Performance evaluation of a medium size charcoal cooler installed in the field for temporary storage of horticultural produce

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Abatract: Evaporative cooling has been used over time as an effective method for controlling the environment in structures. However, documented scientific information on performance of commercial scale storage systems is limited. Based on preliminary laboratory data a medium size charcoal cooler was constructed with a volumetric capacity of 27 m^3 and wall thickness of 100 mm at Kikoo village in Kibwezi district in the Eastern Province of Kenya. The area is known for irrigated horticultural farming under extreme environmental conditions. The developed cooler had a sisal stem ceiling covered with 50 mm thick dry reeds. The cooler was constructed to provide temporary storage for fruits and vegetables, destined mainly for exporting to international markets, as a remedy to minimize loss of quality before collection. The performance of the charcoal cooler was evaluated on the basis of the temperature and the relative humidity with three scheduled daily watering regimes, once at 8:00 h, twice at 8:00 and 12:00 h and three times at 8:00, 12:00 and 14:00 h. These watering regimes aimed at reducing the amount of water used and at the same time to ensure that the charcoal was not completely dried. Temperature and relative humidity were measured in the cooler, adjacent grading room and outside the structure to give the ambient conditions. The cooler had the lowest temperature and the highest relative humidity irrespective of time and watering schedule. Triple watering of the cooler showed the highest temperature decrease and relative humidity increase, differences reaching 11˚C and 38% respectively, compared to single and double watering. Triple watering also maintained the relative humidity in the cooler within the recommended range of 80 to 95% for horticultural produce. The cooler temperature however remained far above the recommended range of 0 to 10˚C for fruits and vegetables. A watering interval of two hours from 8:00 h onwards would be the most appropriate watering regime, considering the extreme environmental conditions and scarcity of water.

Keywords: charcoal cooler, horticultural produce, quality, storage, temperature, relative humidity

Citation: Shitanda D., O. K. Oluoch, A. M. Pascall. 2011. Performance evaluation of a medium size charcoal cooler installed in the field for temporary storage of horticultural produce. Agric Eng Int: CIGR Journal, 13(1): －.

1 Introduction

High losses of over 30% for farm produce are reported in Kenya especially for the perishable and semi perishable produce (Shitanda and Wanjala, 2006). Despite the losses, farmers have continued to depend on traditional methods of food preservation, which are commonly used for short storage of small quantities of produce. Some of the farm produce experiencing high losses include water, milk, honey, fruits and vegetables, which have high value but poor storage quality resulting in tremendous losses from the time of harvest up to the time they are marketed (PA, 2009; FAO, 1989). Less than 20% of the Kenyan population (GoK, 2008) has access to electricity thus making it not only impossible but expensive to use cold storage systems at the rural level. Currently more effort is being directed towards the production and marketing of raw produces. However, little emphasis has been put on the storage, processing and local use of such produce (Shitanda and Wanjala, 2006). Thus there is a need to promote

Received date: 2009-12-27 **Accepted date:** 2011-01-04
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technologies to secure markets and promote production while improving farmers' income. Storage helps to maintain quality, allows for market rescheduling, reduces losses ensures continuous supply of similar quality produce during off-season.

Due to the drastic fall in the world prices of coffee and tea, there has been a steady shift from perennial crop farming in Kenya to horticultural farming with tremendous success. Horticultural farming has therefore improved the use of the scarce arable land, thus earning the country over US$0.2 billion in the foreign exchange. It is now the second foreign exchange earner after tea. Most of the produce is marketed in Europe and the United States of America (HCDA, 2007). However, storage of perishables and semi-perishables at the farm level is still a big challenge in Kenya, resulting in tremendous losses. Simple and effective storage systems can therefore be used to minimize losses thus improving the net returns of farmers who are heavily engulfed in poverty (Jha, 2008).

Cold storage is the main form of storage in Kenya, being used for high value produce like fruits, vegetables and flowers. The storage method is done at the source, during transportation and at the destination. However, modern cold storage systems are very expensive since they rely on electricity whose tariffs in Kenya are among the highest in the world at about US$0.2/kWh (Gok, 2008). Continuous supply of electricity is also not guaranteed especially during the dry season when the water levels in the hydroelectric dams are low, making the storage technology unreliable. Therefore, there is a need for alternative cost effective and simple systems that can be easily adapted for storage of fresh farm produce at the rural level (Goswami, Borah and Baishya, 2008; Jain, 2007). The objective of this study was to evaluate the effects of a medium size charcoal cooler on the temperature, relative humidity and storage quality of selected horticultural produce.

Storage of farm produce especially dairy and horticultural produce is very important since they lose their quality very fast and production occurs far from the market. Without effective and efficient storage systems, losses can be astronomical making the whole production processes uneconomical (Odogola, 1994). During storage, it is important to control the storage environment to ensure effective preservation of the stored produce. Some of the control parameters that are critical in modern storage systems include temperature, moisture and humidity, air velocity, lighting, odour, and pressure (Uluko et al., 2006; Bakker-Arkema et al., 1999). The effects of the storage condition on the shelf life of horticultural produce are shown in Table 1. Basically, the reasons for storage include continuity of the supply during off season, handling of over production, sustainability and continuity of farm operations, reduction of field losses, reduction of quality losses, and stabilization of market prizes.

Table 1 Storage temperature, relative humidity and shelf life of fruits and vegetables

Commodity	Storage temperature/℃	Relative humidity/%	Shelf life
Asparagus	0-2.0	95	2-3 weeks
Beans (green)	5.0-7.0	90-95	7-10 days
Carrots	0	90-95	2-5 months
Cauliflowers	0	90-95	2-4 weeks
Cucumbers	7.0-10.0	90-95	10-14 days
Cabbage	0	90-95	3-6 weeks
Chillies, Capsicums	7.0-10.	90-95	2-3 weeks
Courgettes, Zucchini	0-10.0	90	5-14 days
Eggplants, Brinjals	7.0-10.0	90	1 week
Melons	0-4.4	85-90	5 –14 days
Okra, Lady Fingers	7.0-10.0	90-95	7-10 days
Onions (dry)	0	65-70	1-8 months
Potatoes (white)	5.0-10.0	93	2-5 months
Potatoes (sweet)	12.0-16.0	85-90	4-6 months
Tomatoes (ripe)	7.0-10.0	85-90	4-7 days
Tomatoes (green)	12.0-20.0	85-90	1-3 weeks
Watermelons	4.4-10.0	80-85	2-3 weeks
Apples	1.0-4.4	90	3-8 months
Avocado	4.4-12.5	85-90	2-4 weeks
Mangoes	12	85-90	2-3 weeks
Pineapples	7.0-12.5	85-90	2-4 week
Papayas	7	85-90	1-3 weeks
Carnations	0-2.0	90-95	3-4 weeks

Source: FAO, 1989

During storage, it is important to ensure that the produce kept in the cooler is of good quality and is not damaged or diseased. This is important because damaged or diseased fruits or vegetables respire more and thus producing more heat apart from being susceptible to microbial attack (Shitanda and Wanjala, 2006). All produce that is to be stored in the cooler therefore needs to be graded first and all undesirable fruit discarded.

Careful handling of produce is needed and this includes keeping the produce under shade. This is important because exposure to direct solar radiation heats up the produce thus increasing the amount of heat to be removed during storage. This is because the produce temperature is usually higher than the ambient temperature by about 10℃ (Dash, Chandra and Kar, 2006; Anyanwu, 2004).

Charcoal cooling is aimed providing an environment which is lower than ambient temperature and stays at a higher level of relative humidity for the storage of fresh produce. The high relative humidity results in the produce losing less water. The cooling system consists of a porous structure to which water is added. Through this "wet wall" air is flowing and the air temperature is decreasing due to the loss of sensible heat through the evaporation of water (PA, 2009; Isaak, Kudachikar and Kulkarni, 2004). The temperature is normally lowered by about 5 to 10℃, depending on the relative humidity of the ambient air. Charcoal is commonly used because it has a very porous structure that can hold water and is easily available. Heat in the fruits and vegetable is transferred to the cool air that surrounds it. The air rises by natural convection and gives off the heat which has absorbed. The process of evaporative cooling is shown in Figure 1 with the ambient temperature reducing from t_1 to t_2. Evaporation and moisture addition in the chart involves using energy from air for evaporative cooling thus increasing its water content from w_1 to w_2. The process is represented by a constant wet bulb line (Xichun, Jianlei and Van Paassen, 2008; Brennan et al., 1976).

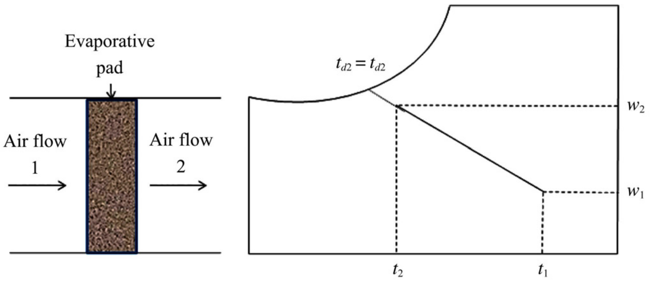

Figure 1 Illustration of evaporative cooling (Akton, 2009)

2 Materials and methods

2.1 The charcoal cooler

The charcoal cooler was constructed at Kikoo in Kibwezi district which is situated about 200 km. Figure 4 below shows the patterns during the day of the temperatures in the cooler, in the grading room and outside. Initially the temperature in the cooler was the lowest at about 26℃ whereas the shade temperature was the highest at about 28℃. The charcoal cooler temperature and the shade temperature increased gradually during the day by about 0.6℃ and 1.4℃ per hour, respectively. Figure 4 below shows the patterns during the day of the temperatures in the cooler, in the grading room and outside. The cooler was constructed as an attachment to an already existing horticultural produce grading house owned by Kikoo Small Scale Farmers Cooperative. The charcoal cooler (Figure 2) was basically a small room measuring 3.7 m long, 3.4 m wide and 2.4 m high with iron sheet (Gauge 32) roof, 100 mm thick charcoal wall based on optimal laboratory data, and sisal stem ceiling covered with 50 mm reeds. The reeds are commonly used for roofing in the rural areas of Kenya. The thickness used was based on the recommendation of the local artisans. The main structure was a timber frame supporting the walls, roof and ceiling. To form the wall, charcoal was held in place with a wire mesh supported by intermediate timber frames. The charcoal on the four sides of the wall was filled up to 100 mm below the roof. The upper space was left to allow natural air circulation.

The cooler had a door filled with charcoal which allowed entry into the grading room. The use of sisal stems (Figure 3a) and reeds which are readily available was aimed at minimizing heat gain from the iron sheets and moisture loss from the cooler. The cooler floor was made of concrete, which allowed easy cleaning and water drainage. Wooden shelves (Figure 3b) were put in the cooler and used as placement surfaces for the horticultural produce thus reducing contamination from the floor.

Three treatments of watering were tested. Watering was done once per day at 8:00 h, twice per day at 8:00 h and 12:00 h and three times per day at 8:00 h, 12:00 h and 14:00 h. When watering, it was ensured that the charcoal was completely wetted and that the water trenches were filled. The trenches minimized water loss as runoff and provided water to the charcoal at the bottom by capillary action. The open water surface also acted as a source for humidification of the cooler. The water supply was from a 5000 liter plastic tank raised 3.4 m and 1.0 m above the ground and charcoal cooler, respectively. Water feed was therefore by gravity allowing simultaneous wetting of the four charcoal cooler walls.

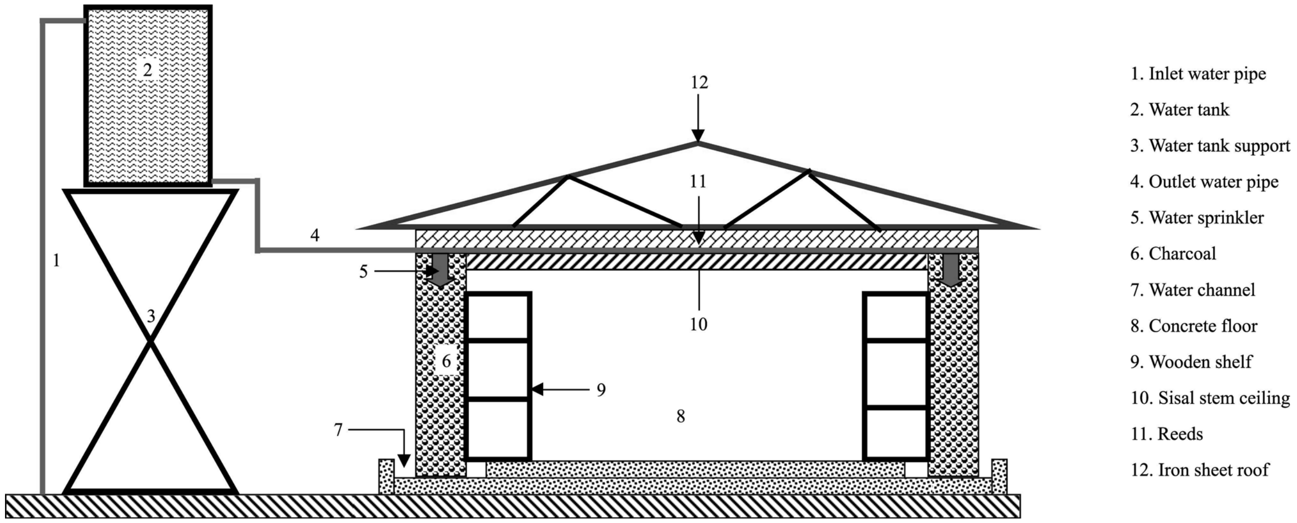

Figure 2 Sketch of the charcoal cooler and the water supply system

a. Cooler showing sisal stem ceiling

b. Cooler showing produce on shelves

Figure 3 Sections of the charcoal cooler

2.2 Temperature and humidity measurements

The temperature and humidity were measured using a digital in-out Thermal-hygrometer (BAA913HG, R&TTE Company, Germany). The measurements were done inside the charcoal cooler, grading room (Shade) and outside the structure, for measuring ambient temperature conditions. Temperature and relative humidity were measured at intervals of half an hour and one hour, respectively, between 8:00 and 14:00 h when most of the produce was picked by the agents. Data of temperature and relative humidity, combined with the time of measurement, were stored in a data logger. Measurements were also done without watering and with the reeds cover. The temperature and humidity data were used in the analyses of the different treatments.

3 Results and discussion

The ambient temperature, however, increased sharply from about 27℃ to about 32℃ between 8:00 h and at 10:00 h. The temperature then increased gradually over the test period to 29℃ in the cooler, 32℃ under shade and 34℃ under ambient conditions. The charcoal cooler temperature was lower than the shade and ambient temperature by about 2.5 and 5℃ respectively showing the charcoal ability to reduce temperature even without watering. There is no scientific explanation currently available on the cooling characteristic of charcoal without watering. However, this behavior may be attributed to the low porosity and poor thermal contactivity of charcoal resulting in low heat gain. The low porosity may also retain water for a long period of time thus contributing to the cooling effect. The minimum attained temperature in the cooler was however still above the recommended range of 0 - 10℃ for the most horticultural produce (FAO, 1986).

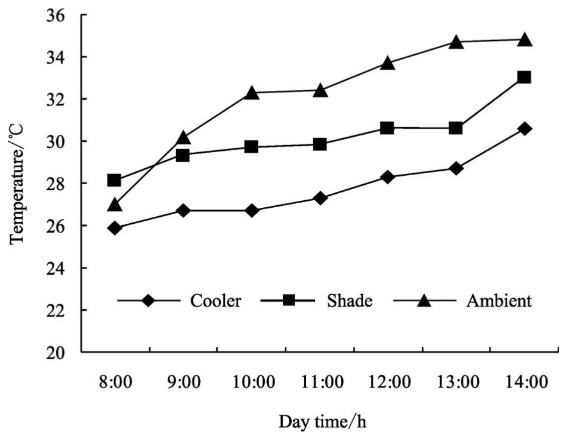

Figure 4 Variation of day time temperature without watering and reeds cover

The relative humidity showed a gradual decrease with time as shown in Figure 5. The cooler had however the highest humidity throughout the testing period starting at 49% whereas the ambient humidity was the lowest starting at 35%. The humidity difference was maintained at an average of 10% and 15% compared to shade and ambient condition, respectively. Therefore, the low temperature contributed to the high relative humidity in the cooler. Despite the increase in relative humidity resulting from the use of charcoal without watering, the attained humidity was far below the recommended range of 80 - 95 for most horticultural produce.

Figure 6 shows the temperature pattern during the day for single watering at 8:00 h. The temperature trend was similar to that for the cooler without watering, which showed a gradual increase for ambient, shade and cooler temperatures. There was also a gradual increase in temperature difference under ambient conditions while the cooler and shade attained a maximum temperature difference of 6.2℃. The initial ambient temperature was about 22℃ and increased gradually to a maximum of about 30℃. The cooler temperature was 3.3 and 1.2℃ below the ambient and shade temperatures, respectively. The lowest cooler temperature of about 24℃ was still far above the recommended range for horticultural produce.

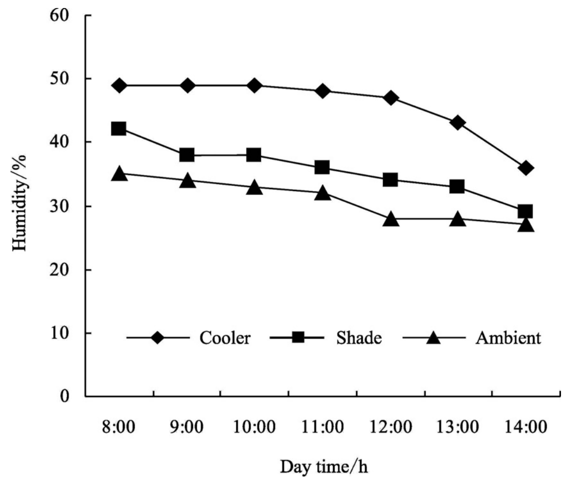

Figure 5 Variation of humidity with day time without watering

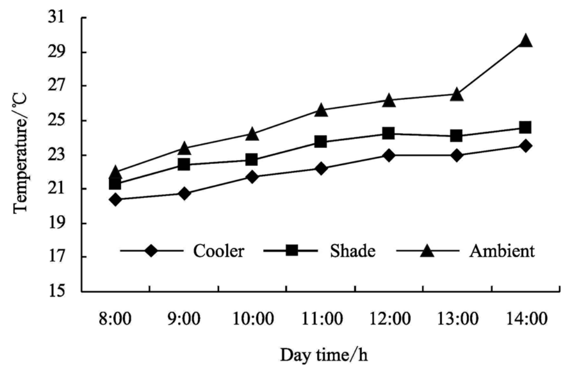

Figure 6 Temperature variation for single watering at 8:00 hour

The relative humidity for single watering decreased gradually with time, with the cooler showing the highest initial relative humidity of about 89% at 8:00 h and a humidity difference of about 7 and 15% above the shade and ambient humidity respectively (Figure 7). Thus watering improved the relative humity by about 5%. The lowest relative humdity attained in the cooler was about 71% compared to 49% for ambient conditions. The decrease in relative humidity with time showed that watering was necessary again after about every 3 hours if the relative humidity was to be maintained within the recommended range.

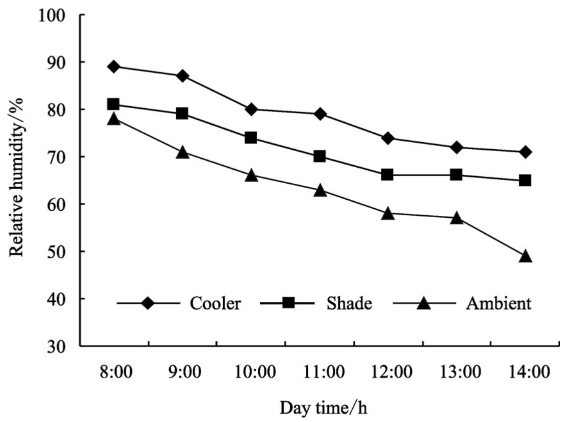

Figure 7 Relative humidity variation for single watering at 8:00 hour

Figure 8 shows the temperature variation for double watering where watering was done twice per day at 8:00 h and 12:00 h. The temperature generally increased with time from a minimum of about 24℃ in the cooler and grading shade and about 26℃ ambient. The grading shade temperature increased gradually, and attained a maximum temperature of about 31℃ equivalent to the ambient temperature at 14:00 h. The cooler temperature however increased to a maximum of about 27℃ at 12:00 h and then suddenly decreased when the charcoal was watered to a minimum of about 25℃ before rising again to a maximum of 26.6℃ at 13:00 h. The highest temperature reduction of about 7˚C was attained at 12:00 h after the second watering. The reduction did however not bring the cooler temperature close to the recommended range for horticultural produce.

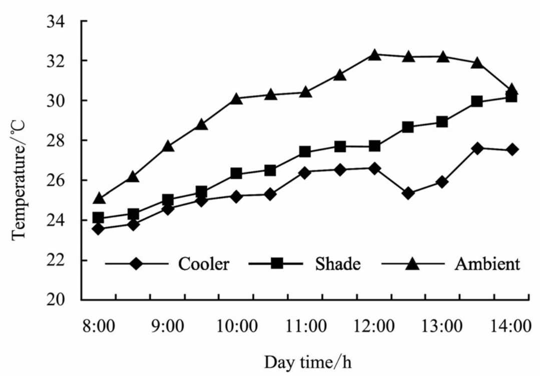

Figure 8 Temperature variation for double watering at 8:00 and 12:00

The relative humidity for double watering generally decreased with time from a maximum of about 79% in the cooler and about 76% in the grading shade and ambient (Figure 9). The cooler relative humidity showed a slight increase from about 65% at 12:00 when second watering was done to about 70% at 12:30 h before decreasing to a minimum of about 63% at 14:00 h. Despite the double watering, the cooler relative humidity remained below the recommended range for horticultural produce. This showed the need for more frequent watering especially at high ambient temperatures.

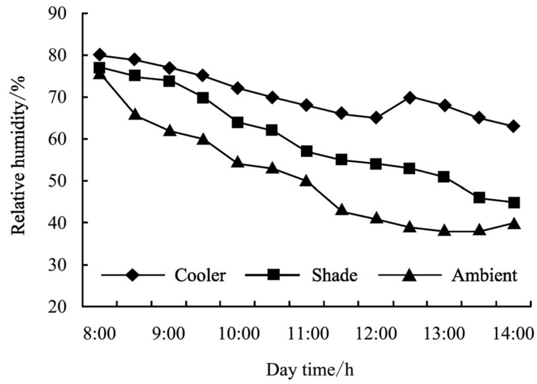

Figure 9 Relative humidity variation for double watering at 8:00 and 12:00 hours

The temperature pattern during the day for triple watering is shown in Figure 10. The cooler temperature increased at a lower rate compared to the ambient and grading shade temperatures reaching a maximum of about 24℃ at 12:00 h. At this point the cooler temperature difference with the grading shade and ambient temperatures were about 4 and 8℃, respectively. The cooler temperature reduced to a minimum of about 21℃ at 12:30 h after the second watering. This resulted in the highest temperature reduction of about 11℃ by the cooler. The cooler temperature then rose again gradually to a maximum of about 23℃ at 14:00 h when the third watering was done. The watering reduced the cooler temperature to a minimum of about 20℃ before rising again gradually to a maximum of 21℃ at 17:00 h. The maximum shade and ambient temperatures attained during the test were about 30 and 32.5℃ respectively. The overall average temperature reduction by the cooler was about 6.5℃ below the ambient condition. Although the cooler temperature was far below the ambient temperature, the lowest temperature in the cooler was above the recommended range for storage of horticultural produce.

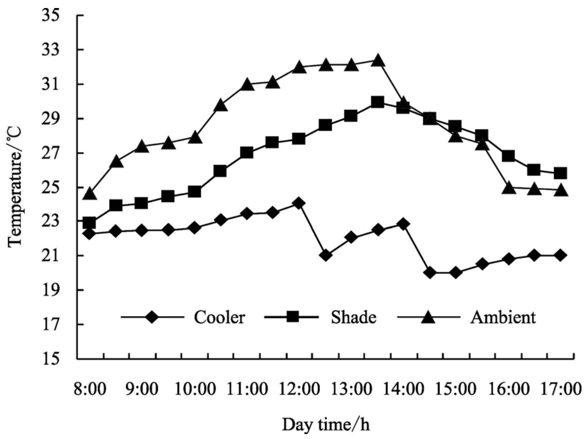

Figure 10 Temperature variation for triple watering at 8:00, 12:00 and 14:00 h

The initial relative humidity of the cooler, grading shade and ambient condition for triple watering were 86%, 81% and 73% respectively (Figure 11). The relative humidity generally decreased with time with the ambient and grading shade humidity reaching a minimum of 35% and 40% at 13:00 and 13:30 h respectively. The cooler relative humudity however reduced to a minimum of 70% at 12:00 h before increasing to a maximum of 87% at 13:00 h when the second watering was done. The relative humidity then dcreased again attaining the lowest value of 79% before increasing again to a maximum of 98% at 15:30, after the third watering at 14:00 h. The final relative humidity for the cooler, grading shade and ambient conditions at 17:00 h were 88%, 52% and 48.5% respectively. The results showed that water was

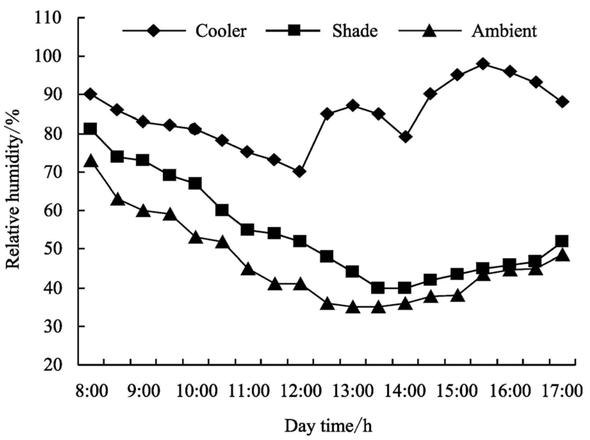

Figure 11 Relative humidity variation for triple watering at 8:00, 12:00 and 14:00 h

necessary to maintain the high relative humidity and watering interval of about two hours would be appropriate to maintain the relative humidity within the recommended range of 80% - 95% (Figure 9). The overall average relative humidity increased by the cooler was about 38% above the ambient condition.

4 Conclusions

The performance of a commercial scale charcoal cooler was evaluated using three daily watering schedules, once at 8:00 h, twice at 8:00 and 12:00 h and three times at 8:00, 12:00 and 14:00 h. The temperature and relative humidity in the cooler were measured and compared to those in the grading shade and the ambient condition. Single watering at 8:00 h showed minimal effect on the temperature and relative humidity. This can be attributed to the initial low ambient temperature and high relative humidity. However, double and triple watering showed a significant effect on the cooler temperature and relative humidity with triple watering showing the highest temperature reduction of 11℃ and relative humidity increase of 38%. The two-hour watering interval at 12:00 and 14:00 h kept the cooler temperature below 23℃ and the relative humidity above 80%. The two-hour watering interval throughout the day would be appropriate for controlling the temperature and relative humidity in the charcoal cooler. It was however noted that the cooler temperature remained far above the recommended range of 0 to 10℃ for the storage of the horticultural produce. Thus the main benefit of the charcoal cooler was on humidity increase with the reduction in the temperature helping to maintain the high relative humidity.

Acknowledgement

The authors wish to extend their appreciation to the International Foundation for Science (IFS) for sponsoring the research and the Jomo Kenyatta University of Agriculture and Technology (JKUAT) for facilitation of the project implementation.

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