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Effectiveness of an evaporative charcoal cooler for the postharvest preservation of tomatoes and kales

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Abstract: The preservation of fresh produce can provide rural households with better diets all-year round and income by reducing their deterioration. Promotion of low-cost temporary storage technologies requires evidence of their effectiveness to attain conducive conditions. Therefore, this study was conducted to assess the effectiveness of an evaporative charcoal cooler for the preservation of tomatoes and kales. The cooler microclimate and outdoor conditions were investigated by measuring the air temperature and relative humidity. During the study period, the maximum temperature difference between the cooler and the outdoors was found to be 9.2 °C while the maximum relative humidity difference was 36.8%. Due to the presence of light rain and, consequently, low solar radiation, the temperature and relative humidity differences were significantly reduced. Despite the light rain, the cooler still registered a maximum relative humidity of 83.5% and a maximum cooling efficiency of 91.5%. Overall, the cooler demonstrated promising results in terms of favourable microclimate conditions, the shelf-life and colour changes for tomatoes and kales.

Keywords: cooling; efficiency; fresh produce; quality; storage

A cooling process ensures that a low temperature is maintained during the postharvest handling which is critical for the preservation of perishable commodities and the reduction of postharvest losses. The low cooler temperature is accompanied by an increase in the relative humidity within the storage room which minimises the moisture loss from the fresh produce (Ambuko et al. 2017). The stored produce, hence, takes a considerably longer time to deteriorate or undergo structural decay because of the reduced risk of microbial growth facilitated by the lower temperatures and higher relative humidity within the cold storage facility (Wills, Golding 2016). The increasing interest in fresh produce (such as fruits and vegetables) over the last decade can be attributed to the increased consumer awareness about their health benefits. Fresh produce deteriorates very rapidly after harvest and, therefore, require proper postharvest handling to preserve its quality. Tomatoes (*Lycopersicon esculentum* Mill.) and kales (*Brassica oleracea* var *acephala* Dc.) are common crops predominantly grown, widely consumed and sold by smallholder farmers in Kenya. This is majorly important because of their relative contribution to the human diet, human health and national economy (Tigist et al. 2013; Manyozo et al. 2018). A lack of knowledge on the appropriate quality preservation practices and technologies can result in high qualitative and quantitative losses in such fresh produce. High postharvest losses (upwards of 50%), especially in vegetables, are attributed to various biological and environmental factors (Ambuko et al. 2017). Microorganisms such as bacteria and moulds

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release their own enzymes as they grow, speeding up the spoiling process brought about by the structural decay. These enzymes occur naturally in live vegetables and are part of the natural aging process.

Cold storage ensures that low temperatures are attained which are best suited for slowing down or controlling the rate of respiration, transpiration, ripening and biochemical changes, all of which are responsible for the deterioration of the produce. Modern preservation systems such as electric refrigerators depend on electricity. However, this kind of energy is costly and unavailable in most of the remote areas making the use of such systems inappropriate. Evaporative cooling technologies do not require any mechanical or electrical energy input to operate and are, therefore, appropriate for smallholder farmers in rural areas without electricity (Ambuko et al. 2017). Additionally, the chambers can be constructed from locally available materials using unskilled labour, thereby making the cost affordable for the resource-poor smallholder farmers (Liberty et al. 2013). Evaporative cooling units are, thus, suitable for application in most rural areas in Kenya in order to minimise the risk of spoilage of fruits and vegetables at collection points and on a retail level.

Due to the affordability and non-complex nature of this cooling system, further studies are still needed to critically assess the system performance in terms of microclimate conditioning and the possible effects on the quality of the produce being stored. Hence, the objective of this study was to assess the effectiveness of an evaporative charcoal cooler for the preservation of tomatoes and kales.

MATERIALS AND METHODS

Description of the evaporative charcoal cooler. The evaporative cooling facility used in this study (Figure 1) consists of a charcoal cooler, a preparation area and an office. The charcoal cooler measured 4 m long, 4 m wide and 2.5 m high. Based on these dimensions, the total volume of the cold storage space, inclusive of the gangway (approximately 5 m^3), is 40 m^3. A room of this size can store fresh produce for up to 14 days. The cooler was filled with charcoal (15 cm thick) held by welds and chicken wire meshes at the inner and outer sides. The wire meshes were fastened tightly so that the walls maintained the shape and hence could not bulge when filled with charcoal. While filling the walls with charcoal, care

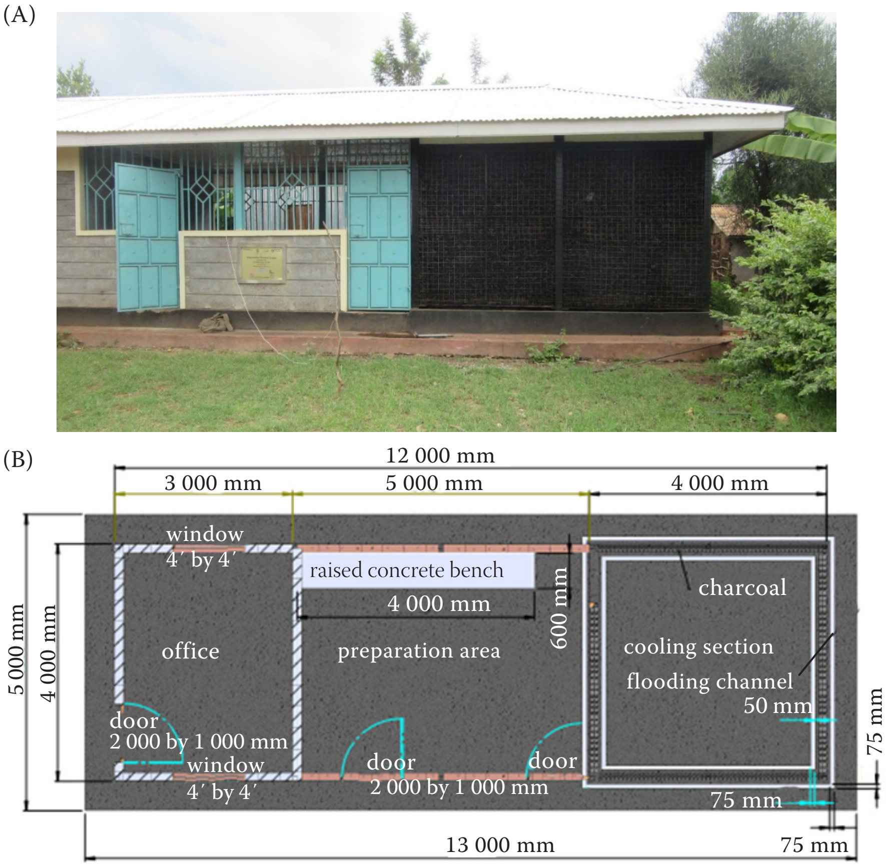

Figure 1. The evaporative charcoal cooler system: (A) developed cooler, (B) ground plan

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was exercised to avoid compressing or packing down the charcoal since this can reduce the air movement across the wall. Such small openings within the charcoal-laden walls ensured adequate air circulation (natural ventilation) in the evaporative cooler.

Charcoal (thermal conductivity of 0.084 $W \cdot mK^{-1}$) was used because of its porous structure that can hold water, its affordability and availability in many places in Kenya. Since air circulation is necessary in the fruit and vegetable industry, a vented plastic crate (0.578 m long, 0.385 m wide and 0.21 m high) was adopted since it improves the shelf-life of the produce, thus enhancing the fresh delivery to the market. A perforated water drip pipe (20 mm in diameter) was fastened above the charcoal walls and this allowed water to flow downwards from a 1 000 L water tank raised at 2.5 m above the ground. The charcoal was drenched with water three times a day. To improve its durability and provide adequate reinforcement, the cooler walls were built with square steel bars with a roof like other buildings. In the design, a preparation area (20 m^2) helped in sorting of the produce prior to storage, while an office (12 m^2) was also utilised in keeping records of the cooling facility (Kanali et al. 2017). The study site (Kimicha, Kirinyaga County) lies at 0.594 "S 37.294 "E, latitude and an altitude of 1 258 m a.s.l.

Data acquisition and analysis. The microclimate conditions (air temperature and relative humidity) were measured inside the cooler, in the preparation area and outdoors (control) using type K thermocouples. The data was relayed to a digital 10-channel data logger (GL200 midi Logger, Graphtec, China). The parameters were counter-checked using a thermo-hygrometer (HN-AK Chino, Japan). The radiation was monitored using a photosynthetically active radiation (PAR) sensor (Onset HOBO, Japan) and the readings were converted to $W \cdot m^{-2}$ using a factor of 2.2 based on findings from earlier studies (Pashiardis et al. 2017; Ren et al. 2018). The data were collected by the respective sensors (three sensors per parameter) at intervals of one hour throughout the testing period (November 2017) under loaded conditions and utilised to compute the hourly means.

Loading the cooling system entailed placing the fresh produce (tomatoes and kales) in plastic crates inside the cooler. Freshly harvested tomatoes and kales were locally sourced from farmers of the Mitooini Irrigation Phase II Cooperative Society (Kanali et al. 2017). In the cooler, the samples were placed on the upper and lower trays inside the cooler. The lower and upper trays were located at 0.2 m (height of one plastic crate) and 1.4 m (height of seven crates) above the ground surface and the horizontal spacing between the two trays was 0.96 m. For comparison purposes, samples were also placed in the preparation area and outdoors under some shade. An ANOVA was performed to ascertain whether or not the use of the charcoal cooler had any significant influence on the microclimate conditions.

The cooling efficiency is defined as the ratio of the actual dry-bulb temperature reduction to the theoretical maximum at 100% saturation (ASHRAE 1997). According to Von Zabeltitz (2011), the cooling efficiency can be simplified as shown in Equation (1). In the equation, $\eta_{cooling}$ is the cooling efficiency (%), T_a is the outside air temperature (°C), T_i is the inside air temperature just behind the pad (°C) and T_{wb} is the wet-bulb air temperature of the outside air (°C). T_{wb} was determined from the known T_a (dry-bulb value) and the relative humidity of the outside air (RH_a) using an ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) psychrometric chart and this was further verified using the available psychrometric calculator approved by ASHRAE (Herrmann et al. 2011).

$$\eta_{cooling} = \left(\frac{T_a - T_i}{T_a - T_{wb}} \right) \times 100 \quad (1)$$

Evaluation of colour and weight changes. During the experiment, the colour and weight changes of the selected produce (tomatoes and kales) were continuously monitored in order to evaluate any potential quality effects. A Chromameter CR-200 colour meter (model 75043055, Minolta, Japan) was used to determine the *L*, *a** and *b** values of the produce at different periods throughout the preservation period. The chromameter was first standardised by obtaining a standard value for a white surface. 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 to be 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 colour difference (ΔE), hue angle (h), chroma (C), and saturation (S) values were obtained using Equations (2 to 5). In the Equation (2), ΔE is the total colour difference (–), L is

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the lightness index (–), a is the greenness or redness index (–), b is the blueness or yellowness index (–), h is the hue angle (degrees), C is the chroma (–) and S is the saturation (–).

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

$$h = \tan^{-1}\left(\frac{b}{a}\right) \quad (3)$$

$$C = \sqrt{\left(a^2 + b^2\right)} \quad (4)$$

$$S = \frac{C}{L} \quad (5)$$

For the weight change, the labelled tomato and kale samples were weighed using an electronic weighing balance (model PB8001, Mettler Toledo, Switzerland). The weight data (initial weight and weight after storage) were then analysed to determine the average percentage weight loss (Manyozo et al. 2018). The statistical analyses were performed to determine the effect of the microclimate conditions on the colour and weight changes of the tomatoes and kales during the storage. All the measurements were conducted with three replications for each parameter. The differences among treatments were evaluated using an ANOVA procedure in Microsoft Excel (version 2016).

RESULTS AND DISCUSSION

The charcoal cooler registered lower air temperature and higher relative humidity values throughout the measurement period compared to the preparation area and outdoors. The maximum temperature difference between the cooler and the outdoors was found to be 9.2 °C while the maximum relative humidity difference was 36.8%. The low temperature difference on the second day, as compared to the first day, was due to light rain showers during the day and, consequently, the low solar radiation. This shows that the solar radiation has a direct influence on the air temperature. This behaviour clearly shows that a rainy or cold season does not favour the utilisation of an evaporative charcoal cooling facility. Generally, the greater the temperature difference, the greater the evaporative cooling effect (Mehere et al. 2014). The highest value of the relative humidity inside the cooler was 83.5%, with significant differences ($P < 0.05$) in the relative humidity noted between the outdoors and inside the cooler. The behaviour of the relative humidity is in agreement with an observation by Manyozo et al. (2018). The evaporative cooler efficiency generally depends on the humidity of the surrounding air. Evaporative-cooled storage structures work on the principle of adiabatic cooling caused by the evaporation of water, made to drip over the charcoal walls. In the cooler, water evaporates into the air raising its humidity and at the same time reducing the temperature of the air (Ronoh et al. 2018).

The variation in the cooling efficiency as a function of the temperature difference is presented in Figure 2. It can be seen from the figure that the cooling efficiency increased with an increase in temperature difference. A maximum cooling efficiency of 91.5% was attained at a high temperature difference of 9 °C. At a low outside air temperature, the interior cooled temperature is marginally lowered and, hence, has a small temperature drop. It implies, therefore, that a higher evaporative efficiency has the potential to significantly increase the cooling capacity of the cooler. The trend is in agreement with the relation depicted in Equation 1, which relates the cooling efficiency as a function of the air temperature parameters (i.e., the outside air temperature T_a, inside air temperature just behind the pad T_i and wet-bulb air temperature of the outside air T_{wb}). The direct relationship between the cooling efficiency and the temperature difference for an evaporative cooling system has been similarly reported by Basediya et al. (2013). A properly designed cooler with a good cooling pad (such as

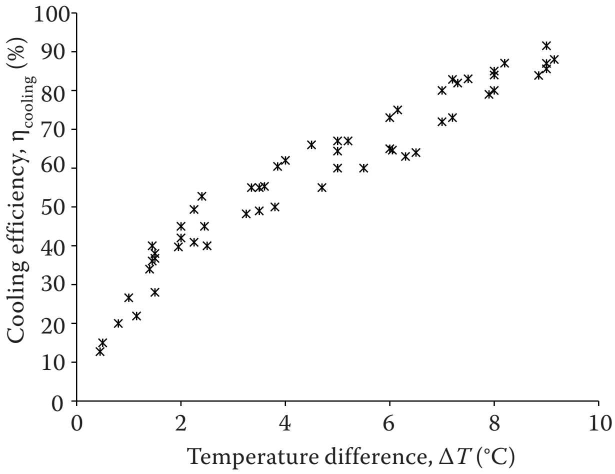

Figure 2. The variation in the cooling efficiency with the temperature differences

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charcoal) coupled with favourable ambient conditions can improve and maintain the cooling efficiency (Ahmed et al. 2011).

The changes in the derived colour parameters and weight of the tomatoes and kales stored in the cooler and outdoors for 48 h are presented in Table 1. The derived parameters included the total colour difference (Δ*E*), hue angle (*h*), Chroma (*C*) and saturation (*S*). From the results, the cooler registered the lowest values of the four derived parameters (Δ*E*, *h*, *C* and *S*) compared to the outdoors particularly for kales. For tomatoes, the Δ*E* and *C* values were lower in the cooler compared to the outdoors. However, the *h* and *S* of the stored tomatoes were higher in the cooler than the outdoors. The decrease in the *h* values indicates more browning, with a distinctive effect on the tomatoes under the outdoor conditions. In the cooler, there was more browning (low *h* values) in the kales compared to the outdoors. The low Δ*E* values for both the tomatoes and kales preserved in the cooler imply less shrinkage compared to the outdoors (Ronoh et al. 2018). Despite the slight variations in the noted parameters, there was a pronounced significant difference ($P < 0.05$) between the cooler and outdoor conditions in terms of the *h* value of the tomatoes stored in the cooler and outdoors. Overall, the colour changes are one of the indications of the physicochemical developmental stages in the preservation of a fresh horticultural produce (Tigist et al. 2013).

After 48 h, the weight loss of the kales inside the cooler and outdoors was 9.8% and 44.0%, respectively. The corresponding weight loss values for the tomatoes were 6.2% and 16.2%, respectively. This implies that the evaporative cooler microclimate increased the shelf-life of the selected produce. This is in agreement with the findings by Basediya et al. (2013) that fresh horticultural produce should generally be stored at lower temperatures because of their highly perishable nature. Generally, the weight loss for both the tomatoes and kales was less than 10%. As expected, a higher weight loss in the tomatoes and kales was experienced under the outdoor conditions, with a more pronounced effect on the kales compared to the tomatoes. The lengthening of the shelf-life is adequate for ensuring that the produce takes a significantly longer time before it goes bad (Basediya et al. 2013; Manyozo et al. 2018; Ronoh et al. 2018). The high relative humidity and low temperatures in the evaporative cooling system discouraged microorganism actions on the selected produce (tomatoes and kales) leading to a lengthened shelf-life (Wills, Golding 2016). The outdoor conditions, on the other hand, provided an optimum environment for the microorganisms' respiration and metabolism of the fresh produce (Ndukvu, Manuwa 2015). In this way, the produce is subjected to a hastened structural decay when compared to that stored in the evaporative cooler. It means then that, under the outdoor conditions, the produce will lose most or all of their nutritive capacities and, hence, negatively affect their marketability. Generally, preservation is based on lowering the system's temperature and maintaining a relatively high humidity (Liberty et al. 2013; Ronoh et al. 2018). It is aimed to not only extending the shelf-life, but also preserving the quality of the vegetable, thereby reducing the postharvest losses associated with storage (Wills, Golding 2016).

CONCLUSION

The use of simple and efficient evaporative charcoal coolers can be a viable solution in the preservation of fresh produce (such as tomatoes and kales), thereby encouraging smallholder farmers to be involved in a sustainable value addition for enhancing food security.

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Table 1. The changes in the colour attributes and weight of the tomatoes and kales during the storage

Produce	Storage	Change in colour attributes (%)				Weight change (%)
		Δ*E*	*h*	*C*	*S*	
Tomatoes	cooler	1.07	19.96	11.20	20.62	–6.2
	outdoors	5.54	4.28	12.26	16.86	–16.2
Kales	cooler	8.27	10.80	15.57	10.82	–9.8
	outdoors	16.75	24.94	32.87	26.92	–44.0

Δ*E* – total colour difference; *h* – hue angle; *C* – chroma; *S* – saturation

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