Progressive Agriculture 30 (2): 209-218, 2019 **ISSN: 1017 - 8139**

Progressive Agriculture
Journal homepage:http://www.banglajol.info/index.php/PA

Design and fabrication of Windchill for low cost vegetable preservation

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Abstract

In Bangladesh, every year a huge amount of vegetables are being lost after harvesting from the field due to inadequate storage facilities at farmers' level. Considering this a low cost storage chamber, windchill was designed and fabricated that consumes low power to operate by a 12V duct fan. The average temperature inside the chamber at no load condition was found 24.7°C with a relative humidity of 77.2% while the outside temperature and relative humidity were 28.9°C and 54%, respectively. Performance of the chamber was tested keeping vegetables inside the chamber for four and five days during pre-test and bulk load test, respectively. During bulk load test the temperature and relative humidity inside the chamber were 24.7°C and 77.1%, respectively while outside the chamber, these were 28.8°C and 52.8%, respectively. After four days weight loss percentage inside the chamber at pre-test condition were 1.76% (tomato), 3.53% (brinjal), 5.2% (greenchili) and 18.16% (red amaranth) while weight loss outside the chamber were 4.18% (tomato), 9.52% (brinjal), 14.44% (greenchili) and 49.44% (red amaranth). Weight loss percentage at bulk load condition inside the chamber was 1.46% while outside the chamber was 15.15% at 5th day. Physical appearance of vegetables kept inside the chamber was also much better than those kept outside the chamber. The panel test result for evaluating physical appearance was found satisfactory based on their acceptance level after preservation. The initial construction cost of the full unit was Tk. 6010 which was found cost effective for farmers to store their vegetables for several days after harvesting.

Key words: Post-harvest loss, relative humidity, temperature, vegetables, windchill

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Introduction

Bangladesh has ranked 3rd position in global vegetable production (The financial express, 2018). The annual production of vegetables during 2016-17 fiscal year was 4.05millionMT and during the 2015-16 fiscal year it was 3.877 million MT. In FY-17 Bangladesh has brought 4.9 million dollars by exporting vegetables. 17 percent of total national GDP is contributed by the agriculture sector and more than 45 percent of the total labor force is employed in this sector. (Yearbook of Agricultural Statistics, 2017).

A huge amount of fruits and vegetables ranged from 23.6% to 43.5% was estimated as a postharvest loss. Every year around 4.09 billion dollar was lost due to postharvest loss of selected fruits and vegetables (Hassan *et al.*, 2010). Food and Agricultural Organization estimated that 30-40% loss of vegetables due to, in part, perish ability and absence of proper post-harvest storage, processing plants and transportation facilities (FAO, 2017). Most of the vegetables are seasonal and highly perishable. So it is needed to store vegetables in a proper way. Only a few commercial cold storages are available for some specific vegetables like potato and tomato but also not available in farmers' level. To reduce the spoilage of vegetables it is necessary to build up some low-cost small size cold storages in farmers' level for any type of vegetable. One such type of system is the evaporative cooling system and has been designed and constructed by some developing countries like China, India, Nigeria (FAO, 1986).Flax (2001), Giabaklou and Ballinger (1996), Dinh (1989) also developed different types of evaporative cooling systems. In Bangladesh, a low cost evaporative cooling chamber was designed and developed in Bangladesh Agricultural University for safe storage of vegetables (Alam *et al.*, 2015).

As a new technology, a low-cost cooling system, called windchill was developed in Canada. It was a low-cost cooling system for food preservation. (Circulate, 2015). Though the technology was developed and only temperature was tested by some researchers in India (Subham *et al.*, 2017) and Ghana (Kanney, 2015), the performance of the food chamber was not evaluated after keeping the food inside the chamber.

Windchill is the lowering of body temperature due to the passing-flow of lower-temperature air. In the windchill food preservation system, only a fan sucked the air into the chamber through aluminum tubing. The tube was buried into the ground where the temperature is less than the atmosphere. When the air was passed through the tubing it was cooled by exchanging the heat with soil via aluminum tubing and also by the expansion of the volume of air when entering into the chamber.

Temperature and relative humidity (rh) are two most important parameters that affect the shelf-life of vegetables. It was found that low-temperature storage protects the quality of vegetables like texture, nutrition, aroma, and flavor (Paull, 1999). The freshness quality of vegetables has an influence on the market price of the vegetables. Low temperature and high humidity also reduce the loss of moisture which results in a low weight loss of vegetables. So it is needed to control the temperature and rh to increase the shelf-life of vegetables and maintain the freshness quality.

Though evaporative cooling is a low-cost cooling system, a water pump for supplying water as well as a fan is needed for getting effective performance which consumes power. But in the windchill food preservation system, only a fan was required to suck the air into chamber through aluminum tubing. Again, it can reduce internal temperature in a very short time when atmospheric temperature is high which is very essential for preserving vegetables. For this, it is needed to design, develop and test the performance of a windchill vegetable preservation chamber. So, the specific objectives of the study are to design and fabricate a windchill vegetable preservation chamber and to evaluate the performance of the chamber as well as quality of products after preservation.

Materials and Methods

The experiment was conducted at the workshop of Farm Power & Machinery department of Bangladesh Agricultural University during February and March 2019.

***Experimental set-up*:** The windchill vegetable preservation unit comprises of two main sections. These are aluminum tubing and insulated chamber. Aluminum tubing cools the outside air and the vegetables were stored in the insulated chamber.

***Design and fabrication of the aluminum tubing*:** Aluminum tubing is the part that cools the outside air before entering into the insulated chamber. It is important to design the tubing properly to cool the air at the desired level. A pipe of 24 ft long and 1.25 in. diameter was cut into twelve sections. The orthographic views of the tubing are shown in Figure 1. The sections were joined with elbow (1.25" diameter) according to the orthographic view. The photographic views of the tubing are shown in Figure 2.

***Installation of the aluminum tubing*:** The tube was installed at 3 ft depth from earth surface to ease the heat exchange between inside air and outside soil of the tube. A funnel was attached with one opening to increase the velocity and reduce the air pressure while another opening was inserted into the chamber.

Photographic views of installation are shown in Figure 3.

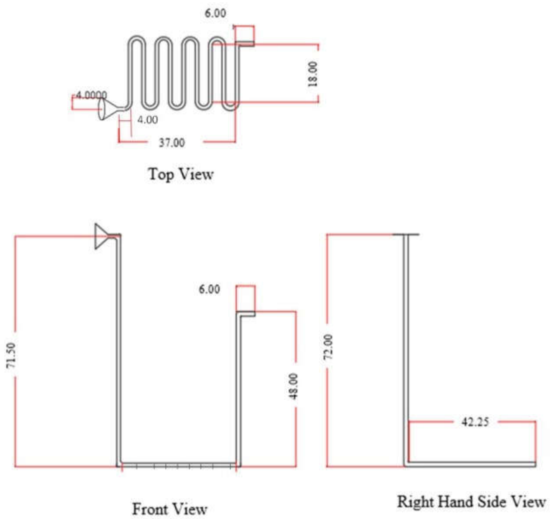
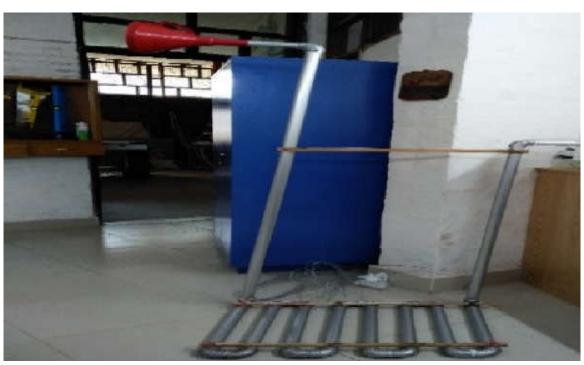


Figure 1. Orthographic views of the aluminum tubing (all measurements are in inches).

(a) Pipe connection



(b) Complete fabrication

Figure 2. Photographic views of the aluminum tubing.

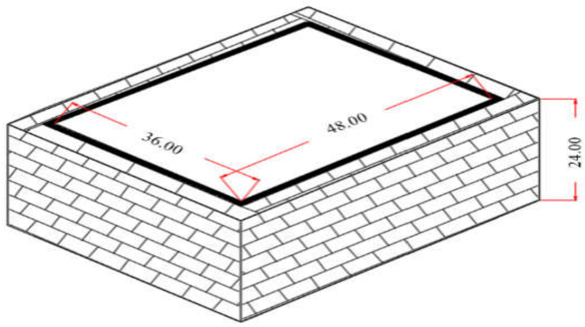
(a) Soil digging to 3 feet

(b) Placement of aluminum tubing in soil

Figure 3. Photographic views of installation tube.

***Design and fabrication of the insulated chamber*: ** An insulated chamber was designed with the aim of storing vegetables. Proper insulation is needed to keep the vegetables fresh. The dimensions of the chamber were 4 ft×3 ft×2 ft as length, width and depth, respectively and made with polystyrene sheet of 1 in. thickness. A ventilation fan was attached with the polystyrene box at a corner. The brick wall was made outside the polystyrene box. The isometric and photographic view is shown in Figure 4a and b.

***Working principle of the Windchill vegetable preservation unit*: ** When the ventilation fan was switched on, it created a vacuum in the chamber and outside air was drawn through the funnel and aluminum tubing. As the temperature beneath the ground level was less than the atmosphere, the air released some heat in the soil around the pipe. Finally when the air entered into the chamber, the pressure was reduced and consequently, the temperature was also reduced according to the law of ideal gas (Dass, 2013). Hence the inside temperature of the chamber was reduced continuously with cooled air. The process is shown in Figure 5.



(a) Isometric view of the chamber (all measurements are in inches).

(b) Photographic view of the chamber

Figure 4. (a) Isometric view and (b) photographic view of the chamber.

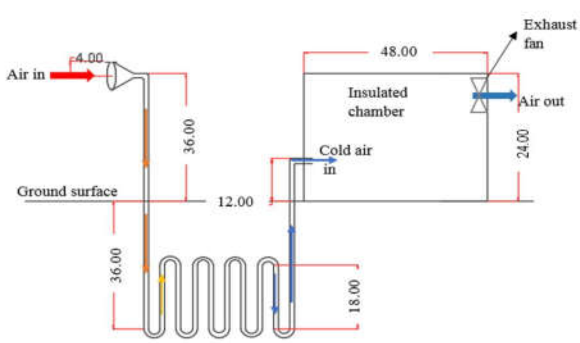


Figure 5. Working process of Windchill vegetable preservation unit (all measurements are in inch).

***Performance test of the chamber*:** The performance parameters of the chamber were temperature and relative humidity, weight loss of the vegetables and physical appearances (color, firmness).

***Temperature and relative humidity*:** Temperature and relative humidity were tested using DHT11 Temperature and Humidity Sensor with an accuracy level of $\pm 2\,℃$ and 5%, respectively.Sensors were operated by using a programmed microcontroller, Arduino UNO R3 that was connected with a computer for reading the sensor values. Data was collected for ten days during day hours at the one-hour interval from 8 to 18 Coordinated Universal Time (UTC).

***Weight loss*:** Weight of vegetables is one of the important factors as weight relates to moisture content which is an important index of quality and circuitously price of the vegetables depend on it. Weight is reduced with the removal of moisture from the vegetables due to high temperature and low humidity. Air velocity is also a factor of moisture reduction. During the pre-test period, the weight of the vegetables was measured using FRH Electronic Precision Balance of accuracy 1g. At load condition period the weights were measured using MEGA Digital with precession level 10g. Every morning the weight was taken by measuring the sample. The percent weight loss was measured by the following formula (Bala, 2016):

$$\text{Weight loss (\%)} = \frac{W - W_n}{W} \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where W= Initial weight of the vegetables (kg), W_n= Final weight of the vegetables after n days (kg) and n= natural number.

***Physical appearances*:** Consumers acceptance of vegetables was evaluated by measuring quality parameters based on physical appearances i.e. color and firmness. The color and firmness of the vegetables were observed once a day. The qualitative evaluation according to consumer's acceptance was conducted through a panel test. Qualitative measures were converted to quantitative values by marking acceptance level as '0' for non-consumable, '1' for poor, '2' for moderate, '3' for good, '4' for very good and '5' for excellent. Qualitative data were analyzed by using Microsoft Excel software in accordance with requirement (Grunert, 2004).

Results and Discussion

***Fabrication of the chamber*:** A windchill vegetable preservation unit was designed and fabricated at the workshop of the Department of Farm Power and Machinery, Bangladesh Agricultural University. The total volume of the chamber was around 679.6L. Figure 6 shows the chamber with aluminum tubing and funnel.

Figure 6. Windchill vegetable preservation unit.

***Performance test results at no load condition*:** Dry bulb temperature (dbt) and relative humidity (rh) was measured at one hour interval and it was observed that maximum difference in temperature was 8˚C to 9˚C at middle of the day when the outside temperature was highest (36 ˚C). Relative humidity was maximum in both inside and outside of the chamber at morning. The outside relative humidity was 88% and inside was 90%. But in middle of the day, outside humidity was reduced drastically and inside humidity variation was little. Minimum humidity inside the chamber was 67% at 1pm. Figure 7 and 8 illustrate the inside and outside temperature and relative humidity variation with time.

***Pre-test results*:** Initially four different items (Tomato, Brinjal, Red Amaranth and Greenchili) were kept to determine the performance and to find out the suitability of items to preserve in the chamber.

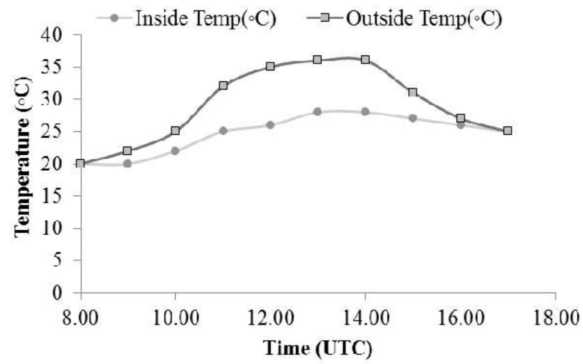


Figure 7. Inside and outside dbt of the chamber at no load condition.

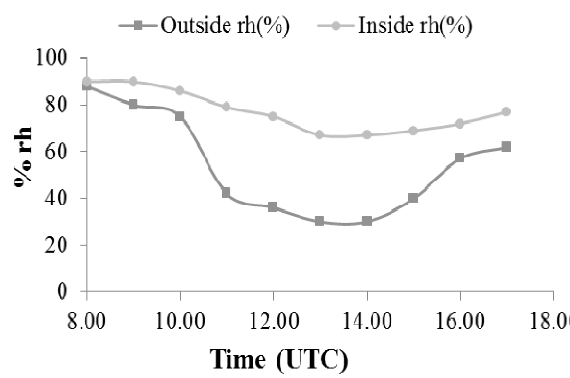


Figure 8. Inside and outside rh (%) of the chamber at no load condition.

***Temperature and humidity at pre-test condition*:** In this case maximum temperature difference between inside and outside was also 8˚C to 9˚C. Minimum rh was found 66% inside the chamber while outside it was 30%. Average maximum temperature difference was found 6˚C and average minimum rh inside the chamber was found 72.2%. Figure 9 shows the inside and outside temperature and rh at different times in a day and Figure 10 shows the average temperature and rh of four days.

***Weight loss measurement at pre-test condition*:** From the Figure 11, it was clear that weight loss percentage of the vegetables outside the chamber were more than the inside. Maximum difference in weight loss was found in red amaranth (31.24%) and minimum in tomato (2.42%) after storing for a period of four days. In brinjal and greenchili it was found 5.99% and 9.2% for the same storing time, respectively. High temperature and low humidity were the reason of weight losses outside the chamber as compared to the inside.

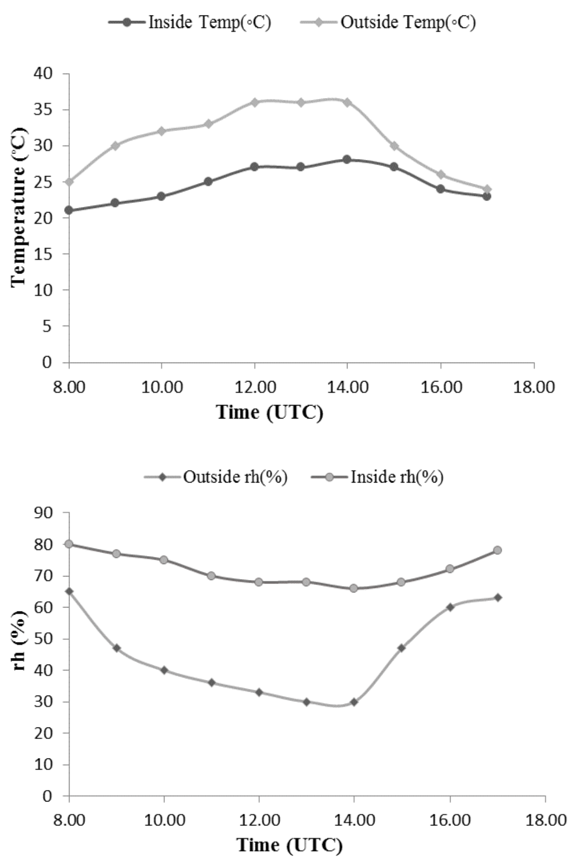


Figure 9. Inside and outside temperature (˚C) and rh (%) of the chamber at different hours during pre test condition.

***Test results at bulk load*:** From the pre-test result it was found that, weight loss percentage was minimum in Tomato. So Tomato was used as bulk load for further test.

***Temperature and humidity at bulk load condition*:** Maximum temperature difference was found 5˚C and minimum rh was 81% and 64% inside and outside of the chamber, respectively at first day due to rain. Maximum average daily temperature was 28.8˚C and

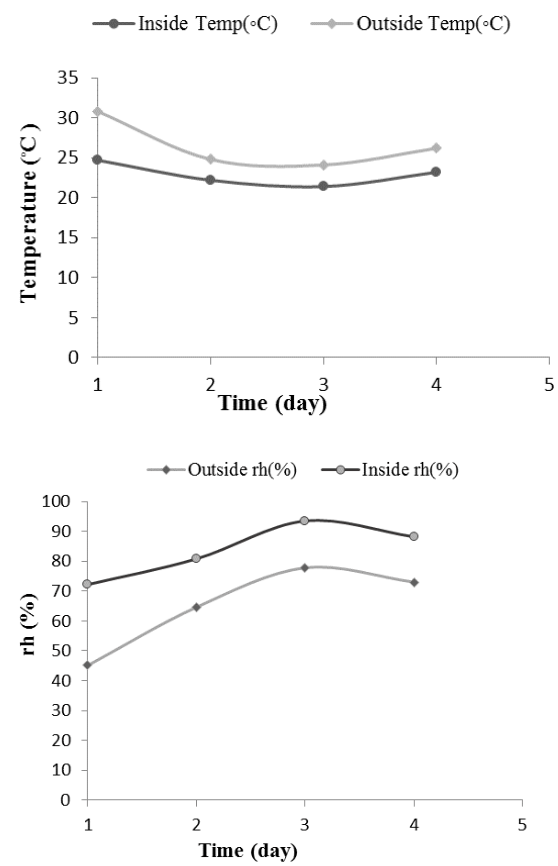
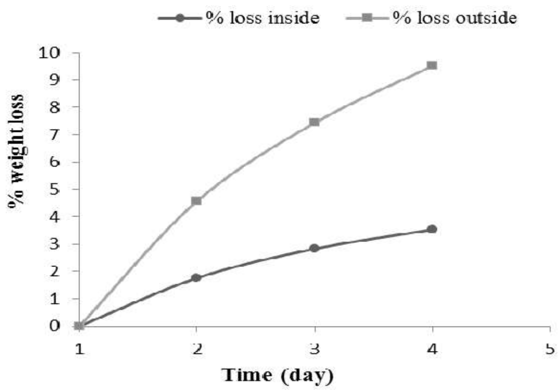


Figure 10. Inside and outside temperature(˚C) and rh (%) of the chamber at different days during pre test condition.

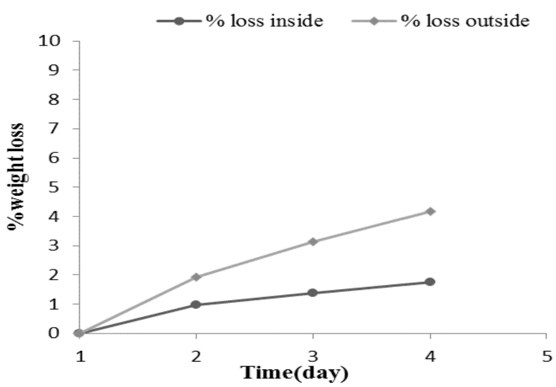
24.9˚C in inside and outside the chamber, respectively. Maximum rh was found in morning and in evening. Minimum average daily rh was found 50.2% and 73% in outside and inside of the chamber, respectively. Figure 12 and 13 illustrate the inside and outside temperature and rh at different times in a day and the average temperature and rh of four days, respectively.

***Weight loss measurement at bulk load*:** Maximum percentage weight loss of vegetables kept inside and outside of the chamber was found 1.46% and 15.15%, respectively after four days. Figure 14 illustrate the percentage weight loss of tomato.

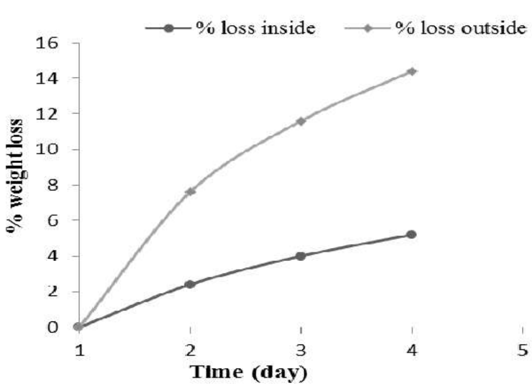
***Installation cost of windchill vegetable preservation unit*:** The fabrication cost of the designed windchill vegetable preservation unit was TK. 6010. Estimation of total fabrication cost is described in Table 1.



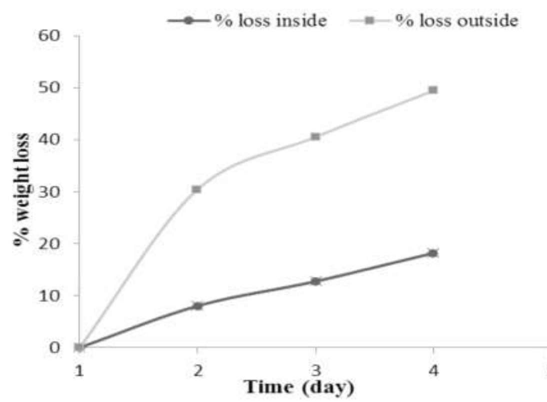
(a) Brinjal



(b) Tomato

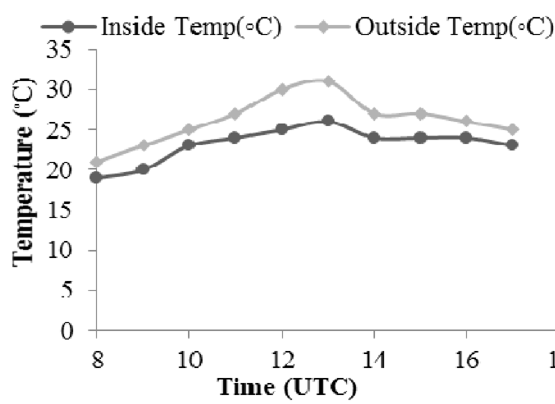


(c) Greenchili



(d) Red Amaranth

Figure 11. Inside and outside weight loss (%) of different vegetables with time (day).



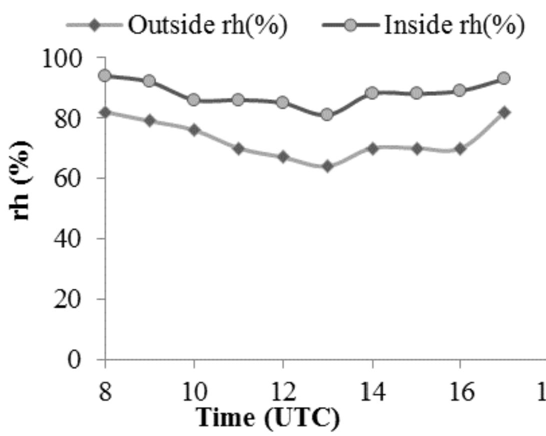


Figure 12. Inside and outside temperature(°C) and rh (%) of the chamber at different hrs during bulk load condition.

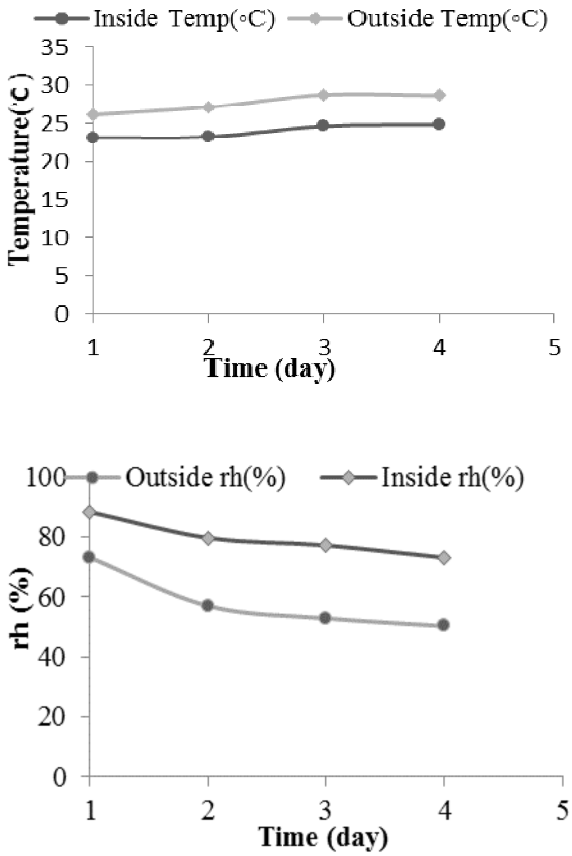


Figure 13. Inside and outside temperature(˚C) and rh (%) of the chamber at different days during bulk load condition.

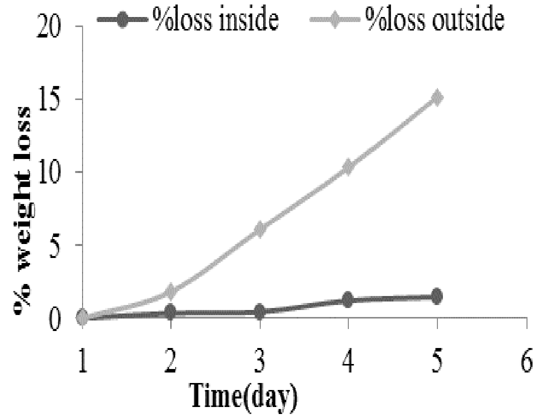


Figure 14. Inside and outside weight loss of tomato at different days during bulk load condition.

***Physical appearance*:** The pictorial views indicate that the change in color and firmness decreases much lower for the products at inside environment than the outside products. No discoloration and firmness variation was found in Tomato and Greenchili after 4th day at inside the chamber while at outside, the product can be consumed but the firmness was reduced which may affect the price. Slight discoloration and firmness were reduced in Brinjal and Red Amaranth at inside environment on the other hand the product kept outside became non consumable after 4th day.

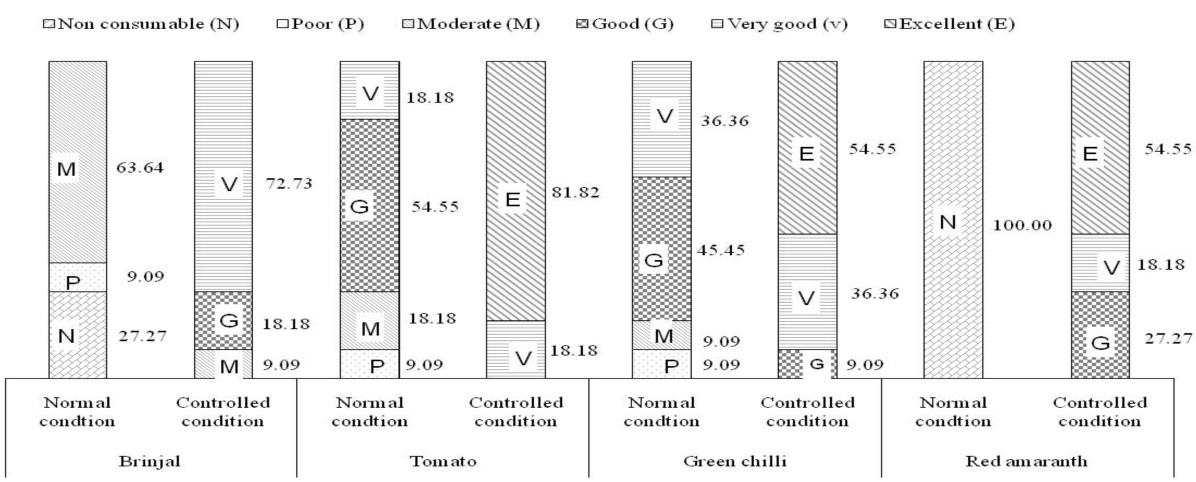


Figure 15. Acceptance (%) of materials in outside and inside conditions.

From the panel test report it was found that in controlled condition after 4 days preservation, the maximum acceptance occurs for tomato. Brinjal also got accepted as consumable by 72%. At the controlled condition red amaranth gave the lowest performance, though it secured its acceptance to 54.55% as 'excellent' but in normal condition, it was totally inconsumable. Green chili also remains fresh and consumable after four days preservation according to the panelists. Figure 15 represents the result of penal test for physical appearance of products in and outside of the chamber.

Conclusion

A windchill vegetable storage chamber was designed and fabricated in the FPM departmental workshop. This study was adopted on the principle that some insects keep their living place comfortable under the ground and on the principle of ideal gas. As the temperature was low and rh was high inside the chamber from the outside, vegetables kept inside the chamber was found fresher and weight loss was less as compared with those kept outside for 3-5 days. From the panel test result, it was assured that the vegetables were consumable after four days which kept inside the chamber. Based on this study, it can be concluded that this storage chamber can be used as temporary means of cost effective storage in farmers' levels for several days.

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