Journal of Postharvest Technology
2018, **06**(3): 60-69
http://www.jpht.info

RESEARCH ARTICLE

Performance evaluation of an evaporative charcoal cooler and its effects on quality of leafy vegetables

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Received: 23.04.2018 Accepted: 15.06.2018

ABSTRACT

Preservation is a critical process used for handling fresh produce such as vegetables while maintaining their quality. This study focused on an evaporative cooling system for use by smallholder farmers. The technique was adopted for preservation of leafy vegetables based on its availability and affordability. The study aimed at evaluating the technical performance of an evaporative charcoal cooler and its effects on the quality of amaranth and spinach. The cooler microclimate and ambient conditions were investigated by measuring air temperature and relative humidity. The maximum cooling potential for the cooler was found to be 16.85°C while the maximum relative humidity difference between the cooler and outdoor conditions was found to be 38.07%. The charcoal cooler attained the highest relative humidity and the lowest temperatures. The analysis indicated that vitamin C, colour and weight of spinach and amaranth reduced with storage time. Based on a usable limit of 70% loss in moisture content, the shelf-life of amaranth was increased from two days in the control environment (outdoors) to seven days in the cooler, while that of spinach increased from three days to nine days. Overall, the charcoal cooler is beneficial in extending the shelf-life of leafy vegetables and preserving their quality.

Keywords: Amaranth, charcoal cooler, preservation, quality, spinach

Citation: Ronoh, E.R., Kanali, C.L., Ndirangu, S.N., Mang'oka, S.M., and John, A.W. 2018. Performance evaluation of an evaporative charcoal cooler and its effects on quality of leafy vegetables. *Journal of Postharvest Technology*, **6**(3): 60-69.

INTRODUCTION

Cooling is a process used to extend shelf-life of agricultural produce through slowing down of the respiration rate. The process is accompanied by an increase in the humidity within the storage room which minimizes moisture loss from the fresh produce (Wills et al., 2007). The stored produce hence takes a considerably longer time to deteriorate or undergo structural decay because of a reduced risk of microbial growth facilitated by lower temperatures and a higher relative humidity within the cold storage facility (Wills and Golding, 2016). Traditional vegetables have an advantage over exotic vegetables in that they are more drought and heat tolerant than exotic varieties such as kales, a commonly grown exotic vegetable. Spinach (*Spinaca olareceae*) and amaranth (*Amaranthus* sp.) are among the major food crops utilized as vegetables. Spinach and amaranth are common high moisture content leafy vegetables in Kenya. They are preferred due to their high vitamin C content, essential minerals and fiber required for healthy living. These vegetables being high in moisture content tend to spoil when stored under high temperatures as well as in places with low relative humidity (Liberty et al., 2013a). With all the nutritive benefits (Rubatzky and Yamaguchi, 2012), postharvest losses such as

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ISSN: 2348-4330

losses due to microbial activities, and losses due to poor storage facilities on the production units are still a big challenge to farmers especially during peak harvest season. Vegetables go bad or rot because of the damage caused by bacteria and mold, enzymatic processes or bruising. Microorganisms such as bacteria and molds release their own enzymes as they grow, speeding up the spoiling process brought about by structural decay. These enzymes occur naturally in live vegetables and are part of the natural aging process.

Storage compatibility should generally be taken into consideration. These challenges force farmers to sell their produce cheaply and thus minimize the returns from their investments. Enzymatic browning leads to discolouration and later spoilage. Bruising physically alters the exterior of vegetables which trigger enzymatic reactions (Barth, 2009). Appearance is almost always a good indicator of quality. During storage, cold temperatures are the best for slowing down respiration (Shanmugavelu, 1989). Cooling is one way that can help in increasing the shelf-life of such vegetables which in turn help in the realization of high returns (Lieberman, 1983). Modern preservation systems such as electric refrigerators depend on electricity. This kind of energy is costly. It is also unavailable in most of the remote areas making the use of such systems inappropriate. The use of simple systems like evaporative cooling system would help in solving preservation problems in such marginalized areas (Liberty et al., 2013b, Basediya et al., 2013).

Evaporative cooling is an innovative and environmental friendly air conditioning system that operates using induced processes of heat and mass transfer where water and air are working fluids (Camargo, 2007; Abdul-Rahaman et al., 2015; Omodara et al., 2016). Such a system provides an inexpensive, energy-efficient, environmentally benign (not requiring ozone-damaging gas as in active systems) and potentially attractive cooling system (Zahra and John, 1996). Evaporative charcoal coolers are used for all types of agricultural produce especially tropical fruits and vegetables. The charcoal-laden walls of the cooler provide an environment which is both lower than ambient temperature and at a higher level of relative humidity for storage of fresh agricultural produce. Due to the affordability and non-complexity nature of this cooling system, further studies are still needed to quantify their technical performance and effects on the quality of the produce such as fresh leafy vegetables. In addition, this zero energy cooling system could be used effectively for short-duration storage of fresh vegetables even in arid and semi-arid regions in Kenya and thus maintain the freshness of the produce. Hence, the objective of this study was to evaluate the performance of an evaporative charcoal cooler system and its effects on quality of leafy vegetables during storage.

MATERIALS AND METHODS

Experimental charcoal cooler

The schematic diagram of an evaporative charcoal cooler used in this study is as shown in Figure 1. The external dimensions of the developed cooler are 2.3 m long, 2.3 m wide, 2.5 m high (front side) and 2.2 m high (rear side). The roof has a slope of approximately 7.5°. The cooler room has charcoal-laden walls of 15 cm thickness held by weld and chicken wire meshes on the inner and outer sides. Charcoal (with thermal conductivity of 0.084 W/(mK) is used because it has a porous structure that can hold water, is affordable and easily available in many places in Kenya. The cooler has a timber door measuring 2 m by 0.7 m. The cooler was developed through modification of an existing cooler at the Agricultural and Biosystems Engineering Department, School of Biosystems and Environmental Engineering, Jomo Kenyatta University of Agriculture and Technology (JKUAT). JKUAT is located in Juja, Kiambu County and lies at a longitude of 37.05° E, latitude of 1.19° S and an altitude of 1550 m above sea level. The water dripping system was redesigned for better wetting of the charcoal-laden walls. The exposed padding spaces were also filled with more charcoal for proper cooling of the vegetables. Additionally, a water tank stand was fixed to securely retain the water tank for wetting charcoal-laden walls of the cooler. To mimic room conditions, an

adjacent shade served as a control for preservation of the leafy vegetables (amaranth and spinach) under outdoor conditions. The selected vegetables for the cooler evaluation (i.e. amaranth and spinach) were ready available from the university farm.

Figure 1: Evaporative charcoal cooler system at the measurement site

Red soil was sourced from the university farm to create a platform for extending the green roof atop the charcoal cooler. The red soil was preferred due to its availability at the experimental site and also fertility to enhance dense and intensive green roof cover. Timber and polythene bags were laid onto the roof area and soil was then neatly spread prior to planting the green plants on the roof. Leakage into the structure was minimized at the roof overlaps. The polythene was as well used as a remedy for conserving water. The green roof plants used were succulent in nature. The reason why green roof technology is used is that it has a tendency to use more energy from the inside conditions resulting in a cooler microclimate (Whittinghill and Rowe, 2012).

The design of the dripping system entailed establishing a water demand from the evaporative cooling system as well as the water required to maintain a healthy green roof. According to FAO (2002), Penman approach method was considered in the design process since it combined the principles of mass transfer and energy budget. The evaporation gives the water demand from the evaporative surface. The total amount of water required for the system was calculated by adding the evaporative and evapotranspiration water demands resulting to 173.38 liters/day. This required a 210 liters tank to satisfactorily supply the system. The water flow rate from the tank was calculated based on the water demand for a 12-hours day. The rate of flow of water from the tank into the system was set using a 12.7 mm multi-jet vane wheel dry type water flow meter (Zhejiang, China).

The incorporated water flow meter was utilized in monitoring and regulating the amount of water used to moisten the charcoal-laden walls of the cooler and hence provide the desired cooling effect on the stored vegetables.

Data acquisition and analysis

The conditions that were investigated included the microclimate inside the cooling system and the control conditions (ambient or outdoor conditions). The variables taken into account were the air temperature and relative humidity, and they were measured using a combined temperature and relative humidity HOBO sensor (model RX3000, USA). One sensor was placed approximately at the center of the cooling system to monitor the microclimate conditions, while the other sensor was placed under the shade to record the corresponding ambient or outdoor conditions (Figure 2). The data was collected by the sensors at intervals of five minutes throughout the testing period under loaded conditions.

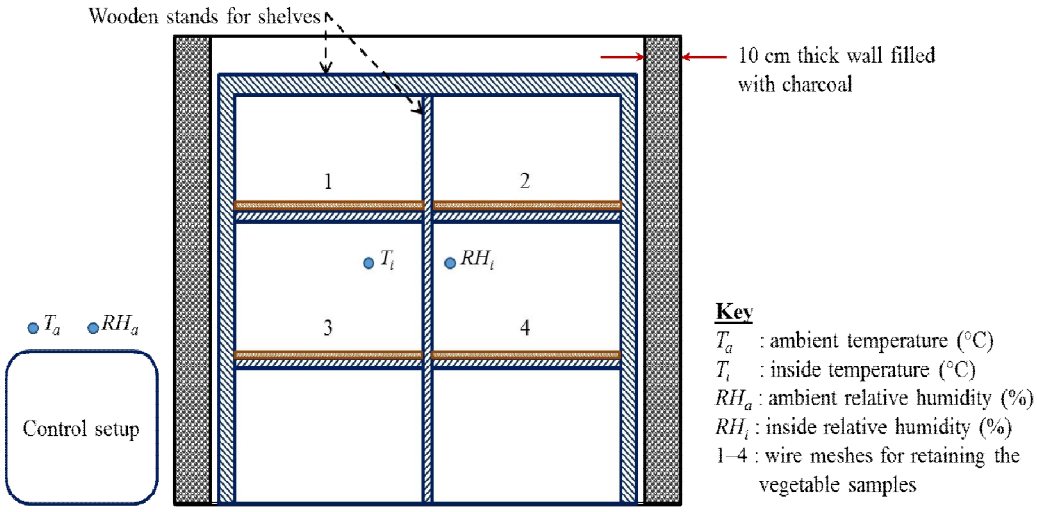

Figure 2: Schematic of components and key parameters in the charcoal cooler and outdoors.

Figure 3: Amaranth and spinach samples arranged on the shelves inside the charcoal cooler.

Loading the cooling system entails placing the leafy vegetables (amaranth and spinach) on the shelf compartments in the system (Figure 3). The data collected continuously for a period of time was then transferred from the data logger using HOBOware software. For data analysis purposes, the daily data was averaged to take care of the inconsistency within the performance evaluation. Analysis of variance (ANOVA) was performed to ascertain whether or not the use of the charcoal cooler had any significant effect on the microclimate conditions.

All measurements were conducted with three replications for each parameter considered in this study. Differences among treatments were evaluated using an ANOVA procedure in Microsoft Excel 2010. The Student's t-test was also used in conjunction with the ANOVA to determine the differences between means. Another key aspect used in interpreting the test statistics is the p-value.

Evaluation of colour, vitamin C and weight loss

The selected vegetables (amaranth and spinach) were also taken to the laboratory for colour and vitamin C content analysis. The Chromameter CR-200 colour meter (model 75043055, Japan) was used to determine the *L*, *a** and *b** values (Fairchild, 2013) of the leafy vegetables at different periods throughout the preservation period. The Chromameter was first standardized by obtaining a standard value for a white surface (Pathare, 2003). The *L* value in the model represents the lightness, with a range from 0 (black) to 100 (white). The *a** value denotes the greenness or redness where the value reduction tends from red to green (positive to negative values). The *b** value, on the other hand, denotes the blueness or yellowness of the sample where a higher value (positive value) represents yellowness. From the measured *L*, *a** and *b** values, the total color difference (Δ*E*), hue angle (*h*), Chroma (*C*), and saturation (*S*) values were obtained using the following formulas (Equations 1-4).

$$\Delta E = \sqrt{\left(L^2 + a^2 + b^2\right)} \quad (1)$$

$$h = \tan^{-1}\left(b/a\right) \quad (2)$$

$$C = \sqrt{\left(a^2 + b^2\right)} \quad (3)$$

$$S = C/L \quad (4)$$

For vitamin C content analysis, the vitamin C of the samples was obtained using a laboratory chemical (trichloroacetic acid, TCA). A 1 % TCA solution was prepared by dissolving 5.0 g of TCA in 500 mL ultra-pure water (Grindberg and Williams, 2010). Titration was done and the titre value converted into vitamin C amount in mg/100 g (Equation 5) as described in the vitamin C testing procedure (AOAC, 2010).

$$\text{Vitamin C} = \frac{titre - \left(blank \times c \times v\right)}{l \times s} \times 100 \quad (5)$$

where, *c* is the standardization value, *v* is the volume made, *l* is the aliquot made and *s* is the sample weight.

For the weight change, the vegetable samples were measured using the electronic weighing balance (model PB8001, Mettler Toledo, Switzerland). The weight data was then analyzed to determine the average weight loss. From the literature, the usable limit was established as 70% loss in the moisture content (Lu et al., 2010). Usability is a limit or rather the amount of moisture loss from the stored vegetables beyond which the vegetable is considered unfit for human consumption. It means that the

vegetables have lost most or all of their nutritive capacities as well as have undergone structural decay. The statistical analyses were performed to determine the effect of the charcoal cooler microclimate conditions on colour, vitamin C content and weight loss of cooled spinach and amaranth during the preservation period.

RESULTS AND DISCUSSION

A variation of air temperature and relative humidity in the charcoal cooler and outdoors (as control) is presented in Figure 4. The charcoal cooler registered the lowest temperatures and the highest relative humidity throughout the measurement period. On average, the maximum cooling potential for the cooling system was 16.85°C and the maximum relative humidity difference was obtained as 38.07%. There were generally significant differences ($p < 0.05$) between the cooler temperature and relative humidity values and the respective values under control (outdoor) conditions. The greater the temperature difference, the greater the evaporative cooling effect (Mehere et al., 2014). The evaporative cooler efficiency generally depends on the humidity of the surrounding air. The evaporative-cooled storage structures work on the principle of adiabatic cooling caused by evaporation of water, made to drip over the charcoal walls. The water flow rate of 0.25 liters/second was sufficient to adequately wet the charcoal and provide a favourable cooling microclimate inside the cooler. The water evaporates into the air raising its humidity and at the same time reducing the temperature of the air.

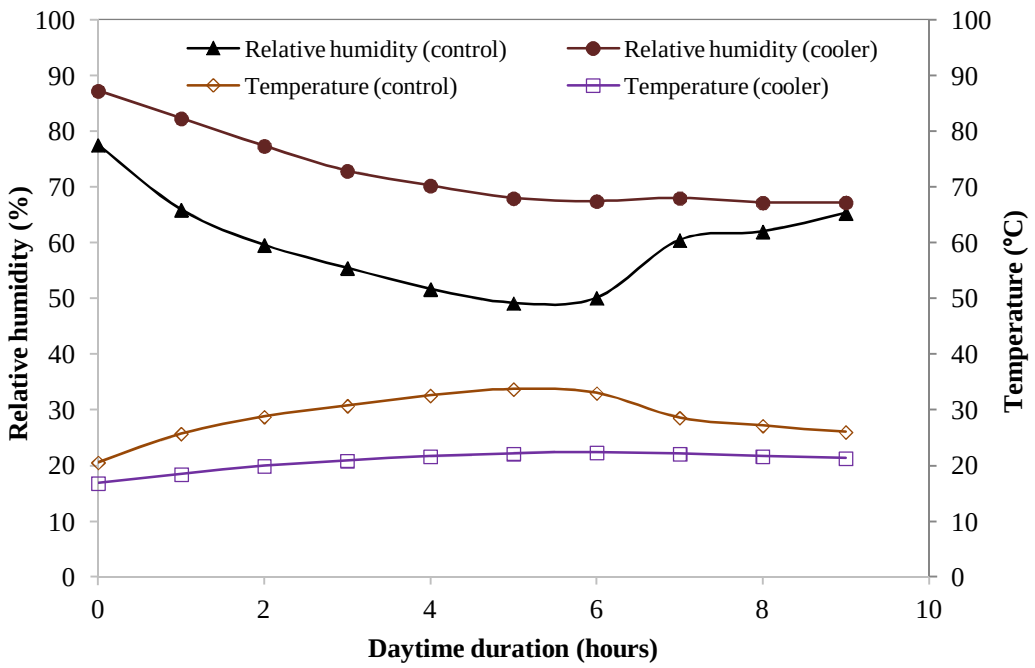

Figure 4: Variation of relative humidity and temperature of air in the cooler and outdoors.

The variation of vitamin C with time during preservation of spinach and amaranth under cooler and outdoor (control) conditions is shown in Figure 5. Vitamin C is one of the most important nutritional quality factors in many agricultural crops. The significant determinant of vitamin C content is how food is stored and prepared. As seen in the figure, the amount of vitamin C content in the preserved produce decreased with increase in time. This can be attributed to the fact that vitamin C is easily oxidized and thus the fact that as the produce was being cooled, the vitamin C was oxidized. The initial vitamin C content of amaranth was found to be 6 mg/100 g, while that of spinach was 17 mg/100 g. For both vegetables, there was a faster

reduction of vitamin C for outdoor conditions compared to the charcoal cooler conditions. Tosun and Yücecan (2008) reported a similar observation on vitamin C decline as influenced by freezing and storage of some vegetables.

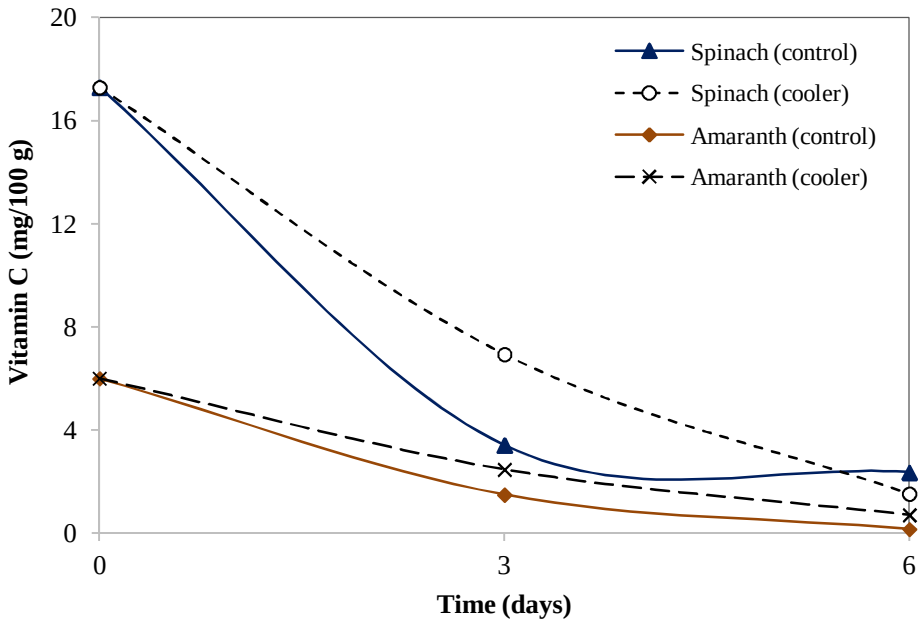

Figure 5: Variation of vitamin C of spinach and amaranth preserved under outdoor and cooler conditions.

Based on the measured *L*, *a** and *b** values, other derived colour parameters of amaranth and spinach are presented in Table 1. These derived parameters included total colour difference (Δ*E*), hue angle (*h*), Chroma (*C*) and saturation (*S*). From the tabulated results, a consistent trend of the parameters is noticeable for both amaranth and spinach. The *h* values, for instance, showed a declining trend for both amaranth and spinach. The decrease in *h* values indicates more browning, with a distinct effect on spinach under outdoor conditions. In the cooler, there was more browning (low *h* values) in amaranth compared to spinach. The Δ*E* values apparently decreased in amaranth but increased in spinach, especially between 0 and 3 days of storage. The *C* and *S* values increased between 0 and 3 days of storage. Thereafter, there was a slight reduction of *C* and S after 6 days. Despite the slight variations in the noted parameters, there were no significant differences ($p > 0.05$) between the cooler and outdoor conditions in terms of the derived colour parameters.

Table 1: Colour parameters of amaranth and spinach preserved outdoors and in the cooler

		Control (outdoors)				Charcoal cooler			
Vegetable	**Day**	**Δ*E***	***h***	***C***	***S***	**Δ*E***	***h***	***C***	***S***
Amaranth	0	52.88	-58.52	18.96	0.38	52.88	-58.52	18.96	0.38
	3	49.50	-61.37	20.24	0.45	46.29	-64.11	20.48	0.49
	6	48.67	-68.44	19.78	0.44	49.47	-72.47	22.21	0.50
Spinach	0	44.40	-53.83	20.28	0.51	44.40	-53.83	20.28	0.51
	3	54.88	-60.62	26.36	0.55	50.28	-56.33	23.95	0.54
	6	52.23	-71.30	24.11	0.52	48.73	-60.21	23.60	0.55

Note: Insignificant differences (p > 0.05) in ΔE, h, C and S between outdoor and cooler conditions.

The weight change was monitored during the measurement period and the cumulative weight loss was used to determine the shelf-life of the vegetables. From this study, the control environment (outdoor conditions) allowed for about two and three days of usability of amaranth and spinach, respectively (Figure 6). After 3 days, the weight loss for amaranth and spinach kept under outdoor conditions (control) was 257% and 43% more than charcoal cooler conditions, respectively. This clearly indicates that the weight loss of both vegetables stored inside the cooler was lower than those stored outside the chamber. The evaporative cooler microclimate increased the shelf-life to eight and nine days for the amaranth and spinach, respectively. This is in agreement with the findings by Basediya et al. (2013) that fresh horticultural produce (such as vegetables) should generally be stored at lower temperatures because of their highly perishable nature. The lengthening of the shelf-life is thus adequate for ensuring that vegetables take a significantly longer time before they go bad. The value addition process is essential to ensure marketability of the vegetables and ensure that the vegetable is available to the consumer for a longer period of time. It is then justifiable that the cooler microclimate helps in enhancing preservation of leafy vegetables.

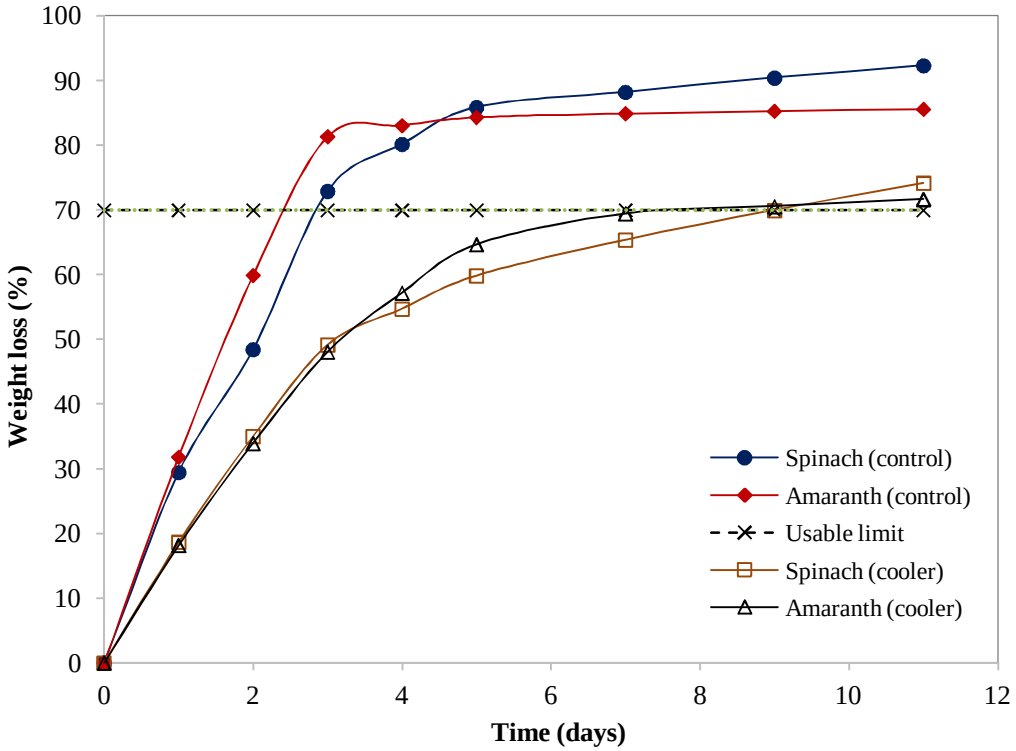

Figure 6: Variation of weight loss of spinach and amaranth under outdoor and cooler conditions.

The modification of the microclimate by use of the evaporative and evapotranspirative cooling principles helps attain the microclimate conditions favourable for longer storage periods. With reference to the developed charcoal cooler in this study, the modified environment helped in reducing respiration and metabolic rates in the stored vegetables. The high relative humidity and low temperatures in the evaporative cooling system discouraged microorganism action on the selected vegetables (amaranth and spinach) leading to a lengthened shelf-life (Wills and Golding, 2016). For the case of the control environment (outdoor conditions), the relative humidity is significantly lower than the cooler's microclimate and the outdoor temperature is also high. The outdoor conditions provide an optimum environment for microorganisms' respiration and metabolism of the leafy vegetables (Ndukvu and Manuwa, 2015). Hence, the vegetable is subject to a hastened structural decay as compared to the vegetables stored in the evaporative cooling system. Generally, preservation is based on lowering

the system's temperature and maintaining a relatively high humidity (Liberty et al., 2013a). It is aimed to not only extend the shelf-life but also preserve the quality of the vegetable, thereby reducing postharvest losses associated with storage (Wills and Golding, 2016; Rayaguru et al., 2010).

CONCLUSION

The findings of this study indicated that the drier the control environment (outdoor conditions), the higher the cooling potential. Climatic parameters such as air temperature and relative humidity had an impact on the microclimate inside the evaporative charcoal cooler. The measured parameters varied due to seasonality brought in by climatic aspects and the earth's revolution. The maximum cooling potential for the cooling system was found to be 16.85°C, while the maximum relative humidity difference was found to be 38.07%. The vitamin C content was found to reduce with storage time. The change in vitamin C content for the control environment was higher than that of the cooling system microclimate. The total colour difference and the hue angle for both samples were found to reduce with storage time. The Chroma and saturation values for both samples increased with time of storage. The usable limit for the crops was evaluated based on the percentage moisture loss throughout the storage period. The usable limit from the literature was estimated at 70% in moisture content loss. With respect to this limit, the charcoal cooler was found to increase the shelf-life of amaranth from two days to seven days, and that of spinach from three days to nine days. Hence, the cooler is beneficial in reducing postharvest losses associated with their storage. Based on the study findings, automation of the dripping system is further recommended. This is to allow uniformity in the water distribution throughout the charcoal padding. The automation that incorporates sensors for determining the water demand for the system would be ideal in that it opens to supply the required amount of water to the padding before it closes. Overall, evaporative cooling system has a very large potential to propitiate thermal comfort during storage of fresh horticultural produce in Kenya.

ACKNOWLEDGMENTS

The authors would like to thank the Department of Agricultural and Biosystems Engineering (JKUAT) for the material and financial support extended to this study. The support received from Renewable Energy for Food (RE4Food) project (EP/L002531/1) during the study period is also highly acknowledged.

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