Performance of Low Cost Postharvest Handling Technologies on Quality of Tomato (*Solanum lycopersicum*) Fruits

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Abstract

*Low cost technologies including CoolBot Cold-rooms (CB-CR) and Zero Energy Cooling Chamber (ZECC) have been made available to value-chain actors in least developing countries. However, little is known about their performance and cost effectiveness to enhance their utilization. This study was conducted to establish comparative performance and cost effectiveness of CoolBot Cold-rooms (CB-CR), Zero Energy Cooling Chamber (ZECC) and Ambient Storage conditions on storability and quality retention of fruits of tomato variety "Assila F1". A 4x3 factorial experiment in Completely Randomized Design (CRD) with two factors; maturity stage (mature-green, breaker and light red) and storage conditions (CB-CR at 13±1°C, CB-CR at 16±1°C, ZECC, and ambient) were used. Following 12 days storage of 6 crates (28.5kg each) per treatment combination, results indicated a significant interaction between maturity stage and storage condition in terms of fruit external colour change (L*C*h*) and marketable fruits (%) but not on soluble solid content (%Brix), titratable acidity (MeqL^{-1}), weight loss (%) and firmness-compression (kg/mm^2). Color change was delayed on mature green (MG) compared to other harvesting stages but much slower on MG fruits stored in CB-CR (13±1°C and 16±1°C) from yellow yellow-green (L*C*h*=57, 31.7, 110) to yellow yellow-red (L*h*C*= 42.9, 43, 50). Percentage marketable fruits were higher on MG harvested fruits stored at 13°C (98.9%) and 16 °C (97.8%) than ZECC (71%) and Ambient (57%). Storage at CB-CR at 13±1°C and CB-CR at 16±1°C were found economically viable with benefit to cost ratio (B:C) of 1.7 and 2.2, respectively. During the season the B:C ratio of storing mature green harvested tomato fruits in ZECC (0.61) was poor but relatively better than that of storage at ambient (0.44) condition. The study therefore recommends adoption of CB-CR technology to ensure better and economical storability of tomato during peak harvesting seasons when demand is low.*

Keywords: CoolBot, ZECC, Postharvest storage technologies, and Tomato harvest maturity stage

Introduction

Growers, handlers, and marketers of fresh horticultural produce in Tanzania experience postharvest loss of 20–50% depending on crop and postharvest handling technologies used. Availability, affordability and access are among factors limiting the utilization of new postharvest technologies. Temperature management is important factor in maintaining quality and extending shelf life of fresh horticultural produce (Kader, 2002). Mechanical refrigeration has been used to provide optimal storage conditions for fresh produce. However, they seem not economical and practically unfeasible among small scale farmers in developing countries due to its high investment and running costs (Kader, 2004; Kitinoja and AlHassan, 2010; Kitinoja *et al.,* 2011; Singh *et al.,* 2017).

Alternative low cost technologies based on evaporative cooling principles such as Zero Energy Cooling Chamber (ZECC) and charcoal cooler have been developed and used for small quantities and short-term storage of fresh horticultural produce in developing countries (Singh *et al.,* 2017). Despite the potential of these low cost technologies in maintaining quality and extending produce shelf life, their effectiveness is limited to areas and seasons with low atmospheric vapour pressure (Tolesa and Workneh, 2018).

CoolBot device is an innovative technology which makes it possible to use digital air conditioners of specified brands to turn a well-insulated room into a walk-in produce cooler (Saran *et al.,* 2013; Majubwa *et al.,* 2022). CoolBot has three temperature sensors; to the air conditioner's fins, air conditioner's temperature sensor (heater) and the storage room. When coupled to air conditioner, the device can trick and override the air conditioner in a well-insulated room and drop air temperature to as low as 3 oC based on the pre-set temperature on the CoolBot unit (Saran *et al.,* 2013; Rivard *et al.* 2016; Majubwa *et al.,* 2022). In Tanzania, the cost of such walk-in cooler with well-insulated walls fabricated from a 20 feet old marine container was estimated at around 4,150 USD (Majubwa *et al.,* 2022). CoolBot cold room has been found effective for storage of a number of horticultural produces. For instance in India, a CoolBot cooler at 12-15°C has been efficient in maintaining firmness, freshness, and marketability of tomato and okra over 21 days of storage (Huidrom *et al.,* 2016). In Ghana, CoolBot cold room has been found to be cost effective compared to traditional shade storage during several months of onions storage (Saran *et al.,* 2012).

CoolBot cold rooms has been effective in retaining optimal temperatures but limited in maintaining ideal range of relative humidity (RH) which is key for storage of some fresh horticultural produce (Tolesa and Workneh, 2018). Overall effectiveness of any postharvest technology also tend to vary with the crop, harvest maturity, season, storage duration, and region of application (Saran *et al.,* 2012). Availability and access to low cost postharvest technologies along the value-chain actors has been significantly improving in developing countries. However, little is known about their performance on key crops and cost effectiveness to enhance utilization. This study designed to establish comparative performance on quality retention and cost effectiveness of CoolBot Cold-rooms (CB-CR), Zero Energy Cooling Chamber (ZECC) and Ambient Storage conditions (Control) in maintaining quality of tomato fruits.

Materials and Methods

Plant materials: Tomato fruits of variety "Assila F1" (Seminis) were harvested on 21st Nov. 2019 from leased farm at Mlali village, Mvomero district, Morogoro, Tanzania. The fruits were selectively harvested at three maturity stages (mature green, breaker, and light red), packed into plastic crates and transported to the mini pack-house at Horticulture Unit, Sokoine University of Agriculture (SUA), Morogoro for storage experiment.

Experimental design: A 4x3 factorial experiment in Completely Randomized Design (CRD) with two factors; maturity stage (mature-green, breaker and light red) and storage conditions (CB-CR at 13°C (62.2% RH), CB-CR at 16°C (70.3% RH), ZECC (21.4 °C, 95.4% RH), and Ambient (22.7 °C, 91.2% RH) were used. A total of 900 (approx. 85.5kg) uniform and undamaged fruits per maturity stage were stored in each of the storage conditions with 300 fruits (28.5kg) per replicate. In each replicate, 30 fruits were numbered and used for tracking physiological weight loss and colour change at three days interval. Percentage of marketable fruits per replicate was established on the 12^{th} day of storage when at least one treatment combination had about 50% of the fruits unmarketable. Six (6) fruits were sampled per replicate at 6 days interval for destructive measurements including; firmness (compression force), soluble solid content (SSC), and titratable acidity (TA).

Relative humidity (RH) and mean temperature at each storage condition was recorded using a HOBO digital relative RH/temperature logger (UX100-003, Onset computer Co., USA). Fruit color change was measured according to Diaz-Mula *et al.* (2012) using a Minolta Chroma meter (Chroma meter CR-400, Konica Minolta Inc., Japan) in the International Commission on Illumination (Commission Internationale de I'Elcairage; CIE) color space; Hue (h*), Chroma (*C), and Lightness (L*). Two measurements were taken per fruit, one on each side along the fruit equator. Fruit weight loss was measured according to Huidrom *et* *al.* (2016) using a Pronto multifunction digital kitchen scale (ZK 14-S, Ozeri, China) and percentage physiological weight loss (PWL) established based on equation 1.

$$PWL(\%) = \frac{Initial\ weight(g) - Final\ weight(g)}{Initial\ weight(g)} \times 100 \quad (1)$$

Fruit firmness in terms of compression force was measured using a hand held pressure tester (FT3011, USA) mounted on a manual test stand. The force (kg/mm^2) required to compress the fruit using a round tip probe of 11mm diameter to 10mm was recorded. Fruit SSC and TA were measured according to Huidrom *et al.* (2016). For SSC, 1ml of blended and well filtered tomato fruit juice sample was added on a handheld digital refractometer (Antago PAL-1, Japan) and readings on percentage brix recorded. The percent of dominant acid (citric acid) in tomato fruit was determined according to Rajwana *et al.* (2010) by pipetting 5ml of tomato juice which was then diluted to 50mls with distilled water and titrate against 0.1N NaOH to 8.2 pH using an automatic potentiometric titrator (HI 901, Hanna Instrument, USA). Percentage of dominant acid was then calculated based on equation 2.

$$Titratable\ acidity(\%) = \frac{0.1N\ NaOH\ used \times 0.064}{Volume\ of\ Sample\ used} \times 100 \quad (2)$$

Where; N = normality.

In order to establish Benefit to Cost (B:C) ratio of the storage technologies; the average amount of electricity (KWh/day) used in each CB-CR unit (13±1°C and 16±1°C) was recorded on a daily basis using a single phase electric meter (DDS28II, Eurotrix, PRC) throughout the storage period. The unit price of electricity (TSh/KWh) was determined by dividing amount of cash paid (100,000 TSh) to the number of electric units (KWh) acquired. Based on established unit price, the cost of electricity used in each cold room unit was determined as the product of number of units used to unit-price. The amount of water (Liters) used to wet the ZECC storage unit and labour costs (TSh/day) involved to apply the water were recorded on a daily basis. Average market price of tomato fruits (TSh/kg) at the beginning and end of the storage experiment was established as mean of prices from 5 contact retail traders at a local market (Mawenzi market), Morogoro municipality. In this experiment the value of unmarketable fruits was considered as part of the cost. The costs and benefits of each storage condition were then calculated based on the equivalent maximum volume of fruits accommodated in ZECC (1,800 fruits = 171kg). Cost-benefit analysis was computed as the ratio of total benefit value obtained to total cost involved under each storage condition (Kader, 2004; Kitinoja, 2013; Alemu *et al.,* 2021).

Analysis of variance (ANOVA) of collected data was conducted using Genstat (Version 4, VSN International, UK) statistical software. Mean separation was based on Tukey HSD at P<0.05.

Results and Discussion

Percentage marketable fruits: In order to determine comparative effectiveness of storage conditions, tomato fruits harvested at mature green, breaker, and light-red maturity stages were stored in CB-CR 13±1°C, CB-CR 16±1°C, ZECC, and at Ambient (control) for 12 days. Following storage, overall results indicated significantly (P=0.01) higher percentage of marketable fruits on mature green fruits stored in CB-CR at 13±1°C (99.89%) and CB-CR at 16±1°C (97.8%) than on other maturity stages across storage conditions. Similarly, the percentage of marketable breaker fruits stored in CB-CR at 13±1°C (90.33%) and CB-CR at 16±1°C (84.56%) were higher than those in ZECC (43%) and Ambient (50.33%). The lowest percentage of marketable fruits was found on light-red fruits stored at Ambient (39.33%) (Table 1). Comparative performance of the storage technologies indicated that, storage of fruits harvested at mature green, breaker, and light red in CB-CR at 13±1°C give 28.9, 47, and 21.9% more marketable fruits, respectively than in ZECC and 42.9, 40, and 32.2% more than those stored at ambient. Similar storage of mature green, breaker and light-red fruits in CB-CR at 16±1°C gave 26.8, 41.6, and 24.4% more marketable fruits, respectively than similar fruits stored in ZECC or 40.8, 34.6, and 34.8% more than those stored at ambient. Due to the potential of ZECC in retaining significantly high percentage of marketable mature green than breaker and light-red fruits, the difference

Table 1: Effect of maturity stage and storage conditions on fruit marketability following 12 days of storage

	%Marketable fruits			
Maturity stage	**13±1 °C**	**16±1 °C**	**ZECC**	**AMBIENT**
Mature green	99.89cD	97.78bC	71.00cB	57.00cA
Breaker/turning	90.33bB	84.56abB	43.00aA	50.33aA
light-red	71.56aBC	74.11aC	49.67bAB	39.33aA

Means bearing the same lower cases within a column OR same Upper cases in a row are not considered to have significantly different percentage marketable fruits based on Turkey HSD at P ≤ 0.05).

in percentage of marketable mature green fruits stored in ZECC compared to CB-CR at 13 ±1°C was reduced. Storage of mature green tomato fruits in ZECC also maintain relatively more marketable fruits (14%) than storage of similar fruits at ambient storage conditions. These results also indicated that ZECC can be used to store more efficiently tomato fruits harvested at mature green than breaker and light-red stages. The observed high percentage of marketable mature green tomato fruits in CB-CR at 13±1°C and CB-CR at 16±1°C than in ZECC (21.4 °C) and ambient (22.7°C) was partly associated with low physiological weight loss accounted by low storage temperatures. Similarly Huidrom *et al.* (2016) reported significantly higher retention of marketable Chilli, torai, brinjal, okra and tomato fruits in cold room at 12-15°C compared to those stored at ambient following 21 days of storage. In respect to maturity stage, Getinet *et al.* (2008) found higher percentage of marketable fruits among mature green tomato stored under cold storage than turning and light-red fruits at same or ambient storage conditions. Higher storage temperature increase rate of transpiration, respiration and ethylene production and hence hasten senescence (Mutari and Debbie, 2011).

Percentage weight loss: Physiological weight loss is the major cause of produce shriveling and loss in freshness. To understand efficiency of the storage technologies in reducing weight loss, percentage weight loss was determined on mature green, breaker, and light-red tomato fruits during the 12 days of storage in each storage condition. Results indicated that, regardless of the maturity stage used percentage weight loss was significantly higher on tomato fruits stored at ambient (4.73% than those at CB-CR 13±1°C (2.37%), CB-CR 16±1°C (2.29%) and ZECC (2.5%) (Table 2). The findings could be attributed to high storage temperature experienced at ambient storage (22.7°C). Physiologically fresh produce have higher water content than dried ones and hence are more turgid and prone to transpiration. High storage temperature increases vapour pressure difference between fruits and surroundings (Getinet *et al.,* 2008). Such differences in vapour pressure increase the rate of moisture removal from tomato fruits to surroundings and hence hasten deterioration (Seyoum and Woldetsadik, 2004).

Table 2: Effect of maturity stage and storage conditions on physiological weight loss of tomato fruits following 12 days of storage at different storage conditions

	%Weight loss of fruits			
Maturity stage	**13±1 °C**	**16±1 °C**	**ZECC**	**AMBIENT**
Mature green	2.30aA	2.23aA	2.87aA	5.22aB
Breaker/turning	2.38aA	2.36aA	2.16aA	4.67aB
light-red	2.44aA	2.27aA	2.49aA	4.29aB

Means bearing the same lower cases within a column OR same Upper cases in a row are not considered significantly different in terms of percentage weight loss based on Turkey HSD at P ≤ 0.05).

Colour change: Colour change on tomato fruits serves as the major indicator of harvest maturity and senescence during storage. Ripening or senescing tomato fruits tend to change colour from green to red. Rate of colour change in tomato fruit can be measured by the decrease in Hue angle (H*) and Lightness (L*) and increase in Chroma (C*) values as it ripens or senesces. High rate of colour change during storage indicates how fast tomato fruit ripens and or senescence (Baldwin *et al.*, 2011) and it is a function of maturity stage, variety, and storage environment (Getinet *et al.,* 2008; Tigist *et al.,* 2011; Arah *et al.,* 2015). This study tracked the rate of colour change in terms of H*, C*, and L* of MG, breaker, and light-red tomato fruits during the 12 days of storage at CB-CR 13±1°C, CB-CR 16±1°C, ZECC and Ambient conditions. Results indicated a significant delay in the decrease of H*, L* and increase of C* values among mature green, breaker, and light-red tomato fruits stored in CB-CR 13±1°C (Fig. 1) and CB-CR 16 ±1°C (Fig. 2) than those in ZECC (Fig. 3) and at Ambient (Fig. 4). The rate of colour change was slow on mature green (MG) compared to breaker and light-red fruits but much slower on MG fruits stored in CB-CR at 13±1°C that changed from yellow yellow-green (L* = 56.6; h* =108; C* = 32.5) to yellow yellow-red (L* = 48.9; h* = 63.1; C* = 36.2) (Fig. 1: a1, a2, and a3). Similar trend was also noted on MG fruits stored in CB-CR at 16±1°C (Fig. 2: b1, b2, and b3). On the contrary, a sharp rate of colour change was observed on MG fruits stored in ZECC (Fig. 3: c1, c2, and c3) and Ambient (Fig. 4: d1, d2, d3). The observed delay in colour change on mature green compared to breaker and light-red fruits stored in CB-CR at 13±1°C and CB-CR at 16±1°C was consistent with previous studies (Getinet *et al.,* 2008; Pinheiro *et al.,* 2013). Similarly, Roberts *et al.* (2002) reported faster colour change on tomato fruits stored at 20°C than at 12°C. High storage temperatures increase respiration rate

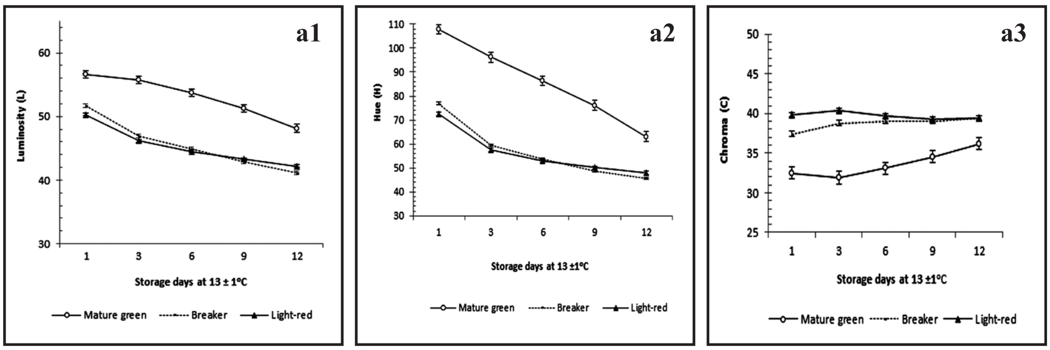

Figure 1: a1, a2, and a3; Shows the trend of change in colour lightness (L*), actual colour (h*) and colour intensity (C*), respectively on mature green, breaker, and light-red tomato during the 12 days storage at CB-CR 13°C.

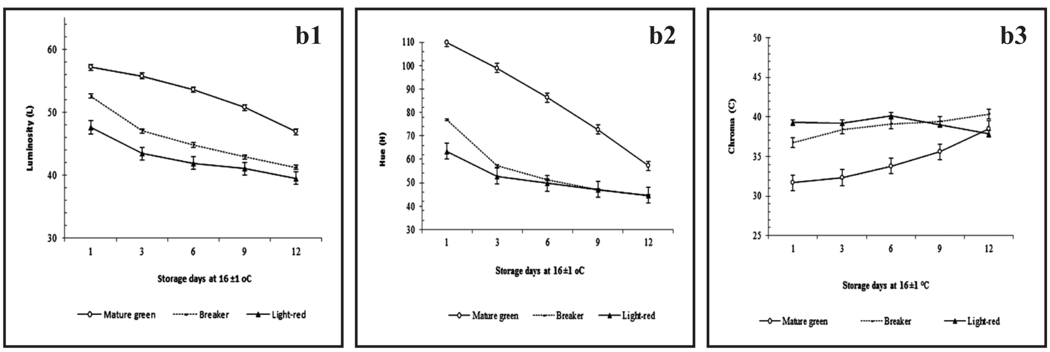

Figure 2: b1, b2, and b3; Shows the trend of change in colour lightness (L*), actual colour (h*) and colour intensity (C*), respectively on mature green, breaker, and light-red tomato during the 12 days storage at CB-CR 16°C.

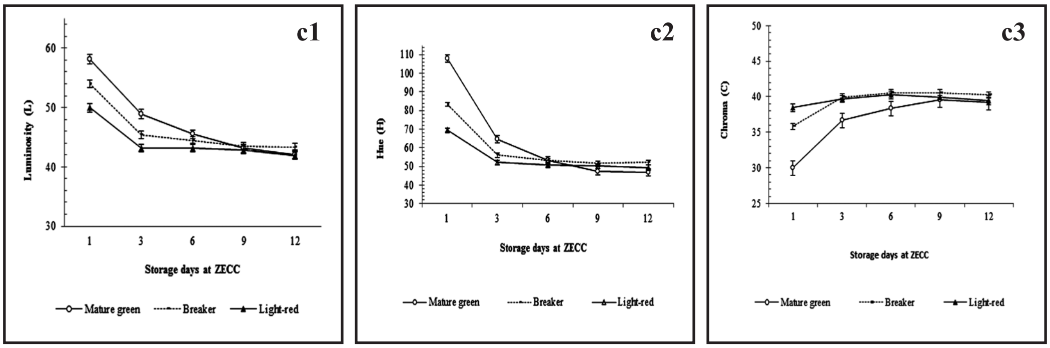

Figure 3: c1, c2, and c3; Shows the trend of change in colour lightness (L*), actual colour and (h*) colour intensity (C*), respectively on mature green, breaker, and light-red tomato during the 12 days storage in ZECC.

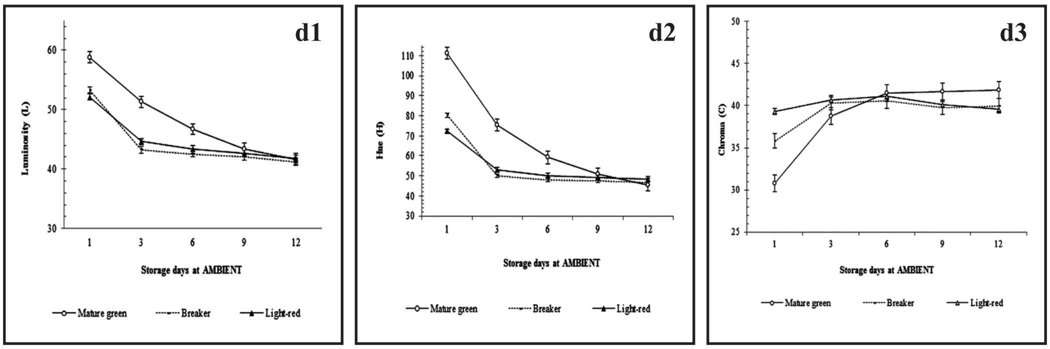

Figure 4: d1, d2, and d3; Shows the trend of change in colour lightness (L*), actual colour (h*) and colour intensity (C*), respectively on mature green, breaker, and light-red tomato during the 12 days storage at Ambient.

and accelerates ethylene production hence hasten ripening (Mutari and Debbie, 2011). Previous studies also indicate that, mature green and breaker tomato fruits have relatively lower ethylene production and respiration rates than red-ripe fruits (Tilahun *et al.,* 2019). Storage of mature green tomato fruits in CB-CR at 13±1°C and CB-CR at 16±1°C was much effective in delaying fruit colour change compared to ZECC and Ambient storage conditions. In addition, the relatively low rate of color change observed on mature green compared to breaker and light red fruits stored at ambient conditions observed in this study suggest the role of harvest timing in maintaining the quality of tomato fruits even at the absence of cold storage facilities.

Fruit firmness: Fruit firmness is a physical indicator of fruit quality in terms of texture. By the 12th day of storage, mature green fruits stored in CB-CR at 13±1°C (with 2.48 kg/cm^2) and CB-CR at 16±1°C (with 2.45 kg/cm^2) demonstrated to be significantly (P=0.015) firmer than similar fruits stored in ZECC (2.01 kg/cm^2) and at Ambient (2.09 kg/cm^2). Similarly, mature green fruits in CB-CR at 13±1°C and CB-CR at 16±1°C were firmer than fruits at other maturity stages under same storage conditions (Table 3). Generally, fruit softening has been attributed to either loss of cell turgidity caused by water loss and or cell wall breakdown due to respiratory processes (Mutari and Debbie, 2011). The relatively higher temperature observed at ambient (22.7°C) storage conditions may have accelerated more water loss and cell break down on fruits at ambient compared to those stored at CB-CB (13±1°C and 16±1°C) and ZECC (21.4°C). These findings relate to the observed higher physiological weight loss reported in this study at ambient than in CB-CB and ZECC (Table 2).

Soluble solid content (SSC), Titratable acidity (TA) and SSC/TA ratio: Both SSC, TA, and

SSC/TA ratio served as indicators of change in internal fruit quality during maturity and storage. In this study, fruit maturity stage and storage condition did not have significant effect on the amount of SSC. Similar to our findings, Tilahun *et al.* (2019) also reported no significant difference in SSC between breaker and light red maturity stages of tomato cultivar TY Megaton stored at 12°C. However, TA varied significantly (P=0.02) with fruit maturity stages where, mature green fruits in CB-CR at 13±1°C had higher TA than light-red fruits at same storage condition. Similarly, mature green fruits in CB-CR at 16±1°C had higher TA than breaker and light-red fruits at same storage condition (Table 4). This indicate an interactive effect of storage condition (temperature) and maturity stage. The results were consistent with Baldwin *et al.* (2011) who reported higher TA on mature green tomatoes of variety Florida 47 stored at 13±1°C. Tilahun *et al* (2019) also reported relatively high TA on breaker compared to breaker and red tomato of cultivar TY Megaton on day 12 of storage. The significantly lower SSC/TA ratio on mature green than on light red fruits in CB-CR at 13±1°C observed in this study (Table 5) could be attributed to higher TA on the former (0.69%) than on the later (0.40%) as SSC did not differ significantly. Previous study by Teka (2013) reported a decline in TA through advancement of maturity stage with the highest on mature green fruits.

Table 3: Effect of maturity stage and storage conditions on fruit firmness (kg/cm^2) following 12 days of storage

	Fruit firmness (Compression - kg/cm^2)			
Maturity stage	**13±1 °C**	**16 ±1 °C**	**ZECC**	**AMBIENT**
Mature green	2.478bB	2.45bB	2.01aA	2.09aA
Breaker/turning	2.034aA	1.96aA	1.93aA	2.05aA
light-red	2.015aA	1.96aA	2.06aA	1.95aA

Means bearing the same lower cases within a column OR same Upper cases in a row are not considered significantly different in terms of compression force based on Turkey HSD at P≤0.05).

Table 4: Effect of Storage condition and maturity stage on fruit titratable acidity (%) on 12 days of storage

	TA (%)			
Maturity stage	**13±1 °C**	**16 ±1 °C**	**ZECC**	**AMBIENT**
Mature green	0.69bA	0.61bA	0.52aA	0.53aA
Breaker/turning	0.55abA	0.42aA	0.49aA	0.45aA
light-red	0.40aA	0.45aA	0.41aA	0.40aA

Means bearing the same lower cases within a column OR same Upper cases in a row are not considered significantly different in terms of TA based on Turkey HSD at P ≤ 0.05).

Table 5: Effect of Storage condition and maturity stage on ratio of fruit soluble solid content to titratable acidity on 12 days of storage

	TSS/TA			
Maturity stage	**13 °C±1**	**16 °C±1**	**ZECC**	**AMBIENT**
Mature green	6.67aA	7.53aA	8.12aA	8.26aA
Breaker/turning	7.84abA	9.67aA	8.59aA	9.65aA
light-red	10.09bA	9.14aA	9.99aA	11.50aA

Means bearing the same lower cases within a column OR same Upper cases in a row are not considered significantly different in terms of SSC/TA ratio based on Turkey HSD at P ≤ 0.05).

Cost Benefit Analysis: Cost benefit analyses of the postharvest storage technologies was based on 1800 fruits of 0.095kg each, which was the maximum amount of fruits that could be accommodated in the ZECC. During the study the average price of electricity, water, labour, and tomato fruits were at 355.87 TSh/Kwh, 30 TSh/20L bucket, 250Tsh/day, and 1500 TSh/kg, respectively. The average price change of tomato per week between 26th Nov. and Dec. 7th 2019 was 142 TShs/kg. Based on the information, total variable costs related to each storage conditions were established to be 28,043 TSh, 21,928 TSh, 79,560 TSh, and 110,250 TSh for CB-CR 13±1°C, CB-CR 16±1°C, ZECC, and ambient, respectively (Table 6). Based on the price change of 142 TShs per week, the value of 1,800 tomato fruits (171kg) before and after storage were 256,500 TSh. and 305,064 TSh, respectively. The Benefit-Cost ratio of storing mature green tomato fruits in CB-CR 13±1°C, CB-CR 16±1°C, ZECC, and ambient were; 1.73, 2.21, 0.61, 0.44, respectively (Table 6).

Table 6: Variable costs and benefit-cost ratios associated with storage of mature green tomato fruits in CB-CR_13±1°C, CB-CR_16±1°C, ZECC, and Ambient conditions for 12 days

SN	Storage condition	Item description	Quantity	Unit Price	Amount (TZS)	B-C ratio
1	CB-CR 13±1°C	Electricity: 6.5 KWh/day x 12 days	78	355.87	27,758	
		Unmarketable MG fruits: 0.011% x 1,800 fruits	0.19kg	1,500	285	
		Subtotal 1			28,043	1.73
2	CB-CR 16±1°C	Electricity: 3.8 KWh/day x 12 days	45.6	355.87	16,228	
		Unmarketable MG fruits: 2.2% x 1,800 fruits	3.8kg	1,500	5,700	
		Subtotal 2			21,928	2.21
3	ZECC	Water: 6 buckets/day x 12 days	72	30	2,160	
		Labour for wetting ZECC: 12 days @250Tsh	12	250	3,000	
		Unmarketable MG fruits: 29% x 1,800 fruits	49.6kg	1,500	74,400	
		Subtotal 3			79,560	0.61
4	AMBIENT	Unmarketable MG fruits: 43% x 1,800 fruits	73.5kg	1,500	110,250	
		Subtotal 4			110,250	0.44

NB: Mature green fruits were used because of their lower unmarketable fruit percentage. The B-C ratio values were based on the benefit of 48,564 TSh, which is the difference of final (305,064 TSh.) and initial (256,500 TSh.) value of the 1800 (171kg) tomato fruits.

The higher Benefit-Cost ratio observed on mature green fruits stored in CB-CR at 13°C and CB-CR at 16°C than on similar fruits stored in ZECC and ambient condition was mainly attributed to lower percentage of unmarketable fruits (Table 6). The value lost due to unmarketable was higher enough to offset the advantage of low running costs for maintaining fruits in ZECC and at ambient storage conditions. On the other hand, despite of the relatively low percentage of unmarketable fruits in CB-CR at 13±1°C (0.11%) compared to CB-CR at

16±1°C (2.2%) yet use of the later could bring more revenue than the former. This was because CB-CR at 16±1°C utilized less electricity and hence lower utility cost than CB-CR at 13±1°C. The B:C ratios also can vary with maturity stage of the stored fruits. For instead based on the percentage of un-marketable breakers (9.67%) and light red (28.44%) fruits stored in CB-CR at 13°C, the benefit to cost ratio could go as low as 0.92 (-3,997TSh loss) and 0.48 (-52,128TSh), respectively. On the other hand, if each cold room filled to maximum carrying capacity of 43,200 mature green fruits (4,104kg) stored in CB-CR at 13±1°C and in CB-CR at 16±1°C one could have a benefit to cost ratio of 32.5 (net profit = 1,130,722 TSh.) and 6.4 (net profit = 1,008,176 TSh.), respectively. However it is well established that, energy consumption rate of refrigeration unit tend to increase with condition, type, and quantity of the stored produce (Anand *et al.,* 2013; Tassou *et al.,* 2009; Adre and Hellickson, 1989). Therefore, any change on the factors could alter the profit gained. The estimated profit gain may also vary up or down stream among seasons in a year with increase or decrease in rate of price change.

Conclusion and Recommendations

The study evaluated comparative performance on quality retention and cost effectiveness of CoolBot Cold-rooms (CB-CR) at 13±1°C and 16±1°C, Zero Energy Cooling Chamber (ZECC), and Ambient storage conditions. Tomato fruits of variety “Assila” as a model crop at mature green, breaker and light-red maturity stage were stored for 12 days in each storage condition. Based on the results, it could be concluded that; storage under CB-CR at 13±1°C and CB-CR at 16±1°C was more effective in delaying fruit colour change, maintaining fruit firmness, TA and SSC/TA than ZECC and ambient storage conditions particularly when fruits harvested at mature green stage. Similarly CB-CR at 13±1°C, CB-CR 16±1°C as well as ZECC storage conditions were also effective in reducing fruit physiological weight loss by an average of 2.3% than ambient storage. Regardless of the fruit maturity stage, storage of tomato fruits in CB-CR at 13±1°C, and CB-CR 16±1°C led to higher percentage of marketable fruits than both ZECC and ambient storage conditions. It was also evident that, harvest of tomato fruits at mature green stage and storage in CB-CR at 13±1°C can increase percentage of marketable fruits more than when storing in ZECC and Ambient, respectively. However, in comparison to CB-CR 13±1°C, ZECC was better off ambient storage by reducing the difference in percentage of marketable fruits to 28.9% as compared to 42.9% observed in the later (ambient storage). Similar effect was also obtained among mature green fruits stored in CB-CR at 16±1°C. The use of CB-CR at 13±1°C and CB-CR at 16±1°C proved to be economically viable for storage of tomato fruits particularly mature green fruits which had the B:C ratio of 1.7 and 2.2, respectively.

This study therefore recommends the use of CoolBot Cold-rooms at 13±1°C or 16±1°C as effective and the best available low cost storage technology for fresh tomato fruits among the tested storage conditions. ZECC storage is also advocated over ambient storage particularly when combined with appropriate harvest maturity timing. However, further studies are suggested to evaluate performance and cost effectiveness of the technology for other key horticultural crops such as sweet pepper, African eggplant and leafy greens. Studies are also required to map the demand, supply and price changes across seasons for key horticultural crops to enhance utilization of the technology.

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