psychometric chart was used.

Cooling efficiency: The developed cold storage effectiveness was based on the cooling efficiency. The cooling efficiency of storage structure was calculated by using a formula (Harris 1987).

$$\text{Cooling efficiency (\%)} = \frac{T1 - T2}{T1 - T3}$$

where T1, dry bulb temperature (ambient) ºC; T2, dry bulb temperature (cooling chamber) ºC; T3, wet-bulb temperature (cooling chamber) ºC.

RESULTS AND DISCUSSION

Cold storage was operated at three different temperatures (8, 12 and 16ºC) for 24 h. In sub-zero controller temperature was set at 8ºC, the temperature range inside the cold storage was recorded as 8.50–9.20ºC corresponding to ambient temperature 26.50–40.70ºC (Fig 2). The average temperature of 8.79 and 33.77ºC was recorded for inside and ambient with standard deviation of 0.24 and 5.01 was recorded during 24 h period. The minimum and maximum relative humidity of 70.10 and 78.30%; 25.30–61.10% were recorded inside the cold storage and in the ambient. The average of inside and ambient relative humidity 70.10 and 25.30% with standard deviation of 2.09 and 12.09 were recorded.

At 12ºC set temperature, the temperature of inside and ambient ranges from 12.50–13.20ºC and 28.70–42.10ºC. The average inside temperature 12.82ºC with standard deviation of 0.25 corresponding to ambient temperature 35.74ºC with standard deviation 4.42 were recorded. The relative humidity ranged from 68.20–79.30% recorded inside the cold storage; corresponding to 25.80-46.0% at ambient. The average of inside and ambient relative humidity of 74.78 and 35.85% with standard deviation of 3.05 and 6.479 were recorded.

At 16ºC set temperature, the temperature range inside the cold storage was recorded as 16.50–17.40ºC corresponding to ambient temperature 29.50–43.90ºC The average temperature of 16.90 and 36.30ºC was recorded for inside and ambient with standard deviation of 0.28 and 4.84 was recorded. The minimum and maximum relative humidity of 70.10 and 80.80%; 21.60–51.10% were recorded inside the cold storage and ambient. The average of inside

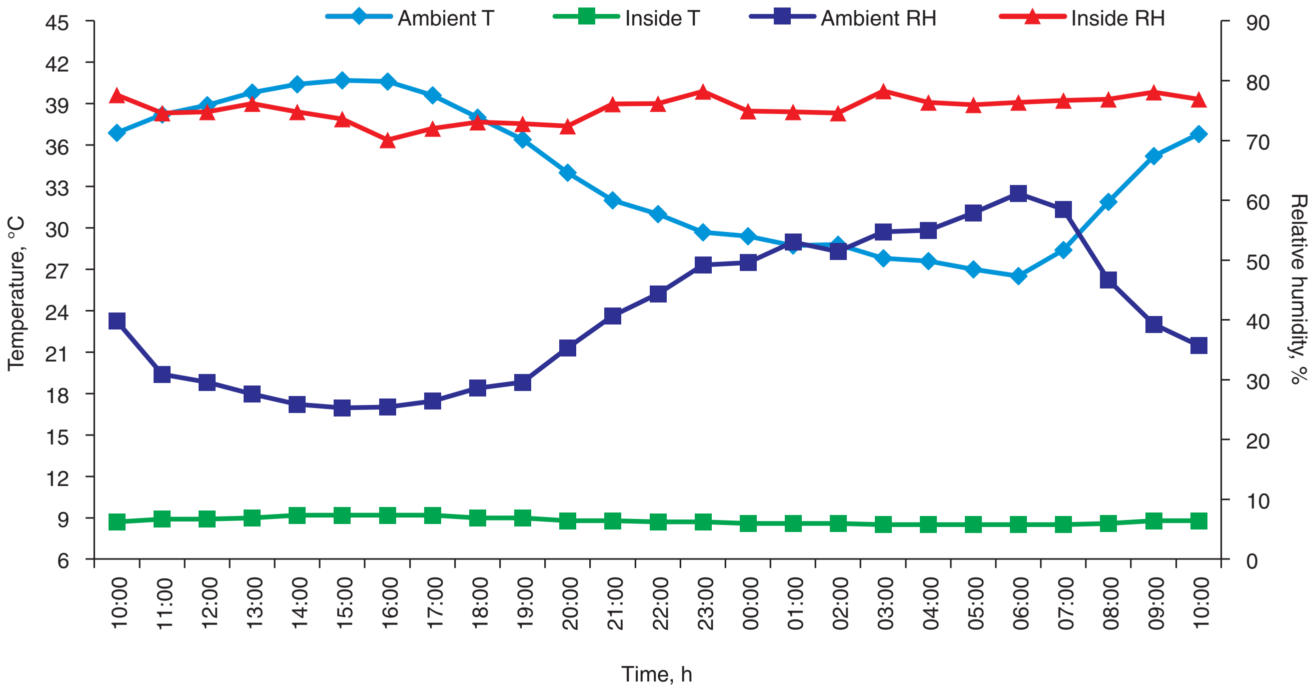

Fig 2 Hourly variation of environment inside the cold storage structure under no-load condition at 8ºC

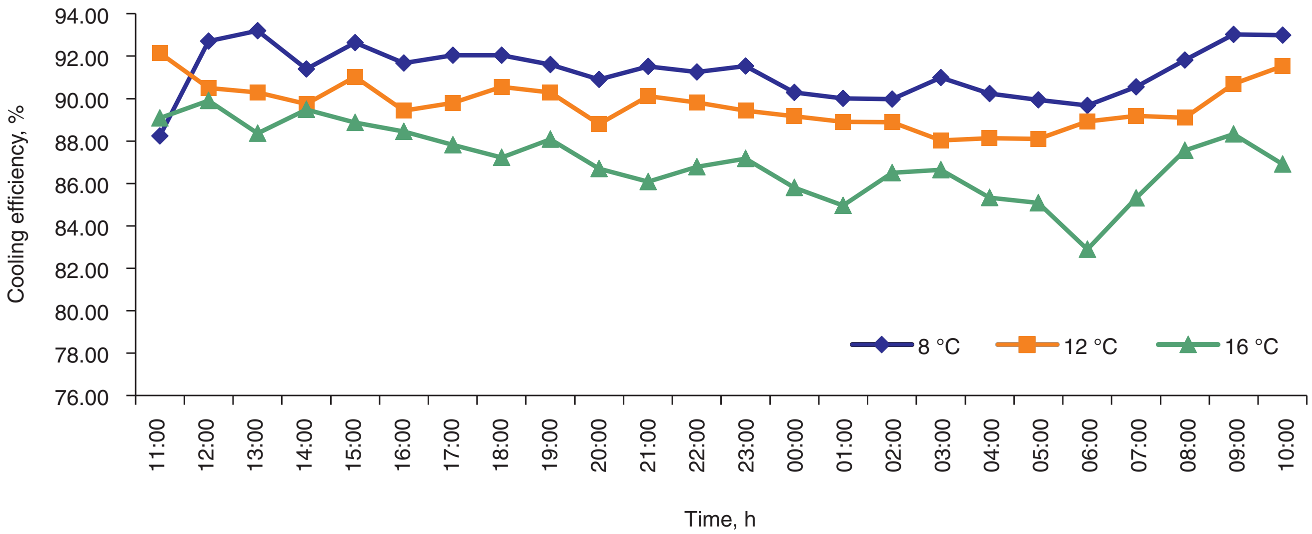

Fig 3 Cooling efficiency of the cold storage.

and ambient relative humidity of 75.26 and 36.26% with standard deviation of 2.90 and 9.69 were recorded.

It is evident (Fig 2) that, during daytime the temperature inside the cold storage increase as the ambient temperature increases and the relative humidity decreased to lowest level. It is also clear that, the fluctuation of inside temperature is more at day time compared to night. The maximum temperature was recorded at 13, 14 and 15 h. It is clear that the wide variations of ambient relative humidity and temperature were found while the narrow variation observed in temperature and relative humidity inside the cold storage structure.

The cooling efficiency values range from 89.67-92.63%, 88.10-89.42% and 85.09-89.49% respectively. The average efficiency of the cold storage is 91.26, 89.69 and 87.05% respectively for three different operating temperatures (Fig 3). This is in agreement with the results reported by Sunmonu *et al*. (2014).

The portable cold storage for cooling fruits and vegetable would help to increase the shelf life of most of the fruits and vegetables enabling the poor farmers to sell their produce at higher rate in the market during off-season. Cold stores intended for long term holding of produce are designed close to produce areas. They will source produce during harvest season and store in bulk without undertaking any retail packaging. During off season periods, the chambers are periodically opened and product released to market fetching the better price to the farmers. This cold storage structure is very useful for rural areas where there is shortage of electricity or its supply is erratic for storage of fresh fruits and vegetables.

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