Development and evaluation of low cost evaporative cooling systems to minimise postharvest losses of tomatoes (*Roma vf*) around *Woreta*, Ethiopia

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Abstract: Low cost evaporative cooling systems were developed and investigated for their cooling efficiency to improve the shelf life of tomatoes. Average cooling efficiencies of bamboo jute and pot in pot coolers before being loaded with tomatoes were 82% and 79% and after being loaded were 67.6% and 61.6%, respectively. Physiological weight losses were 1.03%, 1.32% and 1.42% for bamboo jute, pot in pot coolers and ambient storage, respectively. The sensory results revealed that the shelf life of tomatoes were 5, 19 and 21 days for ambient, pot in pot and bamboo jute coolers, respectively. Storage type has significant difference on cooling efficiency but not on physiological weight loss, physical damage, freshness and rot incidence at $p < 0.05$. Thus, both evaporative coolers were found to be energy efficient, environmentally sound and can be used in areas where there is no electricity to improve the shelf life of tomatoes.

Keywords: cooling efficiency; evaporative cooling; postharvest loss; shelf life; tomatoes.

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1 Introduction

The perishable nature of fruits and vegetables needs effective postharvest handling systems, the main reason for high postharvest losses in the tropical and sub-tropical regions of Africa (Ngcobo et al., 2012). Workneh (2007) and Azene et al. (2011) claim that postharvest losses could discourage farmers from venturing into production and marketing of fresh produce and thus affecting the supply side of consumption of fruit and vegetables in urban areas. According to Coulomb (2008), the world average postharvest losses for fresh produce are estimated at 30%. Postharvest losses in African countries, are hard to estimate (Adeoye et al., 2009) though some authorities estimate losses in fruit and vegetables to be 50% (FAO, 2008; Kader, 2005, 2010) or half of what is grown (Lundqvist et al., 2008).

Postharvest losses in developing countries may occur due to limited availability of cold storage facilities, inadequate packaging for storage and transport, poor infrastructures, lack of processing facilities and poor handling practices. However, most of the postharvest losses incurred on fruits and vegetables in Ethiopia are due to lack of adequate storage facilities. Low temperature handling and storage have been described as the most important physical method for postharvest loss control (Seyoum and Woldetsadik, 2004). In developed countries, methods employed for extending shelf life and minimising postharvest losses of perishable produce include mechanical refrigeration, controlled atmospheres, hypobaric storage, and other techniques. These cooling methods, except adiabatic cooling, are expensive for small scale peasant farmers, retailers and wholesalers in Ethiopia, as they require high initial cost and electric power. Seyoum and Woldetsadik (2004) suggest that low temperature and high relative humidity can be achieved by using less expensive methods such as evaporative cooling.

Evaporative cooling is an adiabatic cooling process whereby the air takes in moisture which is cooled while passing through a wet pad or across a wet surface showed that evaporative cooled storage is more energy efficient than a mechanical refrigeration system as cited in Tilahun (2010). Introduction of simple and low cost alternative storage methods at different stages starting from farm to the retail market are therefore important in developing countries.

Compared with several temperate fruits and vegetables, tropical and subtropical vegetables such as tomatoes present greater storage and transportation problems because of their perishable nature (Mitra and Baldwin, 1997). However, poor postharvest practices are serious concerns and contribute to the poor quality perception and high postharvest losses of tomatoes (Genova et al., 2006). The present study developed and evaluated two low cost evaporative cooling systems from locally available materials that could be utilised to improve the shelf life of tomatoes.

2 Materials and methods

2.1 Study site

The study site, *Woreta*, Ethiopia is located at 11°58’ north and 37°34’ east and it covers an area of 1,174.14 km^2 and average rain fall 1,284.2 ml with 1,820 m above sea level. It has a population of 228,449 (2012 estimate) where 88.9% is a farmer. *Woreta* has an average maximum temperature of 33°C and an average minimum temperature of 10°C. For conducting the experiment, Dudmegn Elementary School was selected and the study period was from January to April 2013.

2.2 Method of construction of evaporative coolers

Construction materials such as sand, metal plate, bags, bamboo, jute, buckets, jug, ink and bricks were collected based on porosity, water absorption or evaporation rate of the material, availability, cost and ease of construction. The holding capacities of the evaporative coolers were 10 and 40 kg of tomatoes for pot in pot and bamboo evaporative coolers respectively. However, when the amount of tomatoes increases, the coolers need modification on their design that could allow the flow of air between layers of tomatoes.

The types of evaporative coolers selected were mainly due to the low cost and availability of construction materials and simplicity of construction. In addition, it was also to make available based on the interest of the users.

Bamboo basket were constructed and covered with a jute cloth. The jute cloth was sewn around the rim of the basket. The lower end of the cloth hung loosely around the bottom, exceeding the length dip into the water. This helps to bring up the water by capillary action through the jute cloth. The basket was covered with loose-fitting woven lid. The lid was also covered with jute cloth [Figure 1(a)]. It was designed with 1 m height, 60 cm diameter and 2 cm thickness.

Figure 1 (a) Bamboo jute cooler (b) Pot in pot cooler (see online version for colours)

(a) (b)

During development of the second type of evaporative cooler, a porous outer earthenware pot with 50 cm diameter and 2 cm thickness and inner pot with 20 cm diameter and 2 cm thickness were constructed and lined with sand (30 cm thick) within which tomatoes were stored [Figure 1(b)].

2.3 Tomatoes

The tomatoes (*Roma vf*) used for the study were free from mechanical damages and the maturity was on their turning stage. Besides, ten kilo grams of tomatoes were used to study for each of the evaporative coolers as well as for the control.

2.4 Data collection methods

2.4.1 Cooling efficiency

2.4.1.1 No load test

No load test was conducted after applying water on the cooling chambers to study the performance of the coolers before being loaded with tomatoes. The temperature and relative humidity inside the closed chamber and outside the chamber were recorded three times a day using Digital Thermo-Hygrometer, TFA Dostmann/Wertheim, Germany.

2.4.1.2 Load test

The coolers were placed under a shade of trees where there is high exposure to wind flow. The control was placed in open plastic containers at ambient conditions the way consumers store tomatoes without cold storage methods at home.

The average cooling efficiency when loaded with tomatoes in bamboo jute for 21 days and pot in pot coolers for 19 days was estimated using the model reported by Al-Sulaiman (2002):

$$C_E = \frac{T_1(db) - T_2(db)}{T_1(db) - T_1(wb)} \times 100 \tag{1}$$

where

$T_1(db)$ dry-bulb outside temperature, °C

$T_2(db)$ dry-bulb cooler temperature, °C

$T_1(wb)$ wet-bulb outside temperature, °C.

2.4.2 Quality of stored tomatoes

2.4.2.1 Physiological weight loss

Physiological weight loss (PWL) of samples was recorded daily over the storage periods using the method described by Gugino (2010). The change in the weight of the samples stored in the bamboo jute coolers, pots in pot and ambient storages was estimated as percentage weight loss using the formula below:

$$PWL = \frac{Original\ weight - New\ weight}{Original\ weight} \times 100 \tag{2}$$

2.4.2.2 Appearance

Appearance was evaluated by consumer panellists for physical damage, freshness and rot incidence of tomato samples using a 1–5 Hedonic scale.

2.5 Data analysis

Triplicate data were subjected to ANOVA using JMP version 5.0 Statistical Analysis Software (SAS Institute, 2003). Means were compared using Student’s t test at $p < 0.05$.

3 Results and discussion

3.1 Cooling efficiency

3.1.1 No load test

During performance evaluation of the cooling systems, the ambient temperature kept on increasing with time, the cooling chambers experienced drop in temperature and thereafter maintained low temperature with time for the remaining testing period. However, the average temperature inside the cooling chambers during ‘no load’ test varied from 11–15°C while in the ambient air temperature varied from 21 to 31°C. The relative humidity inside the evaporative cooling chamber varied from 42% to 75% while at outside it varied from 18% to 63% (Figure 3). In general, as shown in Figures 2, 3, 4 and 5, the experimental temperature measured in this study agreed reasonably well with previous findings which validate the efficiency of the evaporative cooling system developed. In this regard, the average cooling efficiency of bamboo jute cooler and pot in pot cooler during the ‘no load test’ was 82% and 79%, respectively (Figure 2).

3.1.2 Load test

The average cooling efficiency when loaded with tomatoes for bamboo jute and pot in pot coolers were 67.6% and 61.6%, respectively (Figures 3 and 4). This is comparable with values in literature. Al-Sulaiman (2002) reported cooling efficiency of 62.1% with jute pad.

A comparison of the ambient temperature and that of the evaporative coolers have temperature ranges that could be comparable with the suitable storage temperature of tomatoes. Thus, this could have a better implication for knowing the shelf life and quality maintenance of tomatoes produced under warmer areas of the country (Tigist et al., 2012). Hardenburg et al. (1986) mentioned that storage under relatively low temperature is the most efficient method to maintain quality of most fruit and vegetables due to its effects on reducing respiration rate, transpiration, ethylene production, ripening, senescence, and rot development.

The daily temperature readings within each cooler depended on ambient conditions. There was significant difference ($p < 0.05$) in each case between the temperature observed inside the coolers and the ambient temperature (Figures 3, 4 and 5). Maximum temperature inside and outside the coolers was observed between afternoon and evening for both evaporative coolers during the study. This trend was also similar with results reported by other researchers (Ahmed et al., 2011; Dagtekina et al., 2009).

Figure 2 Average daily temperature (T) and relative humidity (RH) of bamboo jute and pot in pot evaporative coolers during no load test (see online version for colours)

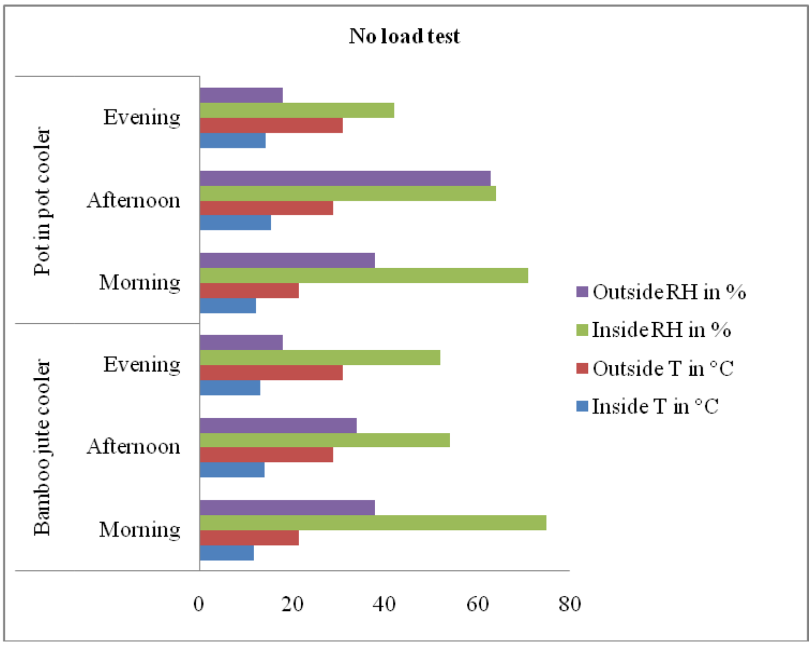


Figure 3 Average daily cooling efficiency of bamboo jute cooler during load test for 21 days of storage (see online version for colours)

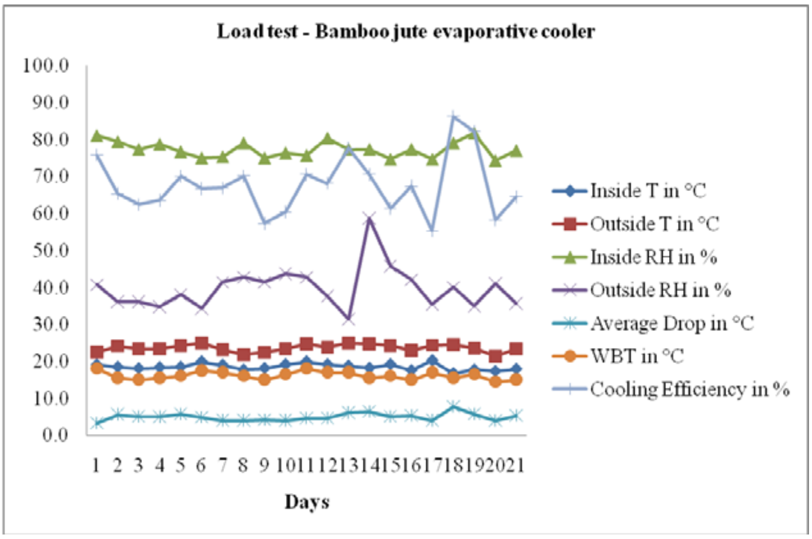


Figure 4 Average daily cooling efficiency of pot in pot cooler during load test for 19 days of storage (see online version for colours)

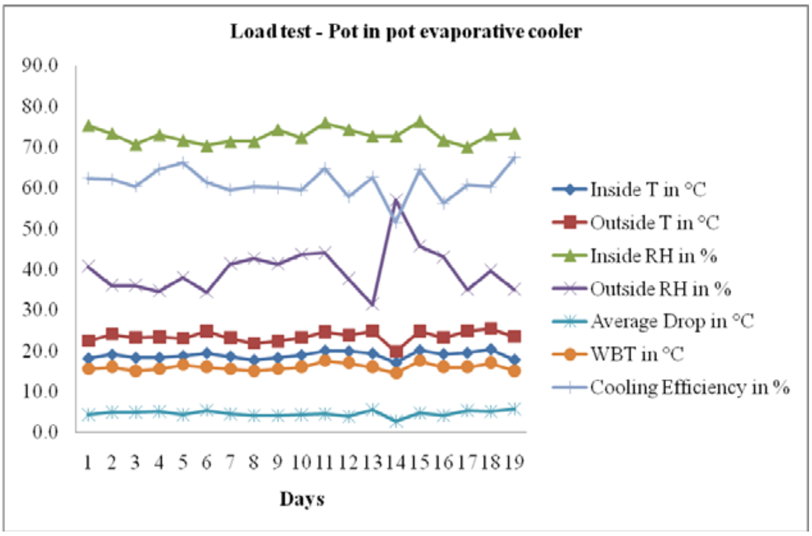
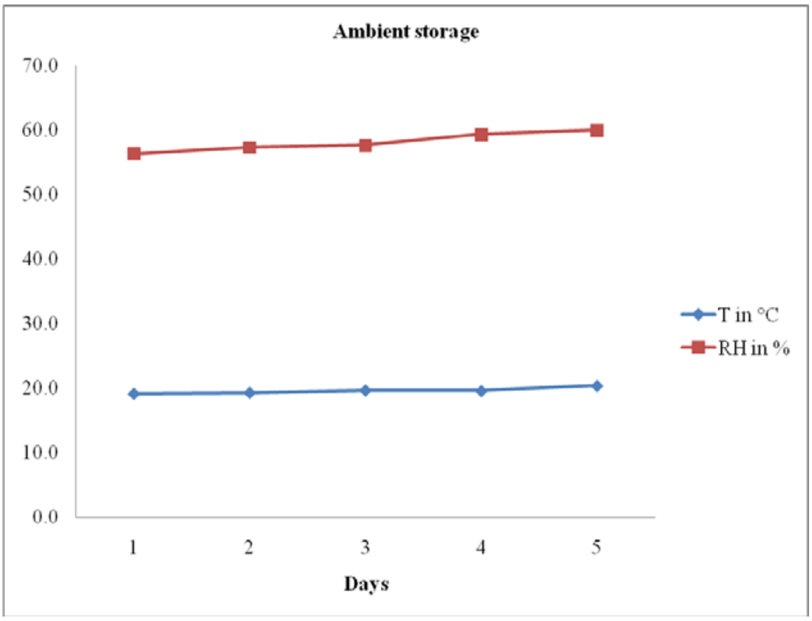


Figure 5 Average daily temperature (T) and relative humidity (RH) of ambient for 5 days of storage (see online version for colours)



The reduction in the variation of relative humidity over time inside the cooler compared to ambient conditions was an indication of the effectiveness of the cooler in maintaining high uniform relative humidity. The marked increase in relative humidity over the ambient values is an evidence of the suitability of the pad materials (jute and sand) as potential cooling pads (Figures 3 and 4).

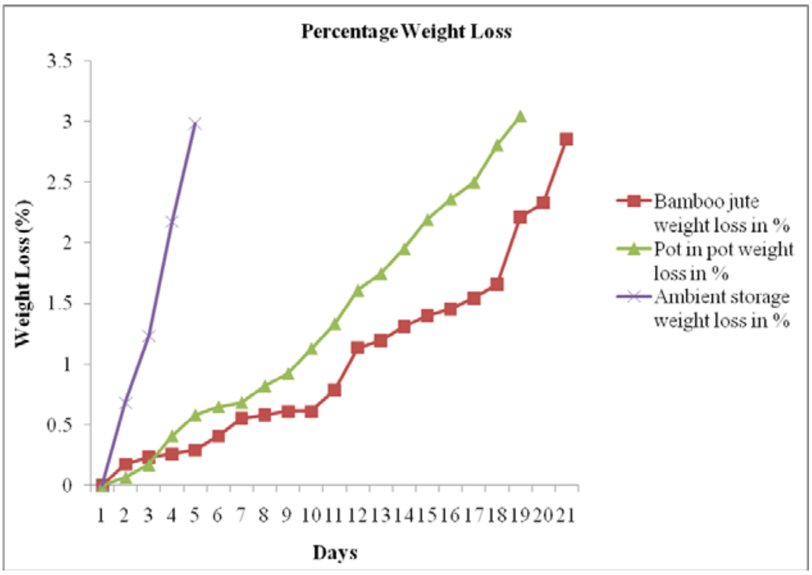
It is generally agreed that mature tomato can be stored for relatively longer period at a temperature of 10 to 15°C and 80% to 95% relative humidity (Castro et al., 2005). In this background, it is interesting to note here that the temperature of the cooling systems also offered relatively similar conditions except that the relative humidity was low. This also agrees with the report (Xuan et al., 2012) that 100% relative humidity was not achievable in direct evaporative cooling systems because 100% saturation is impossible due to two reasons. Firstly, most of the pads are loosely packed, and the process air can easily escape between the pads without sufficient contact with the water. Secondly, the contact time between air and water is not long enough which results that heat and mass transfer is insufficient.

3.2 Quality of stored tomatoes

3.2.1 Physiological weight loss

Percentage PWLs were 1.03%, 1.32% and 1.42% for bamboo jute, pot in pot coolers and ambient, respectively. It was observed that the weight loss was a minimum when the tomatoes were stored in the evaporative cooling systems while it was a maximum in ambient storage as presented in Figure 6. Similar findings were also reported by Tefera et al. (2007) and Hirut et al. (2008) that weight loss of fruits increased as the storage period advanced; increase rate of weight loss could be related to stage of ripeness of tomatoes as there could be increased fruit permeability as ripening progresses.

Figure 6 Average daily PWLs of tomatoes stored in bamboo jute, pot in pot cooler and ambient (see online version for colours)



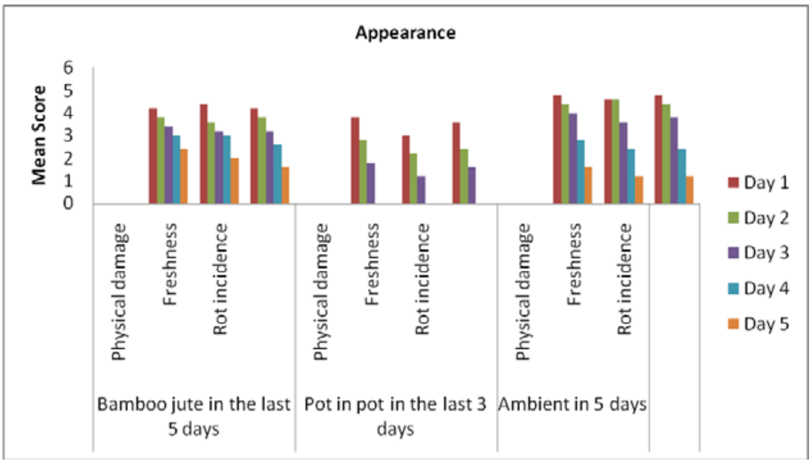
Workneh and Kebede (2004) also reported that weight loss is associated with losses of saleable weight during storage of fruits and vegetables at ambient conditions. Thus, this study indicates that tomatoes greatly differ in the reduction of weight as the storage period advances which partly justify the dominance of tomatoes stored in the bamboo jute coolers and pots in pot cooler as compared with tomatoes stored at ambient conditions that have poor shelf life.

3.2.2 Appearance

Tomatoes stored at ambient condition were found to decay with dark colour and spots which could be due to growth of moulds. In contrast, tomatoes stored both in pot in pot and bamboo jute evaporative coolers were found to be bright in colour. This is because cool temperature slows down colour development and the ripening process. This is because colour development in tomato is sensitive to temperature, having a better plastid conversion when temperature is above 12°C and below 30°C (López and Gómez, 2004).

The sensory results revealed that the shelf life of tomatoes were 5 days, 19 days and 21 days for the ambient, pot in pot and bamboo jute evaporative coolers, respectively. This shows that the two evaporative cooling systems are much better to improve the shelf life of tomatoes as compared to the ambient (Figure 7). This is comparable with the study made by Seyoum and Woldetsadik (2000) at which evaporative cooled storage has shown to maintain the fruits and vegetables 100% marketable for at least 15 days. Under hot climate conditions of Ethiopia, these perishable commodities will became unmarketable within 15 days period, while those stored in the evaporative cooling chambers remained marketable even after two weeks of storage. The reason for this was attributed to the fact that the evaporative cooling system was capable of reducing the temperature and increasing the relative humidity as required for short period fruit and vegetable storage during marketing.

Figure 7 Mean sensory scores of physical damage, freshness and rot incidence of tomatoes stored in bamboo jute, pot in pot cooler and ambient (see online version for colours)



As a result, storage in these evaporative coolers increase shelf lives of most fruits and vegetables to more than two weeks, compared to less than one week shelf life when stored at ambient conditions. Thus, it is clear that these low-cost and appropriate storage facilities should be installed at different centres throughout the hot arid and semi-arid tropical regions in order to promote fruit and vegetables production on private, cooperative or public basis. Evaporative cooling would be used to solve the problem associated with cooling fruits and vegetables.

Generally, storage type has significant difference on cooling efficiency but has no significant difference on PWL, physical damage, freshness and rot incidence at $p < 0.05$ (Table 1) of this study.

Table 1 Effect of storage type on cooling efficiency, PWL, physical damage, freshness and rot incidence

Storage type	*Cooling efficiency (%)*	*Physiological weight loss (%)*	*Physical damage*	*Freshness*	*Rot incidence*
Bamboo jute cooler	$67.6^{a} \pm 7.93$	$1.03^{a} \pm 0.78$	$3.36^{a} \pm 0.69$	$3.24^{a} \pm 0.87$	$3.08^{a} \pm 1.02$
Pot in pot cooler	$61.6^{b} \pm 3.60$	$1.32^{a} \pm 0.95$	$2.80^{a} \pm 1.00$	$2.13^{a} \pm 0.90$	$2.53^{a} \pm 1.00$
Ambient storage	-	$1.42^{a} \pm 1.19$	$3.52^{a} \pm 1.30$	$3.58^{a} \pm 1.47$	$3.32^{a} \pm 1.49$

Notes: Mean values not connected by same letter in a column are significantly different at $p < 0.05$.
^{a,b}indicate statistical significance.

4 Conclusions

This study was based on the principles of evaporative cooling where warm dry air is cooled and humidified by passing it through a wet surface. In this study, it was possible to develop low cost alternative evaporative cooling systems from locally available materials such as bamboo jute and pot in pot coolers. Performance evaluation revealed that the evaporative coolers had a potential to reduce the temperature and increase the relative humidity which is a suitable environment to improve the shelf life of tomatoes up to three weeks keeping acceptable qualities. In addition, the average cooling efficiency during ‘no load test’ for bamboo jute cooler and pot in pot cooler was 82% and 79% and during ‘load test’ was 67.6% and 61.6%, respectively. The percentage weight loss of tomatoes was less in the bamboo jute cooler as compared to those stored in the pot in pot and ambient.

The developed evaporative cooling systems are easy to operate, efficient and affordable most especially for peasant farmers in developing countries like Ethiopia who may find other methods of preservation quite expensive and unaffordable and can address the need for refrigeration in areas where electricity is unavailable and/or areas with high ambient temperature and low relative humidity or windy. This work has also elucidated a means of preserving fresh tomatoes, which if adopted will reduce post harvest losses, hence, increase in income generated from agricultural produce. However, issues to reduce breakage of pot-in-pot evaporative cooler and to prevent growth of moulds on the surface of bamboo jute cooler still need to be solved.

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