Evaluation of fresh and fleshy cucumber quality and shelf-life using charcoal cooler bin in the tropics

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Abstract: Adiabatic evaporative cooling is a concept and process adopted for extending the shelf-life of fresh fruits and vegetables while Cucumber (Cucumis sativus L.) is an economically important vegetable worldwide. Cucumber is highly perishable; its quality must be maintained throughout its postharvest life, from the farm to the market, and to the consumer reduces postharvest losses. More cost effective techniques have to be employed to reduce postharvest losses and to extend the shelf life of fruits and vegetables in the topics. Therefore, the purpose of this study was to evaluate charcoal cooler bin (CCB) performance, and its effects on the quality and shelf-life of cucumbers. The storage microclimate and ambient conditions were measured using a data logger; CCB (12 ℃, 85%), open-air (30 ℃, 78%), refrigerator (10 ℃, 85%), and laboratory (25 ℃, 78%) as the air temperature and relative humidity respectively. By monitoring the physiological, quality parameters, and the effects of the storage media on the storability of cucumber fruits, the effectiveness of the CCB for fresh cucumber preservation through percentage mass loss, visual quality, degree of shrivelling, colour changes and life of expectancy were evaluated. The CCB markedly maintained the freshness, extended the shelf-life, and reduced mass loss of cucumbers fruits at the stated environmental conditions after the 14-day storage period; having a mass loss of 3.4696% relative to cucumber samples stored in the refrigerator, laboratory, and open-air conditions with 8.4176%, 9.8260%, and 11.2696% losses respectively. Therefore, CCB as an inexpensive passive storage system can be reliably used as a medium for sustainably reducing postharvest losses.

Keywords: charcoal cooler bin, cucumber**,** shelf-life, quality, evaporative cooling system

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1 Introduction

Cucumber (*Cucumis sativus L*.) fruit is considered a good source of minerals (e.g., Na, Mg, K, Ca, S, Si, and Fe), vitamins (e.g., thiamin, riboflavin, vitamin C, and niacin), antioxidants, carbohydrates, protein, and dietary fibers (Mostafa et al., 2021; Xylia et al., 2022), hence, its importance all over the world today. Cucumbers contain an appreciable amount of antioxidant properties, vitamins, minerals, and macronutrients which are required for the proper functioning of the body (Aderinola and Abaire, 2019). Due to their social, economic, medicinal, and nutritional values, they are consumed in several ways in all cultures. Fruits and vegetables should be consumed fresh for maximum usefulness to optimally exploit these nutritional values including flavonoids, beta carotene, lignans and triterpenes which act as antioxidants and anti-

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inflammatory agents (Okwori et al., 2017). It has been shown that risks of mineral and vitamin deficiencies, cancer, and other chronic illnesses could be decreased with increased consumption of vegetables such as cucumber (Jahan et al., 2020). Fruits and vegetables are generally regarded as essential herbaceous plants with high moisture content in their fleshy forms (Mogaji and Fapetu, 2011). Cucumber has been reported to have a short shelf life of below 14 days which is usually terminated by chilling injuries, loss of firmness, color, and water content which could occur with or without fungal and bacterial rot (İbrahim and Serhat, 2019). Based on the required values and freshness for cucumber consumption, it is essential to study various ways to maintain the quality and freshness of cucumbers after harvest to the point of consumption. Physiological changes occur due to storage of cucumbers enabling microorganisms' development; this makes them more susceptible to postharvest diseases leading to deterioration (Wenneker and Thomma, 2020). The appropriate techniques and technology suitable for rural, small to medium scale farmers, and fruits and vegetable dealers is the evaporative cooling storage system such as charcoal cooler bin. Charcoal cooler bin technology is known and used to avert post-harvest losses and deterioration. Knowledge of the relationship between temperature and relative humidity of the air in and out of the storage structure vis a vis evaporation is required in a passive system condition. The evaporative processes of charcoal cooler bins can be applied in the storage and preservation of all types of agricultural produce, mainly tropical fruits and vegetables. According to Ronoh et al. (2018), the evaporative cooling process is used to extend the shelf-life of agricultural produce by slowing down the rate of respiration. The stored produce tends to take a considerably longer time for deterioration to be evident 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). Simple systems like evaporative cooling systems (e.g. charcoal cooler bin) would help solve preservation problems in marginalized areas (Liberty et al., 2013; Ronoh et al., 2018). This study tends to proffer solutions for postharvest handling of fleshy and fresh cucumbers to extend the shelf life as well as reduce the rate of deterioration of the fresh and fleshy fruits after harvesting. The objective of this study was to evaluate the quality and shelf-life of tropical cucumbers stored in charcoal cooler bin based on physical, chemical and physiological changes in cucumbers during storage.

2 Materials and methods

2.1 Samples preparation

The cucumber (*Cucumis sativus L.*) used for these studies was freshly harvested from a local farm in Nsukka, Nigeria (latitude 6.68^{o}N, longitude 7.39^{o}E, and 456 m elevation above sea level) on the 16th of December 2020 within the dry low humid season of the tropics. The cucumber fruits were adequately washed with clean water to eliminate pest infestation, and microbial contamination, and to prevent fungal infections. The cucumber fruits were randomly distributed into four groups of five (5) each for the four different storage mediums considered namely: charcoal cooler bin, open-air storage, laboratory storage, and refrigerator (refrigeration storage). They were labeled accordingly for recognition and proper variable monitoring and recording before storing the fruits in different media. The experiment was set up with the prepared cucumber samples on the 16th December 2020 and was terminated on the 30th of December 2020 at the Department of Agricultural and Bioresources Engineering, University of Nigeria, Nsukka.

2.2 Charcoal cooler bin storage

The rate of evaporation on the passive charcoal cooler bin is regarded as volumetric energy transmitted away from the charcoal-water surface by the latent heat of water vapour to achieve the phase change of water to vapour (gas) with time. Water from moist/wetted charcoal surface changes to vapour when heated by the sun or increase in environmental heat change, water vapour then rises into the atmosphere; take the solar energy with it, resulting in a cooling effect. Therefore, the sensible volumetric enthalpy of the charcoal bin storage is given as;

$$H = \int_{t_w}^{t} \rho_w C_w \, dt \qquad (1)$$

$t<t_w$ wetting of charcoal also at evaporative cooling, the enthalpy is given as

$$H = \int_{t_w}^{t} \rho_w C_w \, dt + \rho_w L_w \qquad (2)$$

$t>t_w$ vapour escape from the charcoal bin

Then, the temperature at every stage of evaporative cooling is given as;

$$t = \frac{t_w + H}{\rho_w C_w} \qquad (3)$$

when H<0 (liquid) wet stage

t=tw , $0 \le H \le \rho w L$ at interface

$$t = \frac{t_w + (H - \rho_w L)}{\rho_w C_w} \qquad (4)$$

$H>\rho_w L_w$ gasous (vapour) stage

Where:

ρ_w = density of water (kg m^{-3});

C_w = specific heat capacity of water (J kg^{-1} ^{o}C^{-1});

t = temperature of the air (^{o}C);

t_w = temperature of water [^{o}C];

L = Latent heat of vaporization, 2260 kJ kg^{-1};

H = Enthalpy (J).

Evaporative cooling reduces the cooler bin temperature and consequent air temperature through latent heat absorbed during phase change from water (liquid to gas). The rate of evaporation is given as:

$$ER = \frac{(M_2 - M_1)}{[A(t_2 - t_1)]} \qquad (5)$$

Then, the cooling effect is given as

$$q_{evap} = L\left[\frac{(M_2 - M_1)}{A(t_2 - t_1)}\right] \qquad (6)$$

Where:

M_2 = total mass (kg) of charcoal and water at time (t);

M_1 = total mass (kg) of charcoal and remaining water at time (t);

A = area of the charcoal bin (m^{-2});

t_1 = temperature of air (^{o}C);

t_2 = temperature of wetted charcoal (^{o}C);

q_{evap} = cooling effect (kJ m^{-2} h^{-1}).

The weather data (including air temperature, relative humidity, solar radiation, wind speed, rain, air pressure) were also monitored using a nearby weather station.

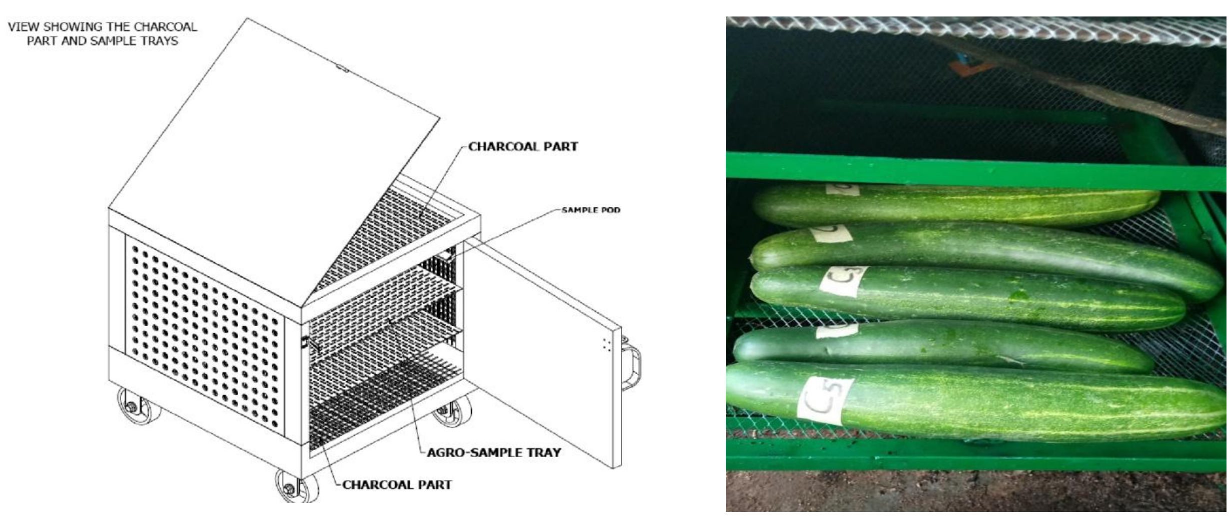


Figure 1 The charcoal cooler bin with fresh cucumber

2.3 Cucumber storage conditions

The fresh and fleshy cucumber fruits were stored in a charcoal cooler bin after charging the charcoal cooler bin, with temperature and relative humidity of 12 ℃ and 85% respectively (Ohagwu et al., 2021), also on a Scanfrost cold storage (refrigerator at 10 ℃ and 85% RH), on open-air (at 30 ℃ and 78% RH), and room conditions (laboratory at 25℃ and 78% RH). The charcoal cooler bin with a capacity of 4 kg/batch was designed with 580 × 540 × 500mm as the outer dimensions, a metal door measuring (200 × 70mm), with perforated side walls for one way cross ventilation after wetting the charcoal; with considerations that the system is passively under the influence of varying tropical weather condition (Ohagwu, et al., 2021). The charcoal cooler consists of charcoal-laden walls of 50 mm thickness held by weld wire meshes on the inner and by well perforated mild steel metal sheets on the outside. It was charged unloaded with water to activate the evaporative cooling before loading the fruits as developed by Ohagwu et al. (2021).

2.4 Mass loss

The physiological loss in mass were calculated as the difference between the initial mass of the fruit and the mass of the fruit at time of measurement and expressed as percentage. Mass losses were determined by weighing the cucumber samples using an electronic weighing balance and recording every day for all storage mediums calculated as a per cent of the initial mass using the following equation (Moalemiyan and Ramaswamy, 2012).

$$WL(\%) = 100 \times \frac{(W_A - W_B)}{W_A} \qquad (7)$$

Where:

WL= The physiological loss in mass of the fruit (%), W_A= the mass on the first day of storage (kg]) and W_B= the mass on the tested day (kg).

2.5 Cooling efficiency

The cooling efficiency (η) of the cooler, indicating the extent to which the dry bulb temperature of the cooled air approaches the wet-bulb temperature of the ambient air were calculated as defined in the following equation (Echiegu and Ugwuishiwu, 2015);

$$\eta = \frac{(To - Ts)}{(To - To,wb)} \qquad (8)$$

Where:

η = Cooling efficiency (%);

T_O= Outside temperature (°C);

T_S= the inside air temperature (°C);

$T_{o,\,wb}$= the outside air wet-bulb temperature (°C).

2.6 Quality parameters

Quality parameters like visual quality, degree of shrivelling and colour changes were evaluated through the use of the rating charts adopted by Muñoz et al. (2017) as the basis of evaluation. The physical evaluations were conducted with the aid of randomly selected five (5) students of the University of Nigeria, Nsukka. The data obtained were analyzed using a measure of central tendency for each storage condition and respective quality parameter with respect to storage time on the graph.

2.7 Storage environmental parametric measurement and data logging system

The temperature and relative humidity of the stored environments were measured using a digital data Acquisition System consisting of an Arduino microcontroller programmed through the Arduino integrated development environment (IDE) embedded into the storage system. Temperature and relative humidity sensors (DHT 11 with an accuracy of 2°C and 5%), a data logger shield/SD card module and a 5V DC power source to power the system were used to measure the parameters. Measurements were taken indoor space of the charcoal cooler bin for the storage space conditions and outside the structure for the ambient conditions. Temperature and relative humidity were measured at ten (10) minute intervals of data respectively, in both experimental conditions. Temperature, relative humidity and time measurements were stored in the data logger. These data were used to analyze the behaviour of the two different cucumber storage setups (Open-Air condition and charcoal cooler bin). Similar measurements were carried out for laboratory storage and refrigerator (already fixed).

3 Results and discussion

3.1 The charcoal cooler and environmental conditions

The charcoal cooler bin storage attained a maximum cooling efficiency of approximately 100% and minimum efficiency of 50.05%, as shown in Figure 2, having the corresponding minimum wet-bulb depression of 3.69 for a higher average relative humidity condition of 73.94% and maximum wet-bulb depression of 11.51 due to very low average relative humidity of 27.16% with respect to the ambient. The temperature of the open-air conditions ranged from 18^{o}C to 32^{o}C, while the charcoal cooler bin temperature ranged between 18^{o}C in the early hours of the day and 25^{o}C at the peak of the daily solar radiation intensity.

The maximum daily average temperature attained by the cooler is 24.82^{o}C and the minimum is 19.71^{o}C while that of the ambient condition is 28.65^{o}C and 26.32^{o}C respectively throughout the 14 days of the experiment. The relative humidity of the charcoal cooler bin ranged from 93% to 95% (on the average 94.71%) while that of the ambient ranged between 12% and 95% (average of 54.32%); Figures 3 and 4 show the trends in average temperatures and relative humidity for the cooler and open-air conditions respectively.

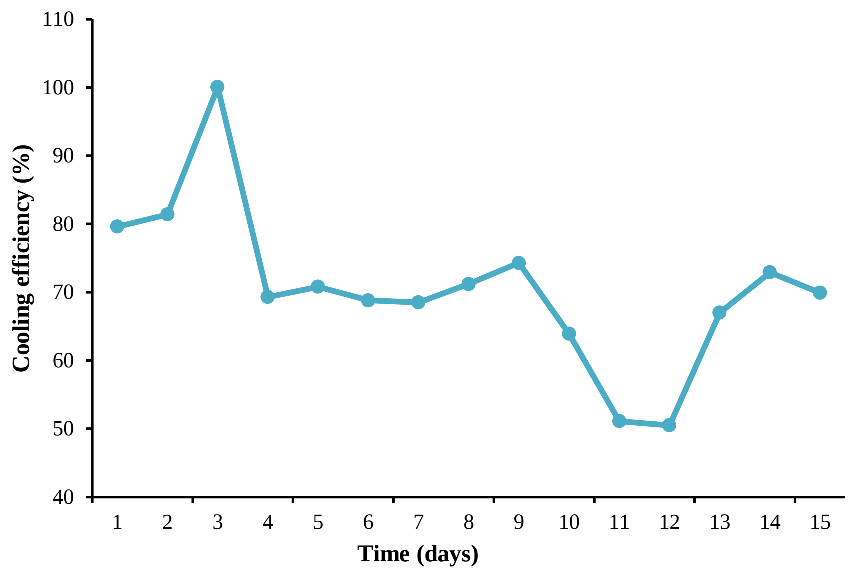


Figure 2 Cooling efficiency of the charcoal cooler bin

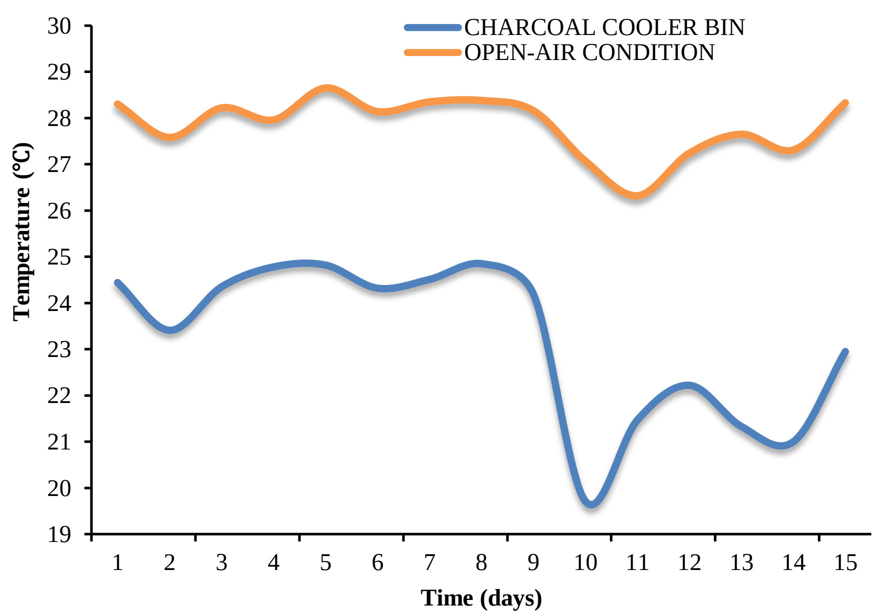


Figure 3 Daily average temperature chart

3.2 Percentage mass loss

The cucumber samples stored in the charcoal cooler bin had an average daily percentage mass loss of 0.2569%, refrigerated samples had a daily average of 0.6099%, and that of the laboratory storage was 0.7458% and 0.8527% for cucumber samples stored in the open-air condition. Figure 5 below showed the mass loss of stored cucumber as a function of storage time and temperature, indicating an increasing average percentage mass loss of the samples during the 14-day storage inside the evaporative cooler, refrigerator, laboratory and open-air conditions with the storage time for the cucumber samples. Based on the results, cucumber samples in the charcoal cooler bin had the least increase in percentage mass loss after the storage period with 3.4696%, compared to cucumber samples stored in the refrigerator, laboratory and open-air conditions with 8.4176%, 9.8260%, and 11.2696% respectively (Figure 6). The charcoal cooler bin microclimate (lower temperature and higher relative humidity) reduced the rate of mass loss of cucumber samples, which agrees with the findings by Basediya et al. (2013) that fresh agricultural produce (such as fruits and vegetables) should generally be stored at lower temperatures; this is because of their highly perishable nature and, indicates that the mass loss of cucumber samples stored inside the charcoal cooler bin storage was lower than those stored outside the chamber. In other storage media, Phal et al. (2013) found that the use of an evaporative cooling system (ECS) and high-density polyethene (HDPE) with higher relative humidity (93%) than the ambient reduced the mass loss of cucumber from 21% in the ambient to 3.09% during eight days with fewer changes in other quality parameters.

3.3 Quality parameters

The charcoal cooler bin storage maintained the visual quality of cucumber samples in good condition (with minor defects) compared to samples stored in other storage media which had the poor condition (severe defects and limit of usability) at the end of 14 days as shown in Figure 7.

Cucumber samples stored in the charcoal cooler had minor signs of shriveling, wilting or dryness compared to samples stored in other conditions which either had evidence of shriveling, wilting or dryness or were severely wilted at the end of 14 days (Figure 8).

Considering all cucumber samples in the different storage mediums, cucumbers stored in the charcoal cooler bin maintained the colour of cucumber and had only minor changes in colour at the end of 14 days compared to other samples, which had either serious evidence of yellowing or significant changes in colour at the end of 14 days (Figure 9). Figure 10 shows the conditions of cucumber samples at the initial and final stages of the experiment clearly showing the colour differences, degree of shrivelling and visual quality.

3.4 Shelf-life and life expectancy

After the 14-day storage period, the data obtained from the mass loss of cucumber stored in the charcoal cooler bin were used to determine the relationship between percentage mass losses with respect to time. These also indicated the possible percentage mass loss of the cucumber samples for the next six (6) days. This part of the study was used to determine the time when the samples will reach their limit in terms of percentage mass loss. According to FAO (2006), when the harvested produce losses 5 or 10 per cent of its fresh mass, it begins to wilt and soon becomes unusable. As indicated in the graph, the percentage mass loss of cucumbers in the charcoal cooler bin will reach 5% after 20 days of storage. Figure 11 shows the trend line and the equation derived from the regression method.

The charcoal cooler bin storage delayed deterioration and increased the shelf life of cucumber which was detected by observing external appearance, shrivelling, the loss of colour, and mass loss data. The loss of colour, wilting, and mass was greater in cucumbers kept in other storage mediums than in cucumbers kept in the charcoal cooler bin. Cucumber fruits stored in the charcoal cooler bin were still acceptable for 14 days with mass loss of less than 5%, while samples kept in other storage mediums were acceptable for nine days for refrigerated cucumbers, six days for cucumbers in room condition and five days for cucumbers in the open air having mass loss greater than 5% respectively.

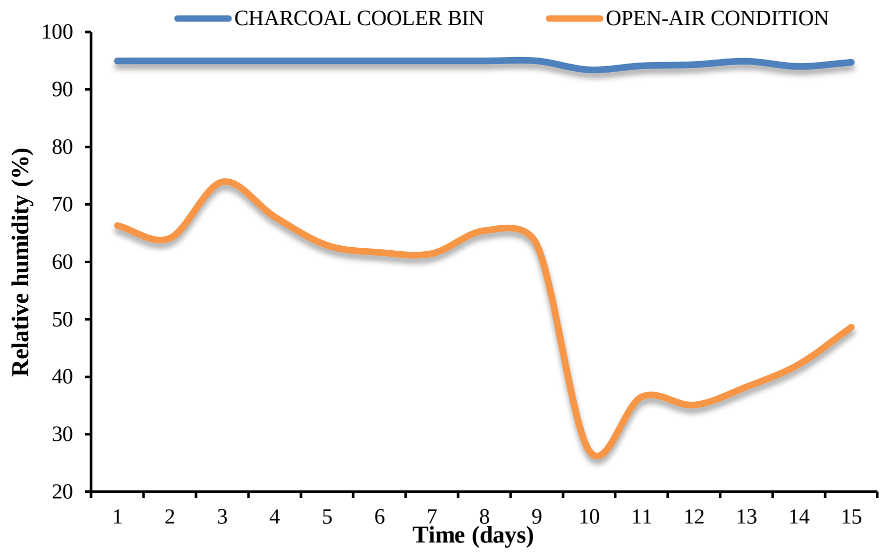


Figure 4 Daily average relative humidity chart

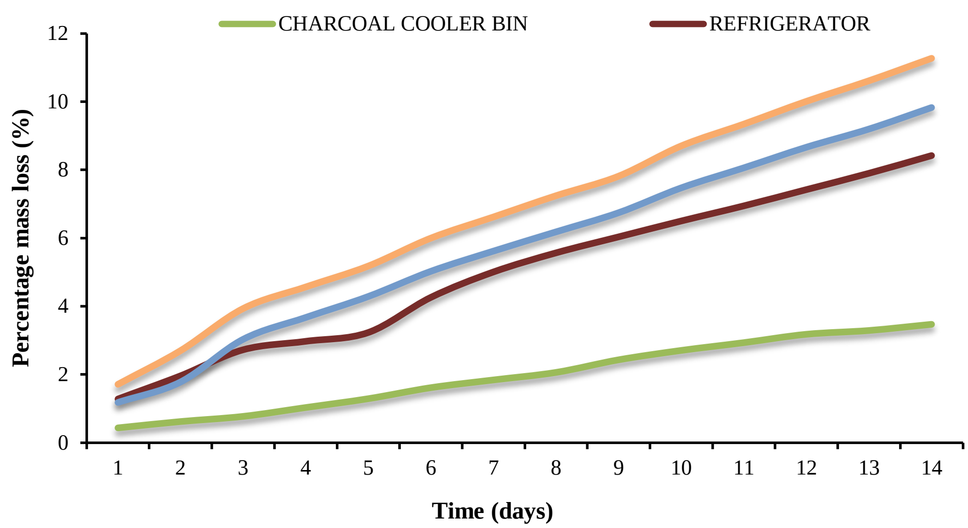


Figure 5 Percentage mass loss of cucumber samples

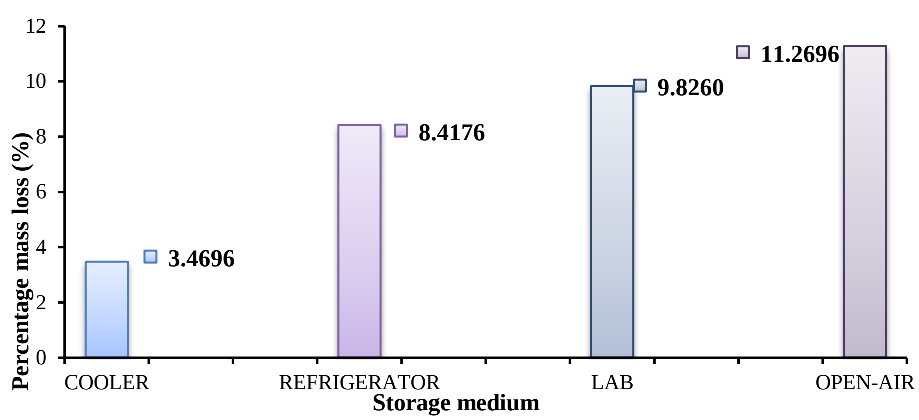


Figure 6 Percentage mass loss after 14 days

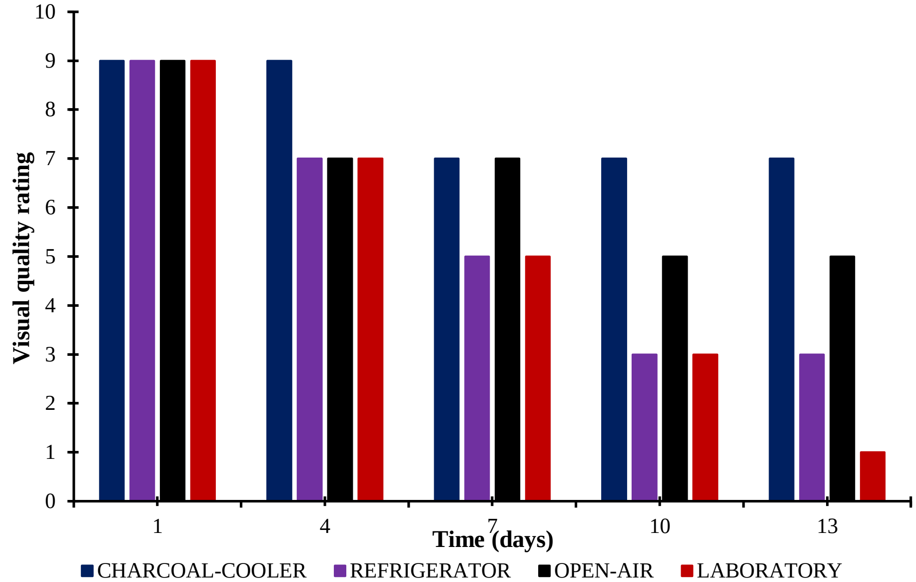


Figure 7 Cucumber visual quality chart

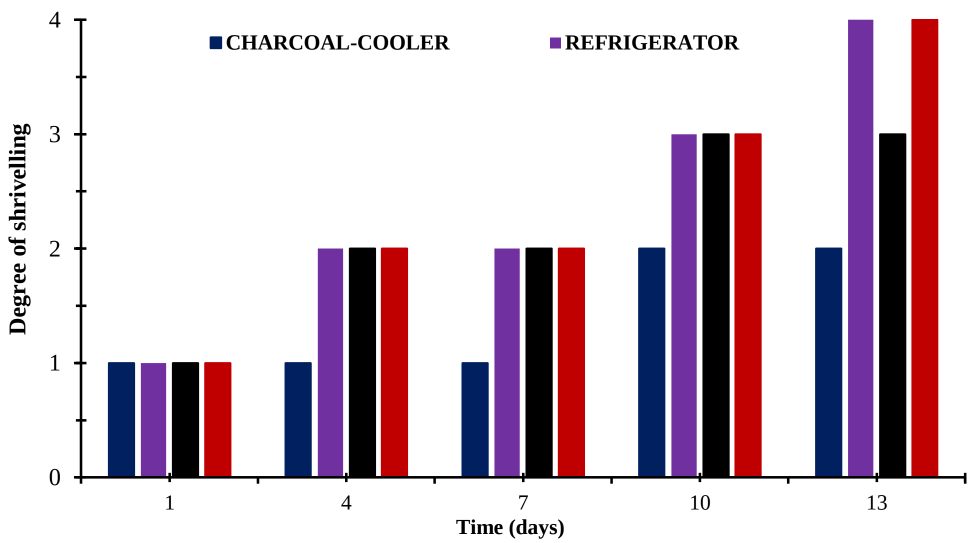


Figure 8 Cucumber degree of shrivelling rating chart

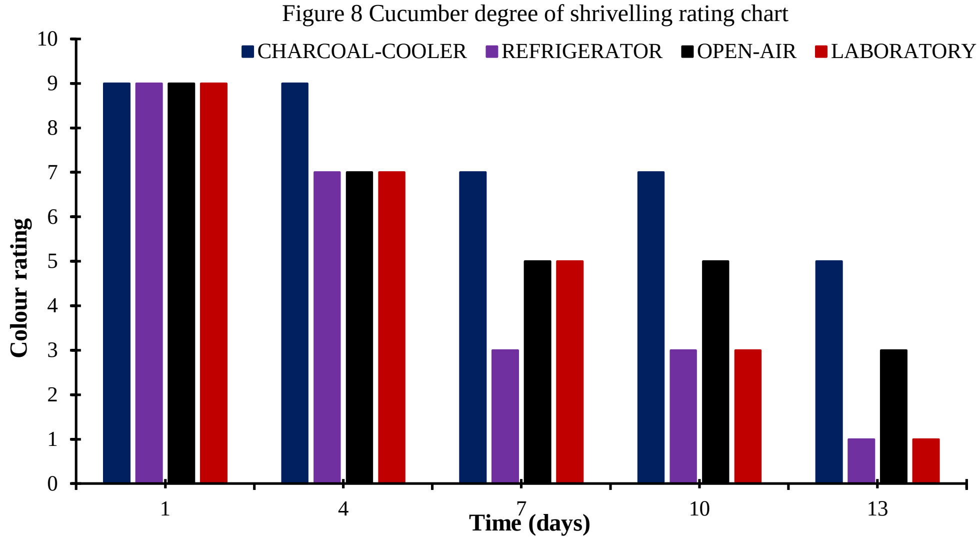


Figure 9 Cucumber color rating charts

（a）Charcoal cooler bin (Day one)

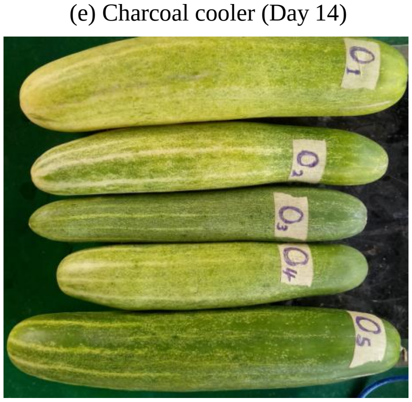
(b) Laboratory (Day one)

(c) Open-Air (Day one)

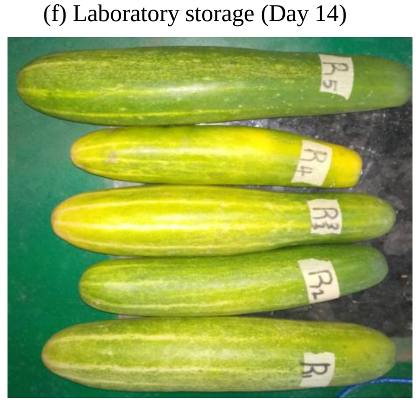
(d) Refrigerator (Day one)

(e) Charcoal cooler (Day 14)

(f) Laboratory storage (Day 14)



(g) Refrigerator (Day 14)



(h) Open-Air (Day 14)

Figure 10 Stored cucumbers at initial a nd final stages of experiment

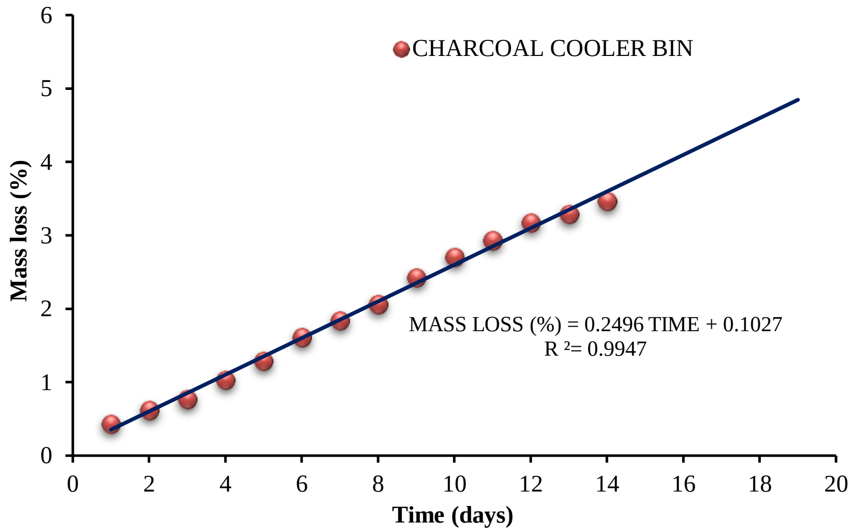


Figure 11 Data trend for time vs. average percentage mass loss of cucumber in the charcoal cooler bin

4 Conclusion

The charcoal cooler bin was effective for reducing moisture loss and prolonging the storage life of cucumbers. The microclimate of the cooler helped to better retain the different quality parameters by reducing colour changes, degree of shrivelling and loss in mass. The charcoal cooler bin was shown to have lower storage temperatures and higher relative humidity than the ambient and room conditions. The storage shelf-life of cucumbers was extended from 2 days in the ambient to more than two weeks in the charcoal cooler bin. Commodities stored inside the evaporative cooler (charcoal cooler bin storage) showed better conditions in terms of mass losses, visual quality, and degree of shrivelling compared to those stored outside the cooler, in refrigerators, laboratory, and open-air conditions. The study proved that the use of an evaporative charcoal cooler can prolong the shelf life of cucumber as well as other fruits and vegetables than exposing the commodity in an ambient or room environment.

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Conflict of interest

The authors declare no conflict of interest.

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