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PERFORMANCE EVALUATION OF EVAPORATIVE COOLING SYSTEMS AS ALTERNATIVE FOR INCREASING THE SHELF LIFE OF PERISHABLE CROPS AT THE FARMER LEVEL IN VUNJO-MOSHI RURAL

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Abstract

Postharvest handling in developing countries continues to be a major challenge for most of the farmers. The low economy in these countries is counted as a major obstacle toward the adaptation of modern postharvest technologies. The present study aimed to assess the existing post-harvest handling practices and test the suitability of evaporative cooling systems for reducing post-harvest losses by using Vunjo-Moshi Rural as a case study. A total of 30 questionnaires covering small commercial farmers were utilised to get information regarding the existing post-harvest handling practices in Vunjo. Two evaporative cooling systems, the Charcoal Cooler Chamber and Sand Cooler Chamber, were created and tested in Vunjo. Their effectiveness was measured by their response to temperature and humidity changes. Results indicated that 87% of the small farmers in Vunjo used local precooling and cold storage methods characterised by low efficiency. Further results showed 77% of all spoilage crops were randomly disposed of in the environment regardless of their impacts. Performance results of designed evaporative systems showed that the Charcoal Cooler Chamber (at its highest performance), could lower the daily ambient temperature by 8.8 °C while increasing the ambient relative humidity from 73.01% to 90.93%. The Sand Cooler Chamber could reduce the daily ambient temperature by 7.8 °C and increase the ambient relative humidity from 73.01% to 93.90%. The performance of both designed systems met the recommended standard for increasing the shelf life of most of the perishable crops cultivated in Vunjo, making them recommended as alternative precooling and cold storage technologies.

Keywords: Charcoal Cooler Chamber, Environment, Evaporative Cooling, Postharvest losses, Sand Cooler Chamber

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Introduction

Globally, small farmers in developing countries face many postharvest handling challenges. Low economies, insufficient power supplies, weather conditions, climate conditions, and low levels of technology increase the postharvest losses to these countries (Odesola and Onyebuchi, 2009; FAO, 2006). The main cause of this problem is lack of affordable and applicable postharvest handling technologies, which could help to increase the shelf life of harvested crops prior to market (Rahaman *et al*., 2014). Spore (2011) reported that 40% to 50% of perishable crops produced have been wasted during postharvest handling. This problem is common in some African, Caribbean and Pacific (ACP) countries.

To increase the shelf life of perishable crops (tomatoes, bell peppers, vegetables, cucumbers, onions, carrots, etc.), environmental factors such as temperature and ambient humidity must be taken under consideration (Hertog *et al*., 2014; Nunes *et al*., 2014). In general, it is known that there are optimum conditions that must be met depending on the crop type, so that to increase the shelf life of any perishable crop. The solution is not only to lower the temperature, but the optimum temperature must be obtained because too low temperature can cause chilling or freeze damage (Nunes *et al*., 2014). Complexity and difficulties in the management of spoilage crops are major factors that increase the tension among environmental researchers.

In Tanzania (rural areas), low shelf life of perishable crops is a major issue because huge quantities of fresh fruits and vegetables spoil at different stages of the postharvest chain. Lack of smooth transportation, insufficient cool storage space and facilities at the farm level, and the high operation cost of mechanical refrigerators are the most significant challenges for many small farmers (Clément et al, 2009).

Many years have passed since researchers began to find simple and affordable solutions to minimise the postharvest losses. The major challenge is to meet the required optimal environmental conditions, which can increase the shelf life of harvested crops prior to market. Evaporative cooling has been widely used to create a favourable environment for perishable crop storage (Odesola and Onyebuchi, 2009). This technology involves the process of allowing natural or forced dry air to pass through the wet materials, causing the heat to be absorbed, then moving the cool moisture to the other side of the materials. The efficiency of this technology depends on the ambient air's relative humidity. This scenario makes the performance of this technology to vary depending on weather and climatic conditions (Camelo, 2004; El-Refaie and Kaseb, 2009).

Previous studies that assessed the applicability of evaporating cooling technologies focused primarily on identifying materials that could be used as cooling pads and their performance in relation to climate and weather conditions (Ai-Sulaiman, 2002; Sandhu *et al*., 2002; Gunhan *et al*., 2007; Jha, 2008; Tilahan, 2010; Vala and Joshi, 2010; Chinenye, 2011; Kulkarni and Rajput, 2011; Nitipong and Sukum, 2011; Samira *et al.,* 2013; Banyat and Bunjerd, 2013; Bishoyi and Sudhakara, 2017; Warke and Deshmukh, 2017; Shahzad *et al*., 2019). There is no documented study regarding the applicability of evaporative cooling system in Vunjo-

Moshi Rural. Therefore, the scientific originality of this study mainly relies on the case study area and comparative performance assessment of two different evaporative cooling systems. The suitability of the charcoal cooler chamber (CCC) and the Sand Cooler Chamber (SCC) system in Vunjo were intensively studied. Also, the assessment of possible environmental and health impacts due to perishable crop spoilage was studied to cover the knowledge gap left by previous researchers (Arah *et al*., 2015), who mainly concentrated on assessing the economic impacts.

2. Materials and methods

2.1 Study area

Vunjo is located at 3° 20' 0" S, 37° 27' 0" E (Figure 1) and is characterised by a tropical Köppen climate type with hot, humid, and mostly cloudy conditions during the hot season and warm and partly cloudy conditions during the dry season. The annual temperature ranges from 15 ^{0}C to 35 ^{0}C, depending on the season. The hot season lasts three months (January to March), with average daily temperatures exceeding 31 ^{0}C. The cool season is from May to July with an average daily temperature below 27 ^{0}C, and the coldest month is July with a daily temperature range between 16 ^{0}C to 25 ^{0}C. Vunjo receives short rains from October to December and long rains from March to May. The month with the most rainfall is April, with an average daily rainfall of more than 12 mm (Malocho, 1998; Spark, 2019).

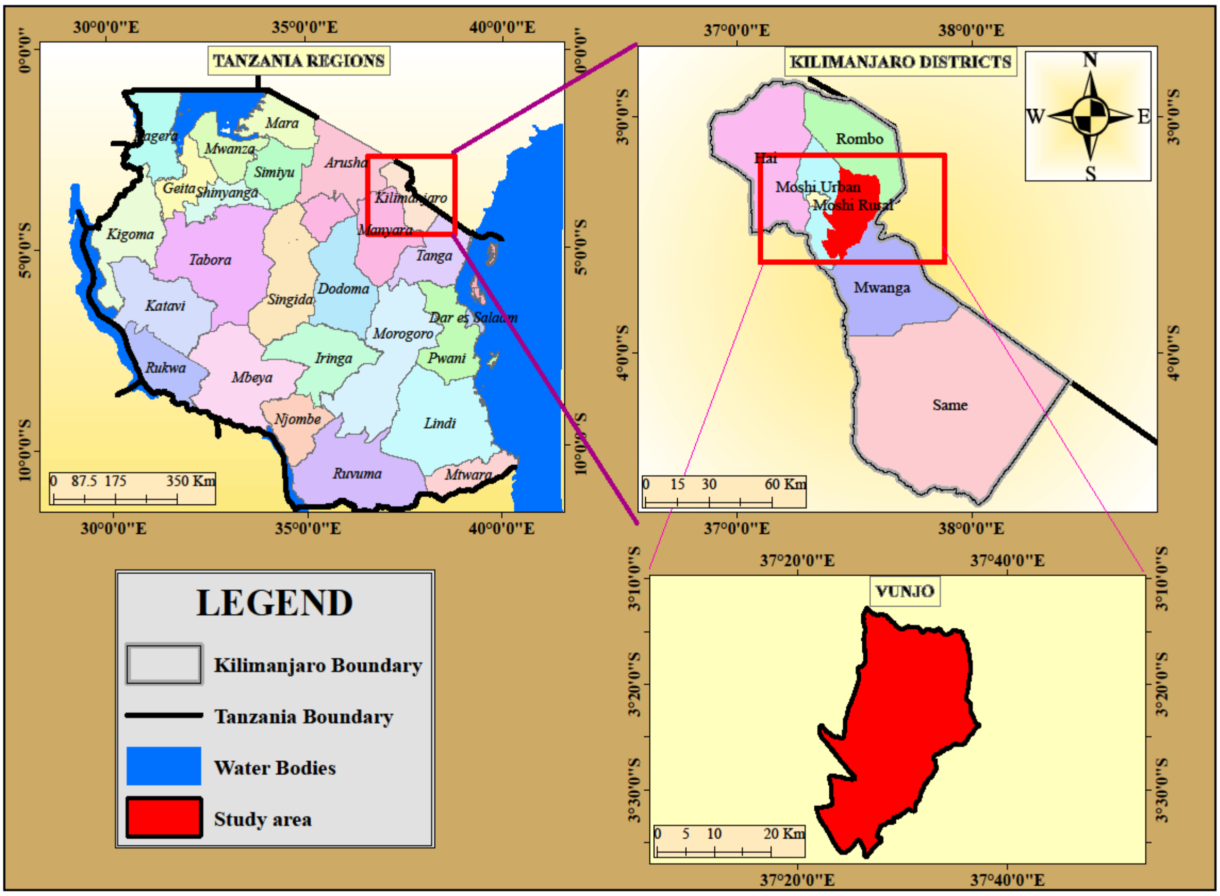

Figure 1. Study area map

2.2 Type and cost of materials, instruments, and tools

Materials that were used in the present study included; charcoal, sand, wire mesh, timber wood, roof grasses, rock blocks, and nails. Those materials were used in the construction of the Charcoal Cooler Chamber (CCC) and the Sand Cooler Chamber (SCC) as shown in Appendix A. Normal commercial charcoal was bought from Himo – Vunjo market and used as raw material in construction of the Charcoal Cooler Chamber. Sand from Kifaru, which basically used in building construction in Vunjo area, was used for the construction of the Sand Cooler Chamber. In present study, a digital Thermo-Hygrometer (CLOCK/HUMIDITY HTC-1) and wet and dry bulb thermometers were used for temperature and relative humidity monitoring. The measurement accuracy of a Thermo-hygrometer is ±1 ^{0}C and ±5 % for temperature and relative humidity, respectively. The measurement accuracy of wet and dry bulb thermometer is ±1 ^{0}C and ±3 % for temperature and relative humidity, respectively. Other tools such as a tape measure, a panga, a hoe, a spade, a mag, and a bucket were used to facilitate the construction and operations of those two evaporative cooling systems.

In the present study, the total cost of materials used in the construction of the Charcoal Cooler Chamber and the Sand Cooler Chamber were 30 USD and 25 USD, respectively. The sizes of the constructed Charcoal Cooler Chamber and Sands Cooler Chamber were 0.75 m × 0.75 m ×1 m and 0.7 m × 0.7 m ×0.7 m, respectively. The materials and the cost of Charcoal Cooler Chamber and Sands Cooler Chamber can slightly vary from one place to another depending on materials and labour force availability and intended size.

2.3 Data Collection Techniques

Four (4) techniques were used to collect the data for the present study: physical observation, questionnaire, interview, and experimental setup.

2.3.1 Physical observations, Questionnaire, and Interview

Before the selection of the sample size for the questionnaire, preliminary visits were made at different wards in Vunjo to determine the major types of perishable crops cultivated and their geographical locations. Initial survey results found that high production of perishable crops was mainly in three wards, East Kirua Vunjo, East Kahe, and South Kilema. These wards were selected to represent other wards during data collection. Furthermore, interviews with ward officers from these three pre-selected wards were done to get information related to the total number of permanent commercial small farmers in each selected ward, geographical distribution, and their farm's location. A total of 42 small commercial farmers were found, and from them, a sample of 30 small farmers /peasants were chosen for questionnaires, ten from each ward. A sample size of 30 farmers was calculated using Solving formula using a margin error of 0.1 ((Isip, 2017). The small farmers were selected based on the types of perishable crops they are cultivating, ease of accessibility, the willingness of farmers to participate, and cooperation from local leaders. All data related to harvesting technologies, storage methods, crop types cultivated, challenges, spoils crop disposal methods, income, and satisfaction with available post-harvest handling technologies were collected using questionnaires.

2.3.2 Experimental setup and operation principle

Two experimental setups were used in the present study, i.e., the Charcoal Cooler Chamber and the Sand Cooler Chamber. Both setups were designed independently and monitored differently, but at the end, their results were combined and compared. Those evaporative coolers (the Charcoal Cooler Chamber and the Sand Cooler Chamber) were designed and constructed at Mrumeni village, East Kirua Vunjo ward, Vunjo Province. The performance of those systems was assessed in May and June by observing their response to ambient temperature and relative humidity. The performance was assessed for seventeen consecutive days, from 20 May, 2019 to 5 June, 2019. The 17 days of monitoring were opted based on the previous researchers who were suggested the evaluation performance of evaporative cooling systems can be evaluated up to twenty days (Lotfizadeh and Layeghi, 2013; Wayua *et al*., 2012). The study was conducted during the highly humid month in Vunjo (May and June) to get the performance of these systems at this season because previous researchers reported the low performance of evaporative cooling systems in high ambient relative humidity areas (Anyawu, 1995; Soponpongpipat and Kositchaimongkol, 2011; Wayua *et al* 2012).

Both systems work under the same principle of the evaporative cooling (Appendix B). Evaporative cooling principle is based on the conversion of sensible heat to latent heat. The warm and dry outdoor air is naturally/forced passed through porous walls or wetted pads that are replenished with water. Due to the low humidity of the incoming air, some of the water evaporated. Some of the sensible heat of the air is transferred to the water and becomes latent heat by evaporating some of the water. The latent heat follows the water vapour and diffuses into the air. Evaporation causes a drop in the dry-bulb temperature and a rise in the relative humidity of the air (Watt, 2012).

2.3.2.1 Charcoal Cooler Chamber

The Charcoal Cooler Chamber was constructed from an open timber frame of approximately 40 mm x 20 mm in section and a pole of about 50 mm x 50 mm in section. The door was constructed by hinged half of the front side. The wooden frame was covered with mesh, inside and out, leaving a 50 mm cavity that could be filled with pieces of charcoal. The total inside dimensions of the charcoal evaporative cooler were 750 mm x 750 mm with a height of 1100 mm (Appendix C).

During monitoring, physical watering (intermittent) was used to wet the charcoal walls. Watering was done three times per day: in the morning (7:00 a.m.), afternoon (11:00 a.m.), and evening (4:00 p.m.), each time using 10 litres of water. The ambient and inside weather (temperature and humidity) were recorded four times per day at an interval of four hours, and the recording process had always taken at least one hour after the watering process.

2.3.2.2 Sand Cooler Chamber

Sand Cooler Chamber was constructed based with two-sided wall of rock blocks, wet sand with a thickness of 100 mm was filled between the walls. At the top of Sand Cooler Chamber was coved with wet sack. The total internal dimension of that system was 700 mm X 700 mm X 700 mm (Appendix D).

The operation of Sand Cooler Chamber system was the same as that of the Charcoal Cooler Chamber, which the intermittent watering process was used to wet the rock blocks, sacks, and sand three times per day with ten litres of water per each watering process. These two setups were located near to each other and under the tree shade. The same ambient weather conditions were used to monitor both systems. The inside relative humidity and temperature for Sand Cooler chamber were also recorded by using digital thermo-hygrometer and wet and dry bulb thermometer, respectively.

2.4 Data analysis

All data collected using questionnaires were analysed using IBM SPSS Statistics 20. Microsoft Excel software program was used to improve the graphics of all Figures produced by IBM SPSS Statistics 20. Experiment results were analysed using Microsoft Excel and represented in charts, such as simple bar charts and simple line charts. Microsoft Excel analysis tools such as ANOVA single factor, t-test, correlation, and regression analysis were also used for data analysis. ANOVA with a single factor was used to assess if there was any significant difference between the ambient weather (temperature and relative humidity) and that inside the coolers at a confidence limit of 95%, while a t-test was used where the two parameters were compared. Correlation analysis was used to find the existing relationship between the monitored parameters, and regression analysis was used to signify those relations. The cooling efficiency for both systems was calculated based on equations 1, 2, 3, and 4.

$$CCC\ Cooling\ Efficiency\ = \frac{(Ambient\ Temp - CCC\ Temp) \times 100\%}{Ambient\ Temp} \ldots\ldots\ldots\ldots\ldots\ldots Eq.(1)$$

$$CCC\ RH\ Efficiency\ = \frac{-(Ambient\ RH - CCC\ RH) \times 100\%}{Ambient\ RH} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Eq.(2)$$

$$SCC\ Cooling\ Efficiency\ = \frac{(Ambient\ Temp - SCC\ Temp) \times 100\%}{Ambient\ Temp} \ldots\ldots\ldots\ldots\ldots\ldots Eq.(3)$$

$$SCC\ RH\ Efficiency\ = \frac{-(Ambient\ RH - SCC\ RH) \times 100\%}{Ambient\ RH} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Eq.(4)$$

Where; CCC stand for Charcoal Cooler Chamber, SCC is Sand Cooler Chamber, RH is Relative humidity.

3. Results

3.1 Types of perishable food crops in Vunjo

The present study found small farmers in Vunjo were cultivating more than one crop but in different plots and sometimes in a different season. From the questionnaire analysis, the present study found that majority (31.3%) of small farmers/peasants in Vunjo cultivate tomatoes, followed by 63.3% who cultivate leafy vegetables, and the least perishable crop to be cultivated was carrots (8.4%) (Table 1). This result indicates that the demand for tomatoes is very high compared to other perishable crops, which explains why it is highly cultivated compared to other perishable food crops in Vunjo. The rate at which tomatoes deteriorate in hot ambient temperatures is very high compared to other crops, so it is very important to have good and affordable cold storage methods in Vunjo so that its shelf life could be increased.

Table 1. Types of perishable goods cultivated at different seasons in Vunjo

Types of crops cultivated	**Responses**		**Percent of Cases (%)**
	Frequency of responses (n)	**Percentage of responses (%)**	
Tomatoes	26	31.3	86.7
Cucumbers	12	14.5	40.0
Bell Peppers	8	9.6	26.7
Leafy Vegetables	19	22.9	63.3
Onions	11	13.3	36.7
Carrots	7	8.4	23.3
Total	**83**	**100**	**276.7**

3.2 Type of cold storage methods used by small farmers/peasants

The present study found that, 87% of the small farmers/peasants in Vunjo use a local cold storage method for storage of their perishable crops after being harvested, and 13% use mechanical refrigerators. The possible reasons for this are the limited supply of grid electricity in Vunjo (mainly where the farms are located) and the financial issues. Further results show that out of those who use traditional storage methods, only 41% use floor storage methods, and 46% do not use any storage methods other than leaving their crops on the farms until the market availability (Figure 2). Further findings from present study show that most of the small farmers/peasants fail to use mechanical refrigerators not only because of an absence of electric power but also because of financial problems—most of the small farmers were poor financially and could not afford the running cost of large mechanical refrigerators.

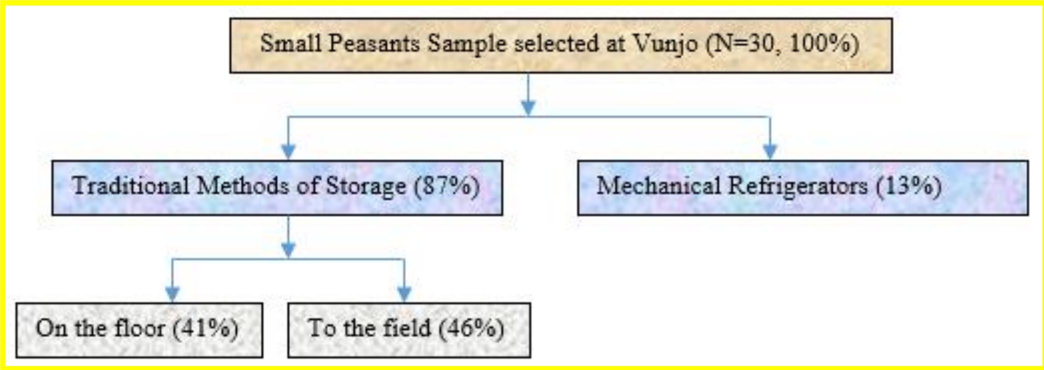

Figure 2. Type of cold storage methods at Vunjo

3.3 Challenges which face small farmers/peasants based on their cold storage methods

The possible challenges were categorised into three categories: efficiency, running costs, and weather conditions. The results showed that about 47% of the small farmers responded that their cold storage methods have been affected by weather conditions (rainfall and temperature), and another 30% agreed that the efficiency of their technologies was very poor. 17% responded that the running cost of their storage was very high (Figure 3). Those who complained about operating costs and electricity consumption were those who used mechanical refrigerators.

Furthermore, the present study found that 37% of the small farmers/peasants were not satisfied with their cold storage methods, probably because there were various challenges that face their methods, such as low efficiency, high running costs, and the unavailability of reliable electricity. Also, the questionnaire analysis shows only 23% of small farmers/peasants were satisfied, and the rest were somehow satisfied with their cold storage methods.

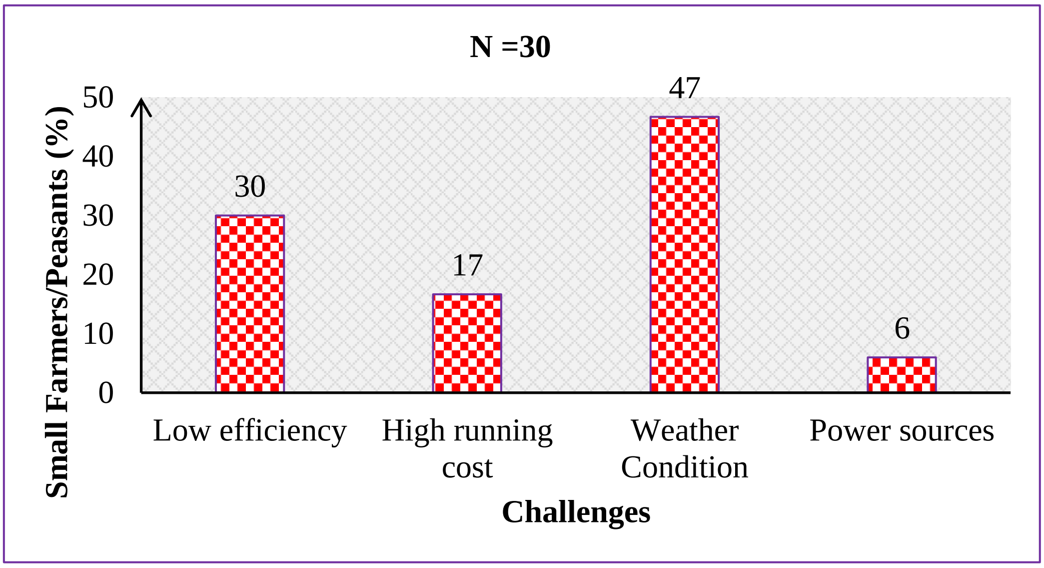

Figure 3. Common Small farmers/peasant Challenges

3.4 Economic loss status due to perishable crops spoilage for small farmers/peasants at Vunjo

Data collected in Vunjo from 30 small farmers/peasant's responses showed that an average of 23.4% of the perishable food crops were lost per year during the postharvest handling process. Bell peppers were the most spoiled crops, with approximately 39% lost per year, followed by tomatoes (29%). The reasons behind these losses were lack of adequate and efficient cold facilities in Vunjo. The real cost and percentage loss per year for other perishable crops are summarised in Table 2. Due to that circumstance, it is true that new local and affordable precooling and cold storage methods are very important to reduce these post-harvest losses.

Table 2. Average Losses of small farmers/peasants (N = 30)

Types of crops	Responses in %	Average money earn/year (TSH)	Average money lost/year (TSH)	Average % of loss/year
Tomatoes	31.3	2,013,704	585,000	29
Cucumber	14.5	2,162,500	328,111	15
Bell Peppers	9.6	1,545,833	596,000	39
Leafy Vegetables	22.9	947,222	199,450	21
Onions	13.3	1,834,444	358,889	20
Carrots	8.4	864,287	127,145	15
Total	**100%**	**9,367,990**	**2,194,595**	**23.4**

NB: The presented data in Table 2, are the average of all responses from 30 respondents

3.5 Perishable crops spoilage and their disposal methods

According to the findings of present study, 77% of spoilage perishable crops at the farm level are freely disposed of to the environment (Figure 4. A). This kind of disposal is not safe because it could attract disease-carrying vectors, which could spread various diseases. Furthermore, 13% of small farmers/peasants responded to using spoilage crops for animal feeding, depending on the types of those crops. Only 10% use the spoilage crops as organic manure to grow their crops, as shown in Figure 4. A). On the other hand, depending on the extent of spoilage, some small farmers/peasants have been forced to sell spoilage crops at low prices. 33% of small farmers/peasants agreed that they always sell these crops, but at a low price compared to fresh ones. Other 43% responded that they are sometimes forced to sell such crops due to buyer pressure (Figure 4. B).

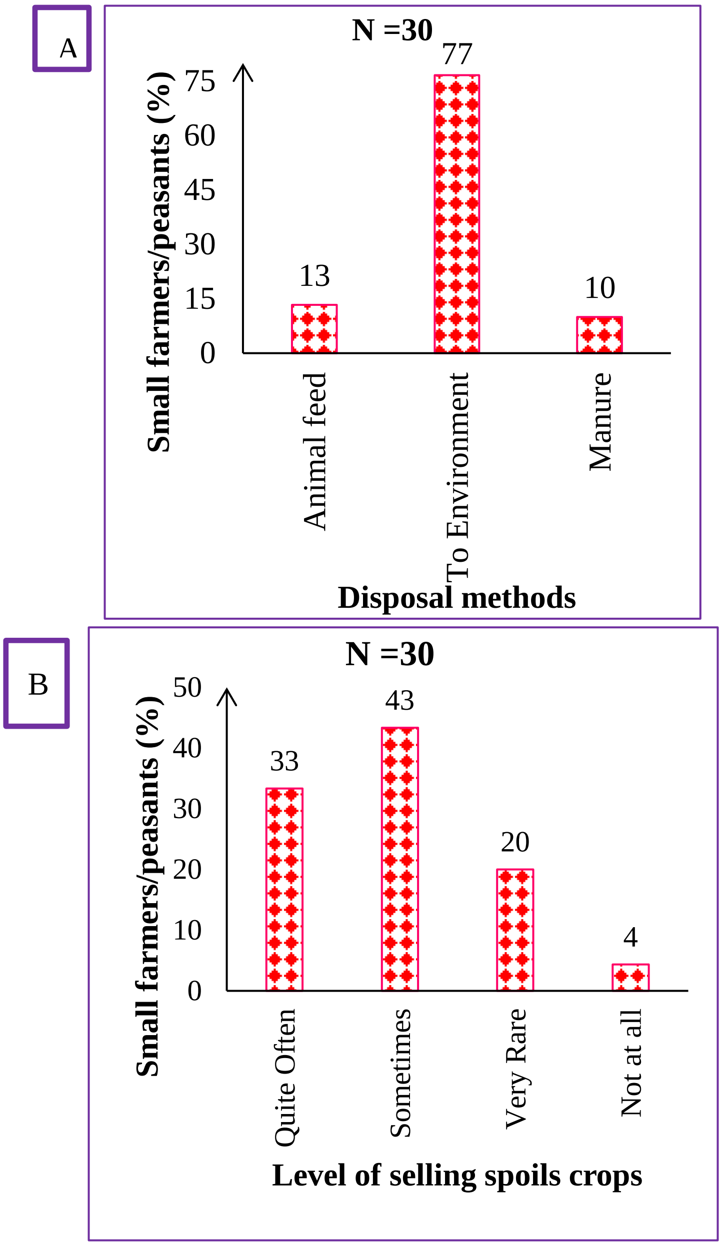

Figure 4. (A) Disposal methods and (B) level of selling spoilage commodities, in Vunjo

3.6 Impacts of improper spoilage crops management to the environments

According to the responses from the various small farmers/peasants in Vunjo, about 90% of those questioned agreed that the flies are most common around their farms due to the random spread of rotten crops. Other common disease carrying vectors in the farm area were mosquitoes (60%), cockroaches (73%) and rats (57%) as shown in Figure 5. All these vectors are disease carrying vectors, and they could help spread diseases like cholera, diarrhoea, typhoid, lymphocytic, plague, dysentery, hantavirus, choriomeningitis (LCMV), leptospirosis, salmonellosis, tularemia, and sometimes viral diseases like poliomyelitis.

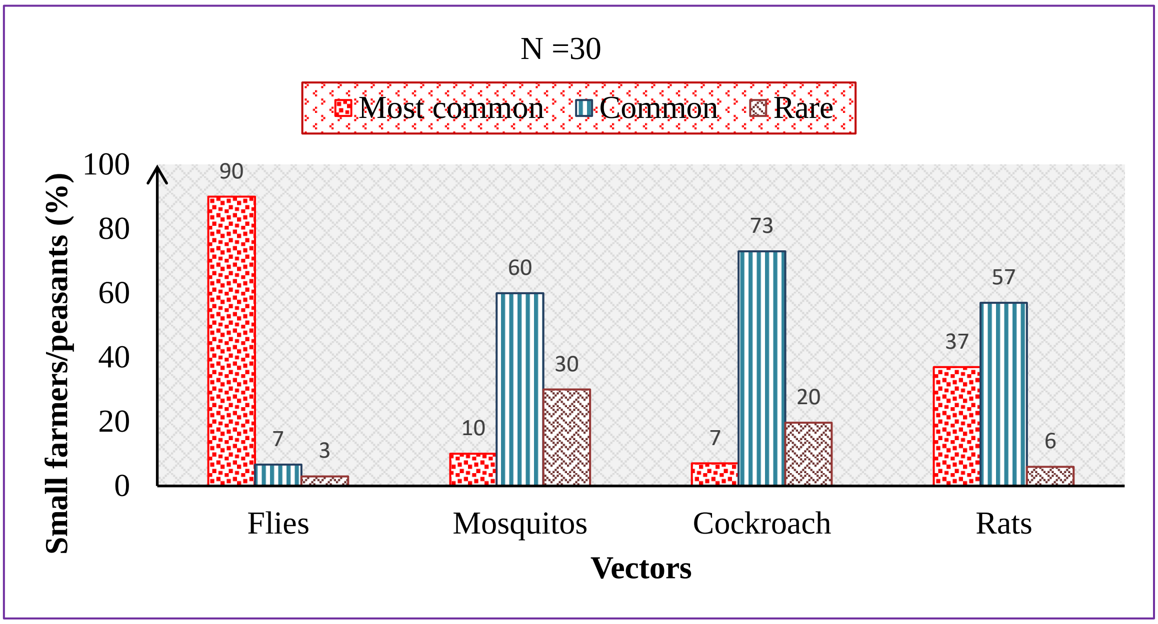

Figure 5. Level of vectors carrying diseases in Vunjo perishable crops farms

3.7 Performance of the Charcoal Cooler Chamber and Sand Cooler Chamber

The performance in both systems was assessed by considering two factors; (i) their response to decrease ambient temperature and (ii) their response to increase ambient relative humidity.

3.7.1 Performance of coolers in temperature reduction

The average daily ambient temperature was 23.02 °C ± 1.15 °C, as measured over seventeen consecutive days. The inside Charcoal Cooler Chamber and Sand Cooler Chamber temperatures were 16.97 °C ± 1.41 °C and 17.83 °C ± 1.44 °C, respectively (Appendix F). The inside Charcoal Cooler Chamber temperature was ranged from 14.90 °C to 18.90 °C while that in Sand Cooler Chamber was 15.80 °C to 19.80 °C (Figure 6). At their highest efficiency, the Charcoal Cooler Chamber and Sand Cooler Chamber had inside temperature of 8.8 ^{0}C and 7.8 ^{0}C lower than the ambient temperature, respectively. On the last day of the experiment, the minimum temperatures (highest performance) for the Charcoal Cooler Chamber and the Sand Cooler Chamber were 14.9 °C and 15.8 °C, respectively.

When those two systems were compared, it was observed that the cooling performance of the Charcoal Cooler Chamber was always better than that of the Sand Cooler Chamber except on the tenth day, where the Charcoal Cooler Chamber temperature was higher (16.3 ^{0}C) than Sand Cooler Chamber (16.1 ^{0}C). The possible source of these results could be the measurement accuracy of a Thermo-Hygrometer and Wet and Dry bulb thermometer used in the present study.

ANOVA Single factor results showed that the CCC and SCC temperatures differed statistically from the ambient temperature at $p \leq 0.05$. A p-value of 5.72781 E-18 was obtained, which signifies a significant reduction of ambient temperature for both coolers. On the other side, t-test results showed there was a significant difference between the inside Charcoal Cooler Chamber and Sand Cooler Chamber temperatures at ($p \leq 0.05$) and this signifies the difference in performance.

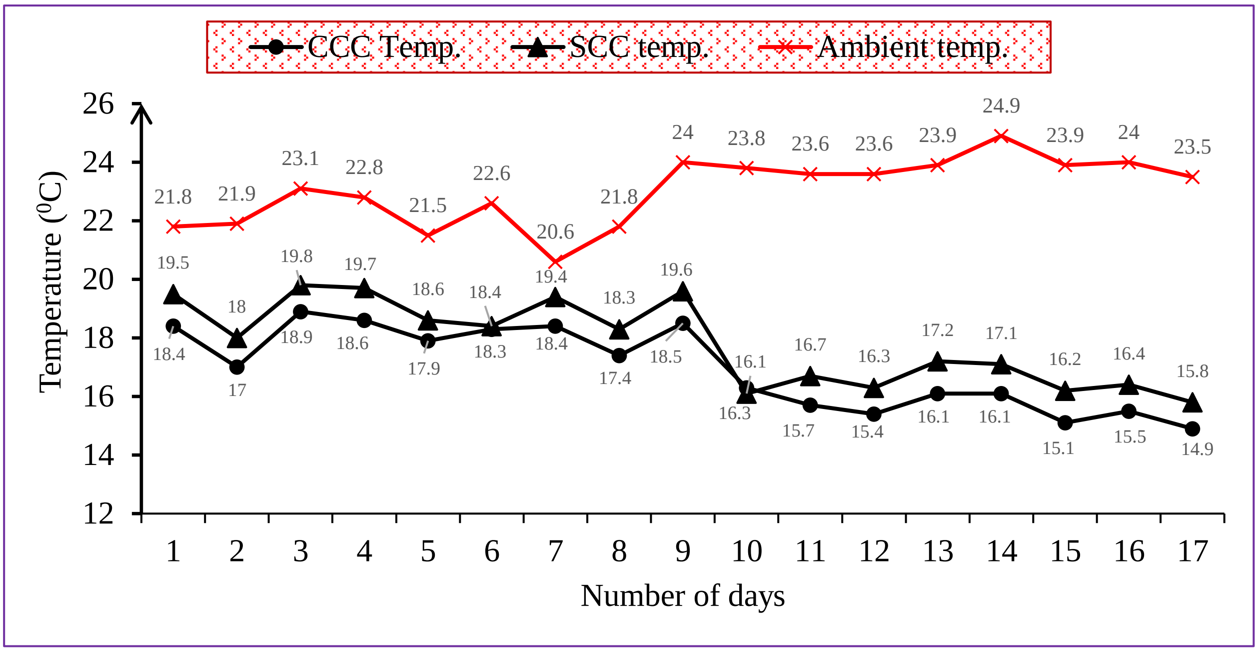

Figure 6. Average daily temperature cooling for Charcoal Cooler Chamber and Sand Cooler Chamber

3.7.2 The Performance of coolers in Relative Humidity

For all monitoring days, results showed that the average ambient relative humidity ranged from 61.75% to 84%. The lowest and highest relative humidity in the Charcoal Cooler Chamber was 87.0% and 94.75%, while in the Sand Cooler Chamber was 85.5% to 97.0%, respectively. On average, the Charcoal Cooler Chamber maintained a relative humidity of 90.93% ± 2.48% while the Sand Cooler Chamber maintained an average humidity of 93.9% ± 3.13% for all seventeen days of monitoring (Appendix F).

Monitoring results showed that out of seventeen days, there were 2 days when the performance of the Charcoal Cooler Chamber was higher than Sand Cooler Chamber in increasing the ambient relative humidity. This reveals that the performance of Sand Cooler Chamber in increasing relative humidity was higher than Charcoal Cooler Chamber. The performance of both systems in increasing relative humidity was ununiform during the first five days due to differences in performance between the studied systems. There were some days when the performance of the Charcoal Cooler Chamber was higher than that of the Sand Cooler Chamber, and vice versa. From the sixth day to the seventeenth day, different results were obtained. The performance of the Sand Cooler Chamber was always higher that of the Charcoal Cooler Chamber (Figure 7).

Statistically, the inside cooler's relative humidity was significant deferent from the ambient relative humidity at ($p \leq 0.05$). ANOVA single factor results showed the p value of 5.40429 E-41 between the groups (CCC, SCC and ambient relative humidity). The t-test results revealed that the performance of coolers in increasing ambient relative humidity differed significantly at ($p \leq 0.05$).

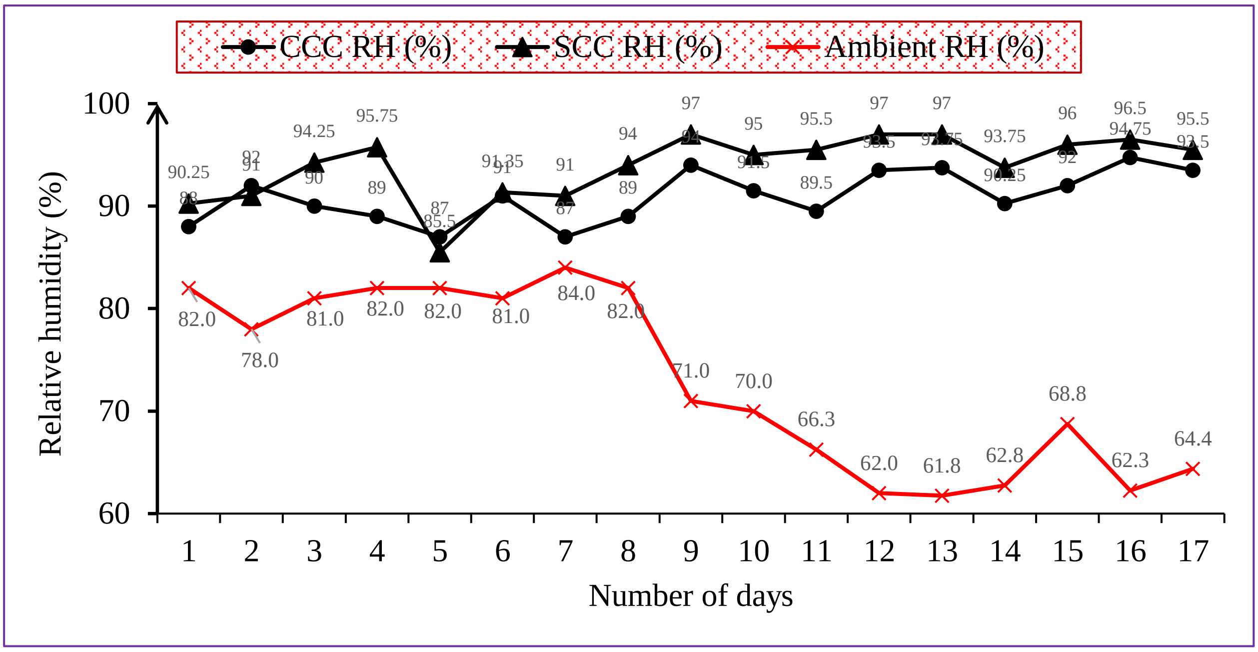

Figure 7. Response of Charcoal Cooler Chamber and Sand Cooler Chamber on increasing the ambient relative humidity

3.7.3 Efficiencies of Charcoal Cooler Chamber and Sand Cooler Chamber

Results showed that the efficiency of Charcoal Cooler Chamber in temperature reduction was always higher than that of the Sand Cooler Chamber expect at sixth day of the experiment. The maximum cooling efficiency was 36.8% and 33.0% for Charcoal Cooler Chamber and Sand Cooler Chamber, respectively. The minimum cooling efficiency for the Charcoal Cooler Chamber and the Sand Cooler Chamber was 10.8% and 5.8%, respectively. The average cooling efficiency was 25.92% and 22.15% for the Charcoal Cooler Chamber and Sand Cooler Chamber, respectively (Appendix F).

The performance of the Sand Cooler Chamber in increasing relative humidity was higher than that of the Charcoal Cooler Chamber from the seventh day to the last day of the experiment's monitoring. In initial six days of the monitoring ununiform performance was observed, sometimes the Charcoal Cooler Chamber performed well than Sand Cooler Chamber or vice versa. The maximum efficiency obtained for the Charcoal Cooler Chamber and the Sand Cooler Chamber was 52.2% and 57.1%, respectively, while the lowest efficiency was 3.6% and 4.0%, respectively. For all seventeen days of monitoring, the Charcoal Cooler Chamber and Sand Cooler Chamber had the average efficiency of 26.68% and 30.86% in increasing ambient humidity, respectively (Appendix F).

3.7.4 Correlation between the studied parameters

The results of the correlation analysis showed that there was a strong and significant positive correlation between CCC temperature and SCC temperature ($r = 0.97$), CCC temperature and ambient relative humidity ($r = 0.85$), SCC temperature and ambient relative humidity ($r = 0.80$), ambient temperature and CCC relative humidity ($r = 0.70$), ambient temperature and SCC relative humidity ($r = 0.73$), and CCC relative humidity and SCC relative humidity (r = 0.71), (Appendix E). These existing positive correlations signify that the parameters were varied together. The increase of one parameter tends to increase another parameter, and vice versa. In that regard, it means the cooler's temperature was positively influenced by the ambient relative humidity. The lower the ambient relative humidity, the lower the cooler's temperatures, and vice versa. On other sides, the cooler's relative humidity was positively influenced by the ambient temperature; the higher the ambient temperature, the higher the cooler's relative humidity, and vice versa.

Contrary, significant negative correlations were observed to exist between CCC temperature and ambient temperature (r = -0.58), CCC temperature and CCC relative humidity (r = -0.57), SCC temperature and CCC relative humidity (r = -0.56), ambient temperature and ambient relative humidity (r = -0.84), ambient relative humidity and CCC relative humidity (r = -0.75), and ambient relative humidity and SCC relative humidity (r = -0.67), (Appendix E). Negative and strong correlations reveal that the small values of one variable tend to be associated with large values of the other (inversely proportional). In that regard, it means the cooler's temperature and relative humidity were negatively influenced by the ambient temperature and relative humidity, respectively.

Conclusively, the performance of both systems is expected to be better in dry weather conditions (low relative humidity) than in wet conditions (high relative humidity areas).

3.8 Shelf life for different commodities when stored in Charcoal Cooler Chamber and Sand Cooler Chamber

Table 3, shows the minimum and maximum performance of both constructed evaporative cooling systems. Results showed that at the highest efficiency, both CCC and SCC almost met the prescribed optimum temperature and relative humidity for most perishable crops. Specifically, the ambient temperature could be reduced at maximum performance from 20.6 ^{0}C to 15.8 ^{0}C and to 14.9 ^{0}C for SCC and CCC, respectively. Conversely, the ambient relative humidity almost increased up to prescribed standards for most perishable crops in both systems.

Table 3. Expected shelf life for different perishable crops when stored in constructed SCC and CCC

SCC Temperature and RH achieved (present study)	Ambient Temperature and RH during the monitoring	CCC Temperature and RH achieved (present study)	Types of crops	Recommended Temperature ^{0}C (Cantwell, 1999; Sargent, *et al.*, 2000; McGregor, 1987)	Recommended Humidity % (Cantwell, 1999; Sargent, *et al.*, 2000; McGregor, 1987)	Predicted Shelf life (Days)
Max Temp. = 19.8 ^{0}C	Max Temp. = 24.9 ^{0}C	Max Temp. = 18.9 ^{0}C	Tomatoes	12.5-15	90-95	14-21
Min. Temp. = 15.8 ^{0}C	Min. Temp. = 20.6 ^{0}C	Min. Temp. = 14.9 ^{0}C	Vegetables	0-13 (depending type of vegetable)	90-99	4-14
Max. RH =97%	Max. RH =84.00%	Max. RH =94.75%	Bell Peppers	7-13	90-95	14-21
Min. RH =85.5%	Min. RH =61.75%	Min. RH =87%	Cucumbers	10-13	95	28
			Banana	13-15	90-95	7-28

4. Discussion

Postharvest handling practises in developing countries play a major role in reducing postharvest losses of vegetables, fresh fruits, and other perishable crops. A present study found in Vunjo, 23.4% of cultivated crops were lost per year due to a lack of good and affordable postharvest handling practises. Olayemi *et al.* (2012) reported that 33% of vegetables produced in rural Nigeria were lost during the post-harvest process due to the unavailability of affordable cold storage facilities. In support of these results, Hodges *et al.* (2010) reported that the issues of postharvest in less developed countries are caused by inefficient postharvest agriculture systems. In that regard, it seems that the postharvest losses in developing countries are mainly contributed with lack of good and affordable cold storage technologies. Arah *et al.* (2015) reported that rough handling, improper pre-cooling method selection, poor cleaning and disinfecting methods, improper sorting and grading, poor transportation methods, and unconducive cold storage technologies can affect both the quality and shelf life of harvested crops. Therefore, proper, efficient, and affordable pre-cooling and cold storage technologies are very important. Starting in the initial stage of harvesting, precooling is very important for reducing excessive field heat to optimum conditions. Excessive field heat increases metabolic activity, microbial activity, and respiration rate, causing perishable crop quality to deteriorate quickly (Bachmann and Earles, 2000; Shahi *et al*., 2012). External factors such as humidity, wind, temperature, and rainfall can affect the quality of harvested crops (Grolleaud, 1997). It is known that during transportation it is very difficult to control all these external factors, but at least the most important ones, such as temperature and humidity, should be optimised.

The present study found that the majority (87%) of small farmers/peasants in Vunjo area use local precooling and cold storage methods due to various factors such as financial issues and a lack of grid electricity power supply (Bensch *et al*., 2019). Out of those respondents (N = 30) only 23% were satisfied with their local precooling and cold storage technologies, while the rest were not satisfied at all. Further results showed that most of those who were satisfied were the ones who use mechanical refrigerators due to their efficiency. Low efficiency of their precooling and cold storage was one of the major factors contributing to the postharvest losses. Similarly, Kiaya (2014) mentioned that high cost and unavailability of efficient facilities, hygiene, and effectiveness are among the major factors that cause postharvest losses at farmer level.

In less developed countries, the main source of postharvest losses is biological spoilage. Some perishable crops need refrigeration for long storage (Kiaya, 2014). Low economic status and the unavailability of grid electricity for most of the producers in developing countries increase the barriers to solving postharvest losses. Furthermore, the unpredictable weather conditions pose another difficulty in achieving good and affordable pre-cooling and cold storage methods. Because of these difficulties, most farmers/peasants left their crops in the fields until market availability. The current study found that the floor (46%) and field (33%), are the two most common local precooling and cold storage methods in Vunjo. Further assessment found that field methods are easily affected by weather conditions, and floor methods are characterised by low efficiency, especially at storage stages.

The biological spoilage of vegetables and fresh fruits not only has an indirect effect (economic losses), but sometimes it can cause serious problems to the environment and finally impact human health. Present study found that 77% of all respondents agreed that the main methods of disposing their spoilage crops is directly to the environments. The open dumping method is improper because it can cause the outbreak of communicable and non-communicable diseases. Kjellén (2001) reported that waste that remains uncollected often creates nauseating piles of debris around collection points and on marginal land such as roadsides, gutters, and waterways. Generally, rotten crop waste has a high content of organic material, thus providing breeding grounds for microorganisms and disease-bearing insects. So, due to these scenarios, it is important to manage any kind of waste by looking at the source rather than using end of pipe solutions. Furthermore, Kjellén (2001) reports that between 25% and 33% of the global burden of disease could be attributed to environmental factors. This extent is greater in needy states, where natural hazards are more prevalent in nearby living and working environments, and individuals have less ability to protect themselves against communicable diseases. The present study found that, out of all respondents, 33% agreed that they usually continued to sell their low-quality crops at low prices to consumers. This behaviour could impact the consumer's health if they find themselves using crops that have started to spoil. To solve these problems, the present study tried to employ the evaporative cooling technology and test its suitability for reducing postharvest losses at farmer level in Vunjo areas.

Evaporative cooling technologies are among the oldest cooling technologies. Despite being one of the oldest, it is still used in the food industry, cooling data centers, and the environment for thermal comfort (Watt, 2012). Evaporative cooling is a heat and mass transfer process that uses water evaporation for air cooling, in which large amount of heat is transferred from air to water, and consequently the air temperature decreases. For a long time, many researchers have attempted to use evaporative cooling technology in the pre-cooling and cold storage of fruits and vegetables (Ndukwu *et al*., 2013) and camel milk (Wayua *et al*., 2012), particularly in rural areas where grid electricity is not available. The present study opted to test two evaporation systems, i.e., the Charcoal Cooler Chamber System and Sand Cooler Chamber System. Both systems are working under the principle of evaporative cooling and are water dependent. Based on the availability of water in the case study area (Vunjo), there is no doubt that the water required to keep these systems functioning properly is not a problem. Present study found 93% of small farmers/peasants are satisfied with the water availability.

The selected systems were constructed with local materials to meet the requirements of many farmers/peasants who demanded cheap and affordable technology. The performance of the Charcoal Cooler Chamber was higher in temperature reduction compared to that of Sand Cooler Chamber. It was observed that the Charcoal Cooler Chamber and Sand Cooler Chamber can drop the ambient temperature by a difference of 2.2 °C up to 8.8 °C and 1.2 °C up to 7.8 °C, respectively. Similarly, Wayua (2012) tested the performance of a Charcoal Cooler Chamber in Kenya for camel milk storage and found that the inside cooler temperature was 1 °C to 11 °C lower than the ambient temperature.

Statistical analysis of the present study found the performance of both systems was highly affected by ambient temperature and relative humidity. At low ambient relative humidity (62% -70%), the high cooling efficiencies of both systems were observed. Similarly, Wayua *et al.* (2012) observed the better performance of Charcoal evaporative systems during the afternoon when the ambient temperature was high and the relative humidity was low. On other side, Anyawu (1995) reported that the Sand Cooler Chamber could be used as a cold storage facility in areas that are characterised by low ambient humidity, and that means the lower the humidity, the better the performance. Furthermore, the statistical results showed that the performance of both systems in reducing the ambient temperature and increasing ambient relative humidity was significantly different. This could be due to different construction materials (cooling pads) used on both systems (Chinenye, 2011; Ndukwu *et al*., 2013; Vala *et al*., 2014).

As it is known that to increase the shelf life and quality of fresh harvested vegetables or fresh fruits, two primary factors to be taken into consideration are temperature and relative humidity (National Horticulture Board, 2010). The performance of both systems was assessed based on temperature and humidity alteration. Their performance in temperature reduction and in increasing relative humidity was close to the prescribed standard for different crops cultivated in Vunjo as shown in Table 3. The results of the present study showed that those systems must be designed to meet the storage standard for Tomatoes, cucumbers, vegetables, bell peppers as well as other crops such as bananas, which are the most deteriorated crops in Vunjo at farmer, retailer, and wholesaler level. According to the literatures (as cited in Table 3), the recommended optimum conditions for different perishable crops were achieved at maximum CCC and SCC performance. In that regard, the shelf life for tomatoes expected to be increased from 4 days to (14-21) days, leafy vegetable from 2 days to (4-14) days, bell pepper from 5 days to (14-21) days, cucumbers from 10 days to 28 days and banana from 6 days to (7-28) days. General observation shows that the required standard for storage of these commodities was met, but there were some days when the performance of these systems was below the required standard due to the weather conditions. Despite of the low performance due to weather conditions, it seems these technologies can be used in Vunjo to reduce the post-harvest losses, taking into consideration that the harvesting seasons in Vunjo often fall within the dry seasons.

5. Conclusions

In Vunjo, the majority (87%) of small farmers relied on traditional pre-cooling and cold storage methods, which were unsatisfactory. Therefore, the adoption of affordable, dependable pre-cooling and cold storage techniques is crucial. Charcoal Cooler Chambers and Sand Cooler Chambers, utilizing evaporative cooling, emerge as viable alternatives due to their cost-effectiveness and easy construction materials. The study reveals their strong performance, suitable for on-farm pre-cooling and retailer/wholesaler cold storage. These systems achieve minimum temperatures of 14.9 °C and 15.8 °C, respectively, showing higher efficiency in lower ambient humidity during dry seasons. Additionally, both systems effectively increase relative humidity, with the Charcoal Cooler Chamber reaching 94.75% and the Sand Cooler Chamber achieving 97% maximum. Implementing these technologies not only reduces postharvest losses but also curtails disease outbreaks from mishandled crops. Their applicability extends to similar rural areas with low humidity, though further research is needed to assess real shelf-life extension and adaptability to varying weather conditions.

Conflict of interest

The authors declare that they have no conflict of interest.

Author's contribution statement

Nelson Joseph Msacky devised the general idea, literature reviews, data collection, data analysis, manuscript preparations, and editing; Leopord Sibomana Leonard contributed to work supervision.

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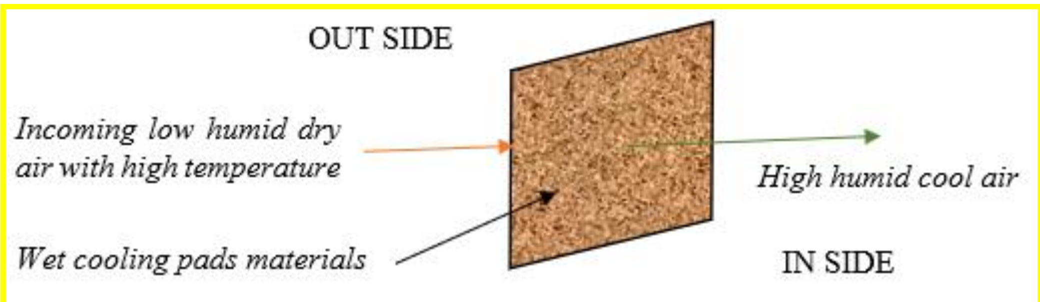
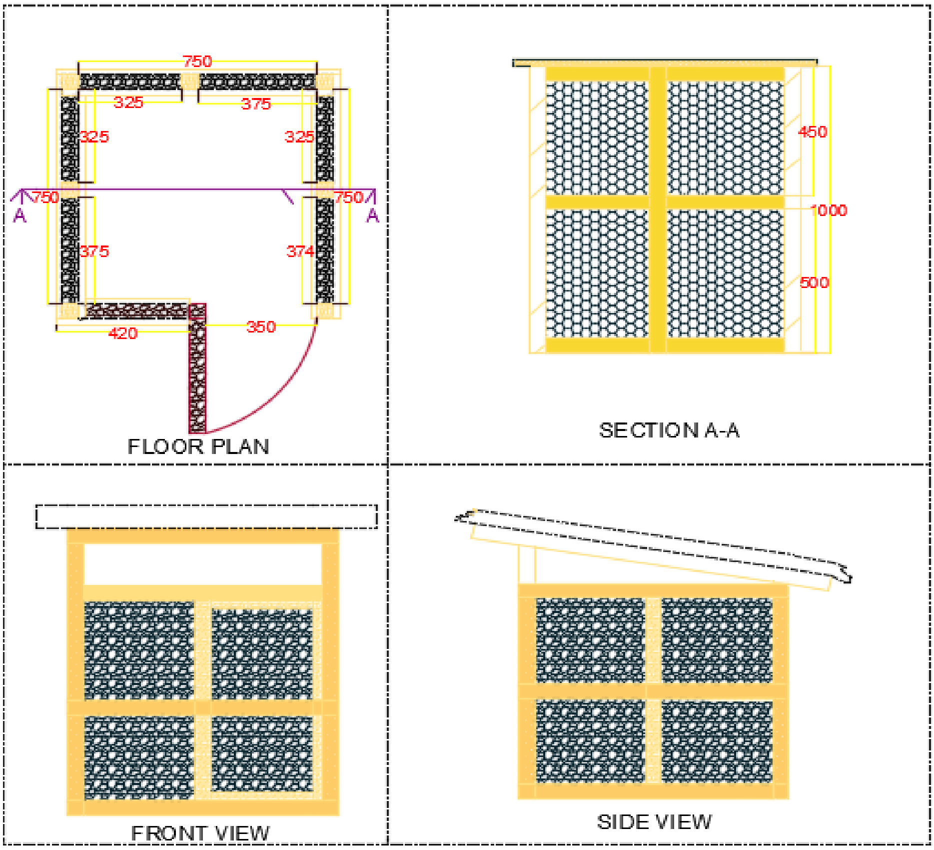
Appendices

Appendix A: Construction materials for Charcoal Cooler Chamber and Sand Cooler Chamber

Appendix B: Mechanism of evaporative cooling process

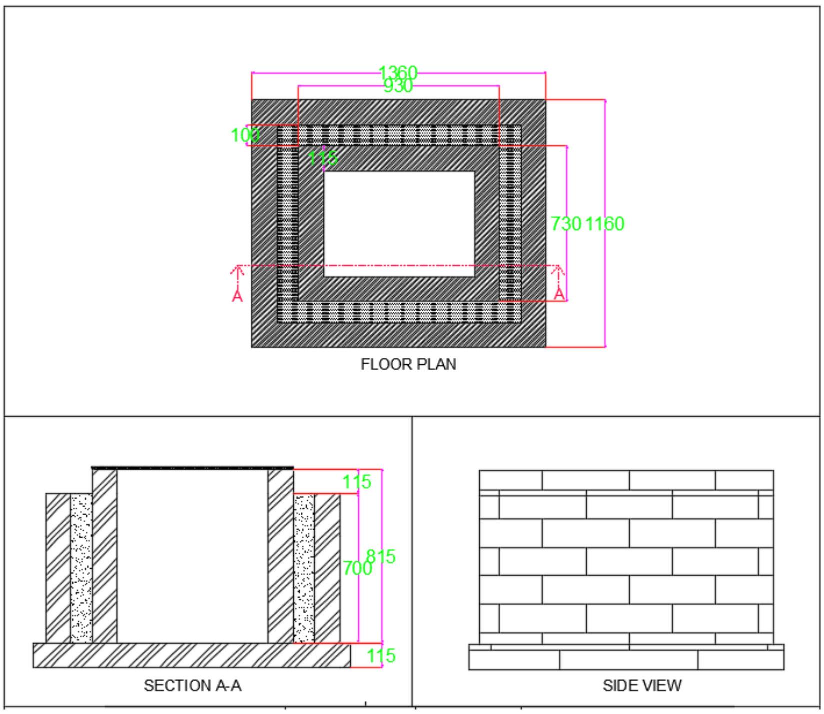


Appendix C: Charcoal Cooler Chamber Engineering Drawings



Note: All dimensions are in mm; Scale 1:20

Appendix D: Static Cooler Chamber Engineering Drawing



Note: All dimensions are in mm; Scale 1:20

Appendix E: Correlation between the studied parameters in both systems

	CCC Temp.	SCC temp.	Ambient temp.	Ambient RH (%)	CCC RH (%)	SCC RH (%)
CCC Temp.	1					
SCC temp.	**0.97**	1				
Ambient temp.	-0.58	-0.57	1			
Ambient RH (%)	**0.85**	**0.80**	-0.84	1		
CCC RH (%)	-0.57	-0.56	**0.70**	-0.75	1	
SCC RH (%)	-0.47	-0.42	**0.73**	-0.67	**0.71**	1

Appendix F: Charcoal Cooler Chamber (CCC) and Sand Cooler Chamber (SCC) monitoring results

Date	CCC Temp. (^0C)	SCC temp. (^0C)	Ambient temp. (^0C)	Ambient RH (%)	CCC RH (%)	SCC RH (%)	CCC Temp Efficiency (%)	SCC Temp. Efficiency (%)	CCC RH Efficiency (%)	SCC RH Efficiency (%)
20/5/2019	18.40	19.50	21.80	82.00	88.00	90.25	15.40	10.30	7.30	10.10
21/5/2019	17.00	18.00	21.90	78.00	92.00	91.00	22.30	17.70	18.30	17.00
22/5/2019	18.90	19.80	23.10	81.00	90.00	94.25	18.20	14.40	11.10	16.40
23/5/2019	18.60	19.70	22.80	82.00	89.00	95.75	18.10	13.40	8.90	17.10
24/5/2019	17.90	18.60	21.50	82.00	87.00	85.50	16.60	13.50	5.80	4.00
25/5/2019	18.30	18.40	22.60	81.00	91.00	91.35	19.10	18.70	12.70	13.10
26/5/2019	18.40	19.40	20.60	84.00	87.00	91.00	10.80	5.80	3.60	8.30
27/5/2019	17.40	18.30	21.80	82.00	89.00	94.00	19.90	15.90	9.20	15.30
28/5/2019	18.50	19.60	24.00	71.00	94.00	97.00	22.80	18.30	33.30	37.60
29/5/2019	16.30	16.10	23.80	70.00	91.50	95.00	31.50	32.20	30.70	35.70
30/5/2019	15.70	16.70	23.60	66.25	89.50	95.50	33.70	29.30	35.10	44.20
31/5/2019	15.40	16.30	23.60	62.00	93.50	97.00	35.00	31.00	50.80	56.50
1/6/2019	16.10	17.20	23.90	61.75	93.75	97.00	32.80	28.00	51.80	57.10
2/6/2019	16.10	17.10	24.90	62.75	90.25	93.75	35.20	31.30	43.80	49.40
3/6/2019	15.10	16.20	23.90	68.75	92.00	96.00	36.80	32.10	33.80	39.60
4/6/2019	15.50	16.40	24.00	62.25	94.75	96.50	35.60	31.70	52.20	55.00
5/6/2019	14.90	15.80	23.50	64.38	93.50	95.50	36.80	33.00	45.20	48.30
Maximum	**18.90**	**19.80**	**24.90**	**84.00**	**94.75**	**97.00**	**36.80**	**33.00**	**52.20**	**57.10**
Average	**16.97**	**17.83**	**23.02**	**73.01**	**90.93**	**93.90**	**25.92**	**22.15**	**26.68**	**30.86**
Minimum	**14.90**	**15.80**	**20.60**	**61.75**	**87.00**	**85.50**	**10.80**	**5.80**	**3.60**	**4.00**
STDEV.	**1.41**	**1.44**	**1.15**	**8.72**	**2.48**	**3.13**	**8.98**	**9.22**	**17.95**	**18.89**