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Development of a Passive Evaporative Cooler for Storage of Tomatoes

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Abstract

A passive evaporative cooling structure was developed for extending the shelf life of tomatoes. The structure was developed as an attempt to solve the problem of temperature management facility which is either absent in the production chain of tomatoes or too expensive and sophisticated to procure and manage by most small scale tomato farmers in Nigeria. The structure was developed using local materials. It has a storage volume of 2.4m^3 and takes advantage of the cooling effect of evaporating water to cool stored tomatoes. It also has cooling pad thickness of 25mmwith an overhead tank which supplies water through a PVC pipe by gravity on the cooling pad to keep it continuously wet. Quality characteristics of stored Mature-green and firm -ripe tomatoes were studied on daily basis at Yola and Ganye concurrently. Results of the study revealed that the extent of cooling of the Passive Evaporative Cooler was6.96 ^{0}C and mean Relative Humidity of 78.3% at Ganye and 7.52 ^{0}C and mean Relative Humidity of 78% at Yola. The efficiency of the structure without load was77.40% at Ganye and 62.00% at Yola. While loaded, the efficiency was67.70% at Ganye and 65.94% at Yola. Under these conditions, deteriorating characteristic such ripening, senescence, infection, and rotting were suppressed by the passive Evaporative Cooler for a period of 21 days for mature-green tomatoes and 14 days for firm-ripe tomatoes. In comparison to the control, the Passive Evaporative Cooler has comparatively less loss.

Keyword: Evaporative cooling, Relative humidity, Ambient temperature, Shelf life, Efficiency

Introduction

One of the major obstacles to the attainment of food security in the tropics is post-harvest losses. This was acknowledged by the United Nations General Assembly in its resolution of September 1975, in which it called on “Countries and competent International organizations” to prioritize reduction in post-harvest losses in developing countries with a view of reaching a 50% reduction by 1985 and to cooperate financially and technically in the effort to achieve this objective (FAO, 2010).

Fruit and Vegetable crops (or horticultural crops) generally, are the most susceptible because of their high water content which make them prone to decay, rot, or spoilage (Bachmann and Earles, 2000). This is exacerbated by poor handling, poor storage, accelerated ripening (also due to poor storage), and loss of water.

Temperature management is the most important single consideration in all post-harvest treatment of perishable crops particularly fruits and vegetables (Bachmann and Earles, 2000; Lisa and Adel, 2003). Lowering temperature to a certain safe limit reduces the rate of biochemical changes (respiration and senescence) in fruits and vegetables and slows down the rate of growth of contaminating micro-organisms (Gustavo *et al.*, 2003). Furthermore, relative humidity needs to be controlled in addition to lowering the temperature (Byczynski, 1997; Bachmann and Earles, 2000) to prevent the fruits and vegetables from wilting and shriveling rapidly.

Evaporative cooling is one of the major means of transferring heat away from horticultural crops and still maintains a relative humidity that is conducive for cold storage of fruits and vegetables. Heat in the air is utilized to evaporate the water resulting in a drop in the air temperature and increase in its relative humidity (Jiang and Akira, 2010; Dzivama *et al*., 2007).

Tomatoes (*Lycopersicon esculentum*) are one of the widely grown and commercially important fruits and vegetables cultivated in many regions of the world. It is a source of food minerals and vitamins especially vitamins A and C. Studies showed that people who eat large amount of tomatoes or tomato products may be at lower risk of some kinds of cancer especially cancer of the prostrate, lung and stomach (Pardee, 2009). It has the ability to thrive on almost any well-drained fertile soil. It is grown both as rain fed and irrigation fed crop. In spite of the importance of this crop however, its storage and preservation in fresh form is a major constrain to farmers (Amratlal *et al.,* (2013). Locally, fresh tomatoes are stored in baskets, spread on mats or clean sand or clean floor, all under a shade or in a room. Usually, tomatoes stored this way do not take long time to ripen and reach senescence, got infected and or got rotten. These conditions have hampered the cultivation of the crop in spite of its economic importance.

Material and Methods

The general objective of this study is to prolong the shelf life of fresh tomatoes and other perishable agricultural products to maximize profit for farmer while the specific objective of the study is to develop a small scale evaporative cooling storage system that is affordable to the small scale farmers.

The major load on the walls of the house is the roof: the roof is made of thatch and 50mmx50mm wood. This load is supported by wooden beams and pillars made of 50mm x 100mm wooden poles.

The walls/pads were made of charcoal and jute materials: it is made of two sheets of wire mesh with chunks of charcoal between them and held together by light wires. The wire mesh was covered with jute material (Frank and Conant, 2010; Shitanda, 2011).

The Passive Evaporative Cooler has three strata and a vent close to the roof to allow warmer air to escape; Shitanda, (2011). The vertical distance between the strata was informed by the report of Lisa and Adel (2003) that interval of about 2.5cm between stored fruits and vegetables are sufficient to allow produce to cool quickly.

Firm ripe and mature green tomatoes were bought from the local farmers in Ganye. All were cleaned and sorted out so that healthy fruits were used. The two groups were then each shared into two: one of each is stored on the three strata of the Passive Evaporative Cooler. The other one of each group is store in a basket in a shade as a control experiment. This is to study the effect of the Passive Evaporative Cooler on ripening, senescence, infection, and rotting in mature-green fruits.

The storage structure was sectioned into two: the left wing (the whole of the left hand side of the entrance) and the right wing (the whole of the right hand side of the entrance). The right wing carried the firm-ripe fruit while the left wing carried the mature-green fruit.

The wall/cooling pad was kept moist by water dripping from orifices in the PVC pipe by gravity. The water flow is regulated by a valve close to the water tank. The structure was sited under a life tree for a shade: to take advantage of cooler nature of shade from lining plants occasioned by transpiration. This view agrees with the report of kitinoja and Kader, (2003) that shade from a living plant is cooler due to transpiration. Figure7 showed the sketch of the storage structure.

Design Calculation/Design Detail

Floor and wall dimension

Floor dimension of 1m x 2m or 2m^2 was used. This dimension is chosen as an attempt to have a structure that tends to a square to aid cooling (Lisa and Adel, 2003). Figure 1 is a sketch of the cooler.

Wall thickness

The 25mm thick charcoal pad forms the wall and it was chosen because the system is passively cooled. (Kheirabadi, 1991).

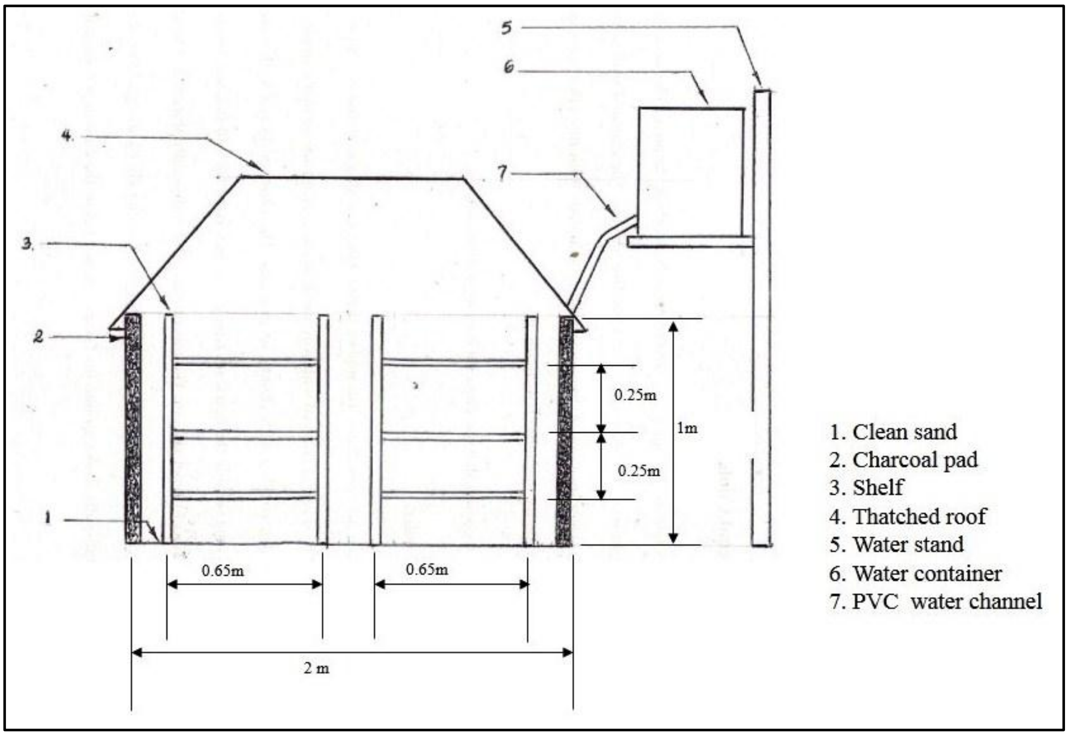

Figure 1: A sketch of the storage structure (not to scale)

Storage space volume

A storage space volume of 1m x 2m x 1.2m or 2.4m^3 was used. Of this storage space, 15cm distance was allowed between the wall and the shelf carrying the fruits; and 40cm.

Rack dimension

The shelves were of dimension 65cm x 75cm. Each shelf carried three layers of stored produce. The shelves were spaced 30cm from each other. Lisa and Adel, (2003) reported that an interval of about 2.5cm is sufficient to allow produce to cool quickly. Figure 2 is the blow out view of the cooler.

Thermal Properties (R – value) of Materials

The thermal properties (R – value) of some of the materials used for construction of the storage structure are listed in Table 1.

Table 1: Thermal properties (R –value) of some of the materials used inthe construction

S/No	Material to be Used	Thermal Property (R – Value) Per Inch
1.	Thatch materials (cellulose)	3.13 – 3.70
2.	wood (about 25cm cross-sectional)	2.50
3.	Locally made ropes (cellulose)	3.13 – 3.70
4.	2"x4" wood	2.50
5.	Chunks of charcoal	-
6.	Jute material (cellulose)	3.13 – 3.70
7.	Chicken mesh	<0.01
8.	Binding wire (30 gauge)	<0.01
9.	Nails	<0.01
10.	1in diameter PVC pipe	

Source: Structures and Environmental Handbook. MWPS-1. 11th ed. (1983); Boyette, et al., (1991). Design of Room Cooling Facility: Structural and Energy Requirement. North Carolina Agricultural Extension Service

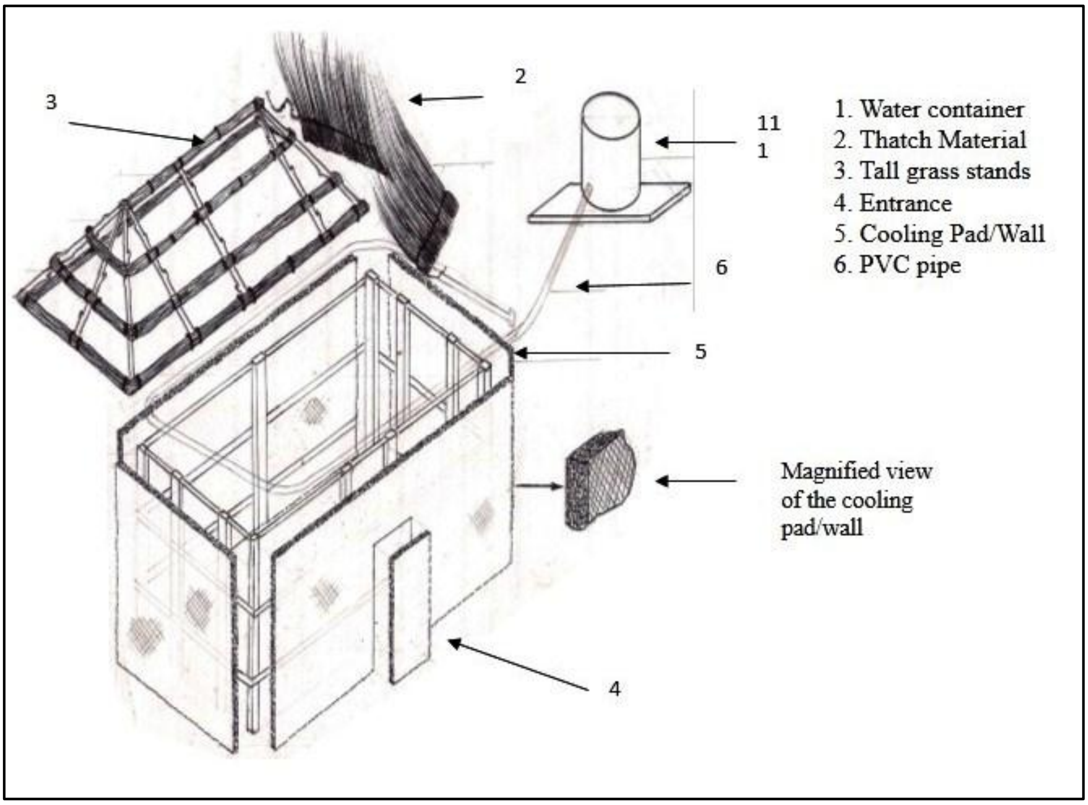

Figure 2: Blow-out view of the Passive Evaporative Cooler

Efficiency of the Passive Evaporative Cooler was computed using the relationship.

$T_L = T_a - [(T_a - T_w) \times \eta]$ (Hewett, 1999)

Where:

T_L = Temperature of air leaving the cooler (Dry-Bulb Temperature),

T_a = Ambient temperature,

T_w = Wet bulb temperature,

η = Efficiency of the evaporative media.

Cooling pad evaluation

Cooling pad evaluation is obtained from the relation.

$$E_{cooling} = \frac{\Delta_T}{T_d - T_w}$$

Where:

$E_{cooling}$ = Cooling efficiency

Δ_T = change in actual temperature,

T_d = dry bulb temperature,

T_w = wet bulb temperature.

Results obtained from the two formulae are in tables 2 and 3.

Results and Discussion

In order to evaluate the performance of the Cooler, some psychrometric properties (ambient temperature, dry bulb temperature and wet bulb temperature) of the storage structure were recorded while the structure is without load (Table 2); relative humidity was obtained from the psychrometric chart for each day. The same data were later taken while the Cooler is loaded with mature-green, and firm-ripe tomatoes – each in some separate group (Table 3). Performance of the storage structure was determined while it was without load and while loaded.

Table 2: Result of No Load Test of the Passive Evaporative Cooler at Ganye and Yola.

Properties	Ganye	Yola
Mean Wet bulb temperature (^{0}C)	24.03	23.23
Mean Dry bulb Temperature (^{0}C)	26.80	26.80
Mean ambient temperature (^{0}C)	32.63	32.63
Mean Relative Humidity (%)	78.03	78.00
Extent of Cooling (^{0}C)	5.53	5.83
Efficiency (%)	77.40	62.00
Cooling pad efficiency (%)	64.30	62.00

Table 3: Result of Loaded Test of the Passive Evaporative Cooler at Ganye and Yola.

Properties	Ganye	Yola
Mean Wet bulb temperature (^{0}C)	22.20	21.76
Mean Dry bulb Temperature (^{0}C)	25.52	25.67
Mean ambient temperature (^{0}C)	32.48	33.16
Mean Relative Humidity (%)	76.92	75.88
Extent of Cooling (^{0}C)	6.96	7.52
Efficiency (%)	67.70	65.94
Cooling pad efficiency (%)	74.30	66.00

Results obtained by observing the impact of the Passive Evaporative Cooler on ripening, senescence, infection, and rot in mature-green (M-G) tomatoes; and senescence, infection, and rot in firm-ripe (F-R) tomatoes at Ganye and Yola were subjected to Analysis of Variance in comparison with local storage method. The results obtained are reported in Tables 4 to 11.

In Table 4, result of Analysis of Variance (ANOVA) on mean performance of Passive Evaporative Cooler (PEC) on ripening compared to the control obtained at Ganye is significant ($p<0.05$). In Table 5, similar result was obtained in Yola. This implies that the fruits ripe slower in the PEC. This result is attributed to the lower temperature in the storage facility. Lower temperatures slow down the ripening process. This agrees with the report of Gustavo *etal*., (2003) that lowering the temperature of a storage facility impedes ripening amongst other physiological activities of fruits and vegetables. Thus, the Cooling structure is able to delay ripening of tomatoes.

Table 6 showed that the effect of the Passive Evaporative Cooler (PEC) on senescence of tomatoes at Ganye and Yola respectively compared with the ambient condition is significant ($p<0.05$). This implies that the Cooler was able to slow down the rate of senescence in the stored fruits at both sites in both firm-ripe and mature green-tomatoes. This agrees with the report of Kitinoja and Kader (2003) that senescence (physiological activity) will be slowed down when temperature is reduced and relative humidity is increased.

Table 4: Mean Performance of Passive Evaporative Cooler compared to Ambient Condition on ripening of Tomatoes in storage at Ganye

					Days			
Treatment	1	2	3	4	5	6	7	8
Storage condition								
PEC			0.00b	0.00a	0.00a	0.00a	0.00a	0.00a
Ambient			30.00a	0.00a	0.00a	0.00a	0.00a	0.00a
Mean			15.00	0.00	0.00	0.00	0.00	0.00
P α f			0.00	.	.	.	.	.
Fruit type								
F-R			0.00b	0.00a	0.00a	0.00a	0.00a	0.00a
M-G			30.00a	0.00a	0.00a	0.00a	0.00a	0.00a
Mean			15.00	0.00	0.00	0.00	0.00	0.00
P α f			0.00	.	.	.	.	.
Size								
Large (1)			15.00a	0.00a	0.00a	0.00a	0.00a	0.00a
Medium (2)			15.00a	0.00a	0.00a	0.00a	0.00a	0.00a
Small			15.00a	0.00a	0.00a	0.00a	0.00a	0.00a
Mean			15.00	0.00	0.00	0.00	0.00	0.00
P α f			1.00	.	.	.	.	.

Mean with same letter in the same column are not significantly different.

Table 5: Mean Performance of Passive Evaporative Cooler compared to Ambient Condition on ripening of Tomatoes in storage at Yola

					Days			
Treatment	1	2	3	4	5	6	7	8
Storage condition								
PEC		0.00b	0.00b	0.00a	0.06a	0.33a	0.50a	0.78a
Ambient		3.00a	27.00a	0.00a	0.00a	0.00a	0.00a	0.00a
Mean		1.5	13.50	0.00	0.03	0.17	0.25	0.39
P α f		0.00	0.00	.	.	.	.	.
Fruit type								
F-R		0.00b	0.00b	0.00a	0.00a	0.00a	0.00a	0.00b
M-G		3.00a	27.00a	0.00a	0.06a	0.33a	0.50a	0.78a
Mean		1.50	13.50	0.00	0.03	0.17	0.25	0.39
P α f		0.00	0.00	.	0.33	1.00	0.03	0.00
Size								
Large (1)		1.42a	13.58a	0.00a	0.08a	0.08a	0.17a	0.33a
Medium (2)		1.58a	13.42a	0.00a	0.00a	0.17a	0.25a	0.33a
Small		1.50a	13.50a	0.00a	0.03a	0.25a	0.33a	0.50a
Mean		1.50	13.50	0.00	0.38	0.17	0.25	0.39
P α f		0.89	1.00	.	.	0.71	0.81	0.67

Mean with same letter in the same column are not significantly different.

Table 6: Mean Performance of Passive Evaporative Cooler and Ambient Condition on Senescence of Tomatoes in storage at Ganye

Trtmnt	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**
Strg cndtn																								
PEC	0.00a	0.00b	0.00b	0.28b	0.11b	0.11b	0.11b	0.61a	0.72a	0.22a	0.33a	0.89a	0.78a	0.33a	0.17a	0.22a	0.11a	0.33a	0.11a	0.17a	0.33a	0.11a	0.22a	0.00
Ambnt	0.56a	2.44a	3.78a	5.17	3.83a	6.56a	13.39a	0.00b	0.00b	0.00a	0.00b	0.00b	0.00b	0.00b	0.00a	0.00a	0.06a	0.00a	0.06	0.00a	0.17a	0.00a	0.00a	0.00
Mean	0.28	1.22	1.89	2.72	1.97	3.33	6.75	0.31	0.36	0.11	0.17	0.00	0.39	0.17	0.08	0.11	0.06	0.17	0.33	0.08	0.17a	0.06	0.11	0.00
Pαf	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.12	0.01	7.11	0.00	0.01	0.10	0.12	0.11	0.00	0.11	0.10	1.00	0.17	0.09	.
Frt																								
F-R	0.56a	1.56a	3.39a	5.06a	1.39a	0.11a	0.11b	0.61a	0.11b	0.06a	0.22a	0.39a	0.44a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00
M-G	0.00b	0.89b	0.39b	0.39b	2.56a	6.56a	13.39a	0.00b	0.60a	0.17a	0.11a	0.50a	0.33a	0.33a	0.17a	0.22a	0.11a	0.33a	0.11a	0.17a	0.33a	0.11a	0.22a	0.00
Mean	0.28	1.22	1.89	2.72	1.97	3.33	6.75	0.31	0.36	0.11	0.17	0.44	0.39	0.17	0.08	0.11	0.06	0.17	0.06	0.08	0.17	0.06	0.11	0.00
Pαf	0.99	0.01	0.00	0.00	0.07	0.00	0.01	0.01	0.00	0.42	0.33	0.64	0.11	0.01	0.10	0.44	0.06	0.00	0.11	0.10	0.17	0.17	0.09	.
Size																								
Large(1)	0.17a	1.25a	1.42a	2.58a	2.75a	2.50a	8.42a	0.33ba	0.16b	0.00a	0.08a	0.42a	0.25b	0.25a	0.08a	8.08a	0.00b	0.08b	0.00a	0.08a	0.08a	0.08a	0.00a	0.00
medium(2)	0.25a	1.08a	1.58a	2.58a	1.50a	3.58a	7.58a	0.58a	0.08a	0.17a	0.33a	0.42a	0.33ba	0.12a	0.08a	0.00a	0.00b	0.33a	0.17a	0.08a	0.08a	0.08a	0.17a	0.00
Small (3)	0.42a	1.33a	2.67a	3.50a	1.67a	3.92a	4.25a	0.00b	0.83a	0.17a	0.08a	0.50a	0.58a	0.08a	0.08a	0.17a	0.17b	0.08b	0.00a	0.08a	0.33a	0.00a	0.17a	0.00
Mean	0.28	1.22	1.89	2.72	1.97	3.33	6.75	0.31	0.36	0.11	0.17	0.44	0.39	0.17	0.08	0.11	0.06	0.17	0.06	0.08	0.17	0.06	0.11	0.00
C	0.27	0.70	0.16	0.39	0.21	0.54	0.75	0.09	0.00	0.52	0.13	0.95	0.10	0.57	1.00	0.85	0.03	0.06	0.38	1.00	0.61	0.61	0.46	.

Mean with same letter in the same column are not significantly different.

Table 7: Mean Performance of Passive Evaporative Cooler and Ambient Condition on Senescence of Tomatoes in storage at Yola

Trtmnt	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**
Strg cndtn																								
PEC	0.00b	0.00b	0.11b	0.11b	0.22b	0.39b	0.56b	0.33a	0.44a	0.56a	0.61a	0.39a	0.17a	0.28a	0.28a	0.11a	0.11a	0.06a	0.22	0.17a	0.00a	0.00a	0.11a	0.00
Ambnt	1.10a	3.11a	4.67a	3.94a	4.22a	6.44a	13.11a	0.00a	0.00b	0.00b	0.00b	0.00b	0.00b	0.00b	0.00b	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00
Mean	2.56	1,56	2.39	2.03	2.22	3.42	6.83	0.17	0.22	0.28	0.31	0.19	0.08	0.14	0.14	0.06	0.06	0.03	0.11	0.08	0.00	0.00	0.06	0.00
Pαf	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.22	0.00	0.00	0.02	0.00	0.02	0.04	0.18	0.33	0.33	0.01	0.10	.	.	0.18	.
Frt																								
F-R	1.06a	2,17a	3.72a	3.67a	1.89a	0.22b	0.22a	0.22a	0.22a	0.39a	0.28a	0.28a	0.17a	0.56a	0.00b	0.00a	0.00a	0.00a	0.00a	0.00a	0.00	0.00	0.00a	0.00
M-G	0.00b	0.94b	1.06b	0.38b	2.56a	6.61a	13.44a	0.11a	0.22a	0.17a	0.33a	0.11a	0.00b	0.22a	0.28a	0.11a	0.11a	0.07a	0.22a	0.17a	0.00	0.00	0.11a	0.00
Mean	0.53	1.56	2.39	2.03	2.22	3.42	6.83	0.17	0.22	0.28	0.31	0.17	0.08	0.14	0.14	0.06	0.06	0.03	0.11	0.08	.	.	0.06	.
Pαf	0.00	0.01	0.00	0.00	0.75	0.00	0.00	0.11	1.00	0.05	0.65	0.28	0.00	0.16	0.04	0.18	0.32	0.32	0.11	0.10	.	.	0.18	.
Size																								
Large(1)	0.33a	1.17a	2.42a	2.92a	2.33a	2.33a	0.58a	0.00a	0.08a	0.25a	0.25a	0.17a	0.25a	0.08a	0.08a	0.08a	0.00a	0.08a	0.00a	0.08a	0.00a	0.00a	0.08a	
medium(2)	0.42a	1.50a	1.92a	2.17a	3.75a	3.75a	7.25a	0.23a	0.33a	0.33a	0.33a	0.17a	0.00b	0.17a	0.17a	0.08a	0.00a	0.00a	0.17a	0.08a	0.00a	0.00a	0.00a	
Small (3)	0.83a	2.00a	1.75a	1.58a	4.17a	4.17a	4.67a	0.25a	0.25a	0.25a	0.33a	0.25a	0.00b	0.17a	0.17a	0.00a	0.17a	0.00a	0.17a	0.08a	0.00a	0.00a	0.06a	
Mean	0.53	1.56	2.03	2.22	3.42	3.42	6.83	0.17	0.22	0.22	0.31	0.19	0.08	0.14	0.14	0.06	0.06	0.03	0.11	0.08	.	.	0.62	
C	0.01	0.25	0.56	0.21	0.41	0.41	0.58	0.15	0.29	0.77	0.81	0.87	0.00	0.79	0.79	0.62	0.38	0.38	0.17	1.00	.	.	0.03	

Mean with same letter in the same column are not significantly different.

On Table 8, the mean performance of the Passive Evaporative Cooler (PEC) on infection of tomatoes at Ganye is significant (p<0.05) in the first 14 days of storage, after the first fourteen days, the mean performance is not significant while in Table 9, the result at Yola indicates significance (p<0.05) in the first six days and on the tenth, sixteenth, eighteenth, twenty-first, twenty-fourth and twenty-fifth days of storage (total of twelve days). The performance was not significant on subsequent days. The facility was able to inhibit infection of tomatoes at both Ganye and Yola for some days. Subsequently, the rate of suppression of infection by the facility depreciates.

In the storage facility, fruit type (mature-green and firm-ripe), and size of fruits (small, medium or large) has no significance on infection of the stored fruits at Yola. This is true because infection is an external influence mostly determined by how healthy and nourished a fruit is, not by fruit type or fruit size.

Table 8: Mean Performance of Passive Evaporative Cooler and Ambient Condition on Infection of Tomatoes in Storage at Ganye

	Days																							
Trtmnt	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Sto. Con																								
PEC	0.00b	0.00b	0.00b	0.06b	0.06b	0.00a	0.06a	0.00a	0.00a	0.11a	0.28a	0.17a	0.22a	0.00a	0.11a	0.06a	0.00a	0.11a	0.00a	0.00a	0.06a	0.00a	0.17a	0.00a
Amb	0.22a	1.00a	2.67a	2.39a	2.39a	0.50a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00b	0.00b	0.00a	0.00b	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a
Mean	0.11	0.50	1.33	1.22	1.22	0.25	0.03	0.03	0.00	0.06	0.14	0.08	0.11	0.00	0.06	0.03	0.00	0.006	0.00	0.00	0.03	0.00	0.08	0.00
Pαf	0.00	0.00	0.00	0.01	0.01	0.13	0.33	0.32	.	0.17	0.18	0.04	0.03	.	0.17	0.33	.	0.17	.	.	0.33	.	0.10	.
Frt																								
F-R	0.22a	0.78a	0.56a	3.61a	1.67b	0.00a	0.00a	0.06a	0.00a	0.56a	0.11a	0.06a	0.11a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a
M-G	0.00b	0.22b	0.11b	0.22b	2.28a	0.50a	0.06	0.00a	0.00a	0.56a	0.17a	0.11a	0.11a	0.00a	0.11a	0.06a	0.00a	0.11a	0.00a	0.00a	0.06a	0.00a	0.17a	0.00a
mean	0.11	0.50	1.33	1.92	1.22	0.25	0.03	0.03	0.00	0.56	0.14	0.08	0.11	0.00	0.06	0.03	0.00	0.09	0.00	0.00	0.03	0.00	0.08	0.00
Pαf	0.09	0.02	0.02	0.00	0.02	0.15	0.32	0.32	.	1.00	0.78	0.49	1.00	.	0.17	0.33	.	0.17	.	.	0.33	.	1.00	.
Size																								
Lrg (1)	0.00a	0.25a	0.42a	1.33a	0.50a	0.08a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00b	0.00a	0.08a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.08a	0.00a
Med(2)	0.17a	0.75a	1,67a	2.67a	0.75a	0.33a	0.08a	0.00a	0.00a	0.17a	0.17a	0.08a	0.08ba	0.00a	0.00a	0.00a	0.00a	0.08a	0.00a	0.00a	0.08a	0,00a	0.08a	0.00a
Smll(3)	0.17a	0.50	1.92a	1.75a	2.41a	0.33a	0.00a	0.08a	0.00a	0.00a	0.25a	0.17a	0.25a	0.00a	0.08a	0.08a	0.00a	0.08a	0.00a	0.00a	0.08a	0.00a	0.08a	0.00a
Mean	0.11	0.50	1.33	1.92	1.22	0.25	0.03	0.03	.	0.06	0.14	0.08	0.11	0.00	0.06	0.03	0.00	0.06	0.00	0.00	0.03	0.00	0.08	0.00
Pαf	016	0.19	0.19	0.51	0.13	0.76	038	0.38		0.16	0.56	0.24	0.12	.	0.61	0.38	.	0.01	.	.	0.38	.	1.00	.

Mean with same letter in the same column are not significantly different.

Table 9: Mean Performance of Passive Evaporative Cooler and Ambient Condition on Infection of Tomatoes in Storage at Yola

	Days																							
Trtmnt	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Sto. Con																								
PEC	0.00a	0.00b	0.00b	0.05b	0.06b	0.28a	0.06a	0.11a	0.00a	0.06a	0.22a	0.17a	1.50a	0.22a	0.00a	0.06a	0.00a	0.06a	0.06a	0.00a	0.06a	0.11a	0.17a	0.00a
Amb	0.61a	1.72a	3.94a	2.39b	1.11a	0.28a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00b	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a
Mean	0.31	0.86	1.92	1.22	0.58	0.28	0.03	0.06	0.00	0.03	0.11	0.08	0.75	0.11	0.00	0.03	0.00	0.03	0.03	0.00	0.03	0.06	0.08	0.00
Pαf	0.00	0.00	0.00	0.00	0.00	1.00	0.33	0.18	.	0.33	0.07	0.00	0.00	0.13	.	0.33	.	0.33	0.33	.	0.33	0.15	0.10	.
Frt																								
F-R	0.00b	1.28a	3.33a	2.28a	0.17b	0.11b	0.00a	0.06a	0.00a	0.00a	0.11a	0.06a	1.50a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a
M-G	0.00b	0.44b	0.61b	0.17a	1.00a	0.44b	0.06a	0.06a	0.00a	0.06a	0.11a	0.11a	0.00a	0.22a	0.00a	0.06a	0.00a	0.05a	0.06a	0.00a	0.06a	0.11a	0.17a	0.00a
mean	0.31	0.86	1.97	1.22	0.58	0.28	0.03	0.06	0.00	0.03	0.11	0.08	0.75	0.11	0.00	0.03	0.00	0.03	0.03	0.00	0.03	0.00	0.08	0.00
Pαf	0.00	0.02	0.00	0.00	0.00	0.02	0.33	1.00	.	0.33	1.00	0.57	0.00	0.13	.	0.33	.	0.33	0.33	.	0.33	0.15	1.00	.
Size																								
Lrg (1)	0.17a	0.50a	1.58a	1.67a	0.42a	0.25a	0.00a	0.08a	0.00a	0.00a	0.17a	0.08a	0.00b	008a	0.00a	0.00a	0.00a	0.00a	0.08a	0.00a	0.08a	0.00a	0.08a	0.00a
Med(2)	0.25a	0.67ab	1.75a	1.58a	0.42a	0.17a	0.00a	0.08a	0.00a	0.00a	0.08a	0.17a	0.00b	0.17a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.08a	0.08a	0.00a
Smll(3)	0.50a	1.42a	2.58a	0.42b	0.92a	0.42a	0.08a	0.00a	0.00a	0.08a	0.08a	0.00a	2.25a	0.08a	0.00a	0.08a	0.00a	0.08a	0.00b	0.00a	0.00a	0.08a	0.08a	0.00a
Mean	0.31	0.86	1.97	1.22	0.58	0.28	0.03	0.06	0.00	0.03	0.11	0.08	0.75	0.11	0.00	0.03	0.00	0.03	0.03	0.00	0.03	0.06	0.08	0.00
Pαf	0.28	0.09	0.12	0.00	0.22	0.33	0.38	0.63	.	0.38	0.79	0.38	0.00	0.86	.	0.38	.	0.38	0.38	.	0.38	0.59	1.00	.

Mean with same letter in the same column are not significantly different.

Table 10: Mean Performance of Passive Evaporative Cooler and Ambient Condition on Rot of Tomatoes in Storage at Ganye

	Days																							
treatment	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Sto. Con																								
PEC	0.00a	0.00b	0.00b	0.17b	0.00b	0.06a	0.11a	0.17a	0.00a	0.28a	0.06a	0.17a	0.06a	0.22a	0.17a	0.00a	0.11a	0.00a	0.11a	0.00a	0.11a	0.17a	0.06a	0.00a
Amb	0.33a	1.17a	3.89a	4.28a	0.77a	0.11a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a
Mean	0.17	0.58	1.94	2.22	0.39	0.83	0.06	0.08	0.00	0.14	0.03	0.08	0.03	0.11	0.08	0.0	0.06	0.00	0.06	0.00	0.06	0.08	0.03	0.00
Pαf	0.01	0.00	0.00	0.00	0.00	0.57	0.17	0.10	.	0.14	0.33	0.10	0.33	0.12	0.96	.	0.17	.	0.17	.	0.17	0.10	0.33	.
Frt																								
F-R	0.33a	0.94a	3.78a	4.11a	0.33a	0.06a	0.11a	0.00a	0.00a	0.27a	0.06a	0.11a	0.06a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a
M-G	0.00b	0.22a	0.11b	0.33a	0.44a	0.11a	0.00a	0.17a	0.00a	0.00a	0.00a	0.06a	0.00a	0.22a	0.17a	0.00a	0.11a	0.00a	0.11a	0.00a	0.11a	0.17a	0.06a	0.00a
mean	0.17	0.58	1.94	2.22	0.39	0.83	0.06	0.08	0.00	0.14	0.03	0.08	0.03	0.11	0.08	0.00	0.06	0.00	0.06	0.00	0.06	0.08	0.03	0.00
Pαf	0.13	0.00	0.00	0.00	0.51	0.57	0.17	0.10	.	0.14	0.33	0.57	0.33	0.12	0.96	.	0.17	.	0.17	.	0.17	0.10	0.33	.
Size																								
Lrg (1)	0.08a	0.33a	1.33a	2.75a	0.42a	0.08a	0.08a	0.08a	0.00a	0.08a	0.00a	0.08a	0.08a	0.17a	0.08a	0.00a	0.08a	0.00a	0.08a	0.00a	0.08a	0.08a	0.00a	0.00a
Med(2)	0.17a	0.42a	1.92a	3.33ab	0.25a	0.08a	0.08a	0.08a	0.00a	0.08a	0.08a	0.08a	0.08a	0.08a	0.08a	0.00a	0.08a	0.00a	0.08a	0.00a	0.00a	0.08a	0.00a	0.00a
Smll(3)	0.25a	1.00a	2.98a	0.58ab	0.50a	0.08a	0.00a	0.08a	0.00a	0.25a	0.00a	0.08a	0.00a	0.08a	0.08a	0.00a	0.00a	0.00a	0.00a	0.00a	0.08a	0.08a	0.08a	0.00a
Mean	0.17	0.58	1.94	2.22	0.39	0.08	0.06	0.08	0.00	0.14	0.03	0.08	0.03	0.11	0.08	0.00	0.06	0.00	0.06	0.00	0.06	0.08	0.03	0.00
Pαf	0.50	0.00	0.47	0.08	0.47	1.00	0.61	1.00	.	0.70	0.38	1.00	0.38	0.85	1.00	.	0.61	.	0.61	.	0.61	1.00	0.38	.

Mean with same letter in the same column are not significantly different.

Table 11: Mean Performance of Passive Evaporative Cooler and Ambient Condition on Rot of Tomatoes in Storage at Yola

	Days																							
Trtmnt	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Sto. Con																								
PEC	0.00a	0.00b	0.06b	0.00b	0.33a	0.17a	0.22a	0.06a	0.00a	0.06a	0.00a	0.11a	0.06a	0.06a	0.00a	0.06a	0.00a	0.00a	0.06a	0.06a	0.00a	0.11a	0.00a	0.00a
Amb	0.83a	2.61a	4.67a	3.83a	0.72a	0.11a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a
Mean	0.41	1.31	2.31	1.92	0.53	0.14	0.11	0.28	0.00	0.03	0.00	0.06	0.03	0.03	0.00	0.03	0.00	0.00	0.03	0.03	0.00	0.06	0.00	0.00
Pαf	0.00	0.00	0.00	0.00	0.18	0.63	0.05	0.33	.	0.33	.	0.15	0.33	0.33	.	0.33	.	.	0.33	0.33	.	0.18	.	.
Frt																								
F-R	0.83a	1.50a	4.28a	3.56a	0.39a	0.17a	0.11a	0.56a	0.00a	0.06a	0.00a	0.06a	0.06a	0.56a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a
M-G	0.00b	1.11a	0.44b	0.28b	0.67a	0.11a	0.11a	0.00a	0.00a	0.00a	0.00a	0.06a	0.00a	0.00a	0.00a	0.06a	0.00a	0.00a	0.06a	0.06a	0.00a	0.11a	0.00a	0.00a
mean	0.42	1.31	2.36	1.92	0.53	0.14	0.11	0.28	0.00	0.03	0.00	0.06	0.03	0.03	0.00	0.03	0.00	0.00	0.03	0.03	0.00	0.06	0.00	0.00
Pαf	0.00	0.41	0.00	0.00	0.33	0.63	1.00	0.33	.	0.33	.	1.00	0.33	0.33	.	0.33	.	.	0.33	0.33	.	0.16	.	.
Size																								
Lrg (1)	0.25a	0.58b	1.58b	2.58a	0.59a	0.08a	0.00a	0.00a	0.00a	0.00a	0.00a	0.08a	0.08a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.08a	0.00a	0.08a	0.00a	0.00a
Med(2)	0.42a	1.08ba	2.08b	3.00a	0.33a	0.25a	0.17a	0.00a	0.00a	0.00a	0.00a	0.08a	0.08a	0.00a	0.00a	0.00a	0.00a	0.00a	0.08a	0.00a	0.00a	0.08a	0.00a	0.00a
Smll(3)	0.58a	2,25a	3.42a	0.17b	0.75a	0.08a	0.17a	0.08a	0.00a	0.08a	0.00a	0.00a	0.00a	0.08a	0.00a	0.08a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a
Mean	0.42	1.31	2.36	1.92	0.53	0.14	0.11	0.28	0.00	0.03	0.00	0.06	0.03	0.03	0.00	0.03	0.00	0.00	0.03	0.03	0.00	0.06	0.00	0.00
Pαf	0.59	0.02	001	0.00	0.48	0.41	0.36	0.38	.	0.38	.	0.59	0.38	0.38	.	0.38	.	.	0.38	0.38	.	0.63	.	.

Mean with same letter in the same column are not significantly different.

In Table 10, mean performance of the Passive Evaporative Cooler on rot of tomatoes compared with rot of tomatoes under ambient condition – that is the method employed by local farmers in Ganye is significant in the first 7 days of storage ($p<0.05$), and on tenth, seventeenth, nineteenth, twenty-first and twenty-fifth days (total of twelve days). It is not significant in the rest of the days. In Table 11, the mean performance of the PEC on rot of tomatoes at Yola compared to that of the ambient condition in the same location is significant ($p<0.05$) in the first five days of storage, and on the tenth, twelfth, sixteenth, eighteenth, nineteenth, twenty-second, twenty-fourth and twenty-fifth (total of thirteen days). It is however not significant on the remaining 10 days of storage. This could be that a disease was introduced in the store by some means and was harbored. Bachmann and Earles (2000) had reported that lowering temperature could inhibit infection in stored fruits and vegetables. Since performance of the cooler is significant for thirteen days out of twenty five days, This may be due to the fact that the temperature is not low enough as suggested by Bachmann and Earles (2000) (10^0C-18^0C for ripe tomatoes) to check infection long enough. On the average, the Passive Evaporative Cooler had comparatively succeeded in reducing the rot of tomatoes. Counting the rotten fruits recorded during the storage period, 8.15 % of the stored mature – green fruits were rotten at Yola, 8.15 % of the stored mature –green fruits rot at Ganye, 10.19 % of the stored firm-ripe fruits were rotten during 15 days of storage at Ganye, and 7.04% of the stored firm-ripe fruits were rotten after fifteen days of storage at Yola. This is a marked improvement on the local method of storage which record 100% rot the first week of storage.

Type of fruits stored has no significance on rot of tomatoes at Ganye ($p>0.05$), so also is size of fruits. At Yola however, mean performance of the PEC with respect to type of fruits (firm-ripe or mature-green) on rot is not significant except on fourth, fifth, tenth twelfth, fourteenth, sixteenth, eighteenth, nineteenth, twenty-second, twenty-fourth and twenty-fifth days of storage that is a total of eleven days when it is highly significant.

Conclusion

A passive evaporative cooling structure had been developed from locally obtained materials. It was able to prolong the shelf life of tomatoes by lowering the temperature of the storage environment through passive evaporative cooling. The shelf-life of mature-green tomatoes was prolonged to twenty-five days and that of firm-ripe tomatoes to about fourteen days. This is about twice the period they can be stored under ambient condition. Quality characteristics studied have, to an extent, been preserved by the passive evaporative cooler with success. It succeeded in suppressing ripening, senescence, infection and rot of tomatoes by lowering temperature and maintaining a relative humidity conducive for storage of tomatoes. The storage structure operated successfully without electricity: thus, cost of power that limits storage of fresh fruits has been minimized. The efficiency of the storage structure had been found to be 77.40% at Ganye and 67.70% at Yola. Evaluation of the structure showed that large and medium size tomatoes store better than the small size tomatoes. Cost of cold storage has been cut down by using local and cheap materials successfully to develop the storage structure. After the storage period, the stored crops were still acceptable by consumers as fresh fruit even in the presence of fruits from other sources that day.

From the results obtained it was concluded that: Shelf-life of tomatoes can be prolonged using the passive evaporative cooling facility developed. Ripening, senescence, infection and rot are impeded in fresh tomatoes by the passive evaporative structure.

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