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ENHANCING THE SHELF LIFE OF KALE AND TOMATO USING A ZERO-ENERGY COOLING CHAMBER IN ETHIOPIA

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ABSTRACT

The post-harvest fruit and vegetable loss in Ethiopia is estimated to reach 40 %. In this research, the authors assessed the effectiveness of a zero-energy cooling chamber (ZECC) in prolonging the shelf life of kale and tomatoes in two locations: Addis Ababa and Woliso. The ZECCs were constructed using bricks and sand with dimensions of 1.5 m wide and 2.15 m long. The experiment involved five treatments: two storage devices with two precooling treatments in ZECC and room storage as a control. Following a completely randomized design (CRD) with three replications, 500 g of kale and 1 kg of tomatoes were stored in each device. Key parameters, including physiological loss of weight (PLW), wilting index, visual quality, and total soluble solids (TSS), were monitored, alongside environmental factors such as temperature and relative humidity (RH). The ZECC significantly reduced maximum temperature (up to 6.82°C) and increased RH (up to 40%) compared to room storage, resulting in a shelf-life extension of kale by 2 days and tomatoes by 10 days. These effects were more pronounced in Woliso, a warmer location. Irrespective of storage devices and precooling treatments, in Addis Ababa, ZECC extended the shelf life of tomatoes from 16 to 24 days (50%) and kale from 1.5 to 3.5 days (133.3%). In Woliso, tomatoes' shelf life increased by 83.3% (from 12 to 22 days), while kale's shelf life rose from 1 day to 2.5 days (150%). In addition, the breakeven analysis showed that ZECC generated additional income of USD 158 and USD 226 from tomato storage in Addis Ababa and Woliso, respectively, and USD 241 and USD 204 from kale storage. The cost recovery period for ZECC (USD 439) was shorter in Woliso (1.9 years) than in Addis Ababa (2.8 years) for tomatoes, and 1.8 years in Addis Ababa versus 2.2 years in Woliso for kale. The result from our study demonstrates that ZECC is a practical and affordable method to reduce postharvest losses, extend shelf life, and enhance income for vegetable growers, offering potential benefits for food security in Ethiopia and similar settings.

Key words: Zero energy cooling chamber, shelf life, Ethiopia, kale, tomato

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INTRODUCTION

The production and marketing of vegetable crops are a source of livelihood for numerous households in Ethiopia. Several vegetables grow in the country under rainfed and irrigation systems [1]. In 2023, the area harvested for vegetables was reported to cover 318,756 hectares, yielding a total of 1,651,732 tons [2].

Due to the high-water content ranging from 65% to 95%, vegetables undergo rapid deterioration from the moment of harvest until the produce reaches consumers' tables, resulting in significant loss. In Ethiopia, postharvest loss of fruits and vegetables, at various stages: harvesting, storage, transportation, and marketing, ranges from 15 to 70%. Postharvest loss of vegetables alone is about 40% [3]. In a load-tracking experiment conducted in Northwestern Ethiopia by Eskindir [4], the mean postharvest loss of tomatoes within 5 days along the unrefrigerated supply chain was reported to be 26 %. The study identified the storage and handling of tomatoes at room temperature and low relative humidity for extended periods as the primary causes of postharvest losses along the supply chain. Furthermore, the lack of adequate cool storage space at the farm level and refrigerated storage at the market level aggravates the loss of fruits and vegetables for small-scale farmers [5].

For small-scale farmers, adopting low-cost, locally fabricated cooling structures like ZECC offers practical solutions to mitigate postharvest vegetable losses [6]. It is usually constructed using readily available materials such as bricks, sand, wood, straw, gunny or burlap sacks, and twine [7]. Originating in India in the early 1980s, the brick ZECCs were developed to combat postharvest losses in regions lacking electricity [8]. Typically, these structures consist of a double-brick wall supported by a base layer of bricks, often covered with a straw mat. The gap between the brick walls is filled with river sand to retain added water for evaporative cooling. Vegetables are stored inside the ZECC in plastic crates or containers. Studies have shown that ZECC maintains lower temperatures and higher relative humidity (RH) compared to the ambient environment, slowing down ripening processes, and preserving the quality of perishable crops like tomatoes [7, 9]. For instance, in Rwanda, ZECC maintained temperatures 15 to 18°C lower than room temperature and RH of approximately 95 % during hot months[6]. Several studies have demonstrated that vegetables stored in ZECC exhibit better quality and longer shelf life compared to those stored at ambient temperatures[7]. In Ethiopia, small-scale farmers and roadside retailers often suffer significant post-harvest losses due to a lack of proper storage facilities. Recognizing the potential of ZECC to reduce this loss and the lack of concrete research in the Ethiopian context, building on its experience from other countries, the World Vegetable Centre conducted experiments to evaluate the potential of this specific technology.

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MATERIALS and METHODS

Study Area and Vegetables

The storage structures were constructed at 2 distinct locations: one at 9.018091°N, 38.815270°E, situated at an elevation of 2375 meters above sea level (m.a.s.l) in Addis Ababa (AA), and the other at 8.571714°N, 37.999927°E, located at an elevation of 2116 m.a.s.l in Woliso, south-western Ethiopia. Woliso has a mean annual temperature of 17.7°C and relative humidity of 58.7% [10] while in AA the mean annual temperature is 17.1°C with a relative humidity of 61.2% [11]. The structure had dimensions of 1.5 meters in width and 2.15 m in length (with interior dimensions approximately 0.7 m wide and 1.40 m long). The storage space height was about 1 m and estimated to store 6 crates of vegetables[12]. Each structure was built using one thousand bricks and four cubic meters of sand. The vegetables used for the experimentation were Ethiopian kale and tomato. The kale used for this specific experiment was the perennial type of the local variety (*Brassica oleracea L. var. acephala)*. The tomato variety chosen for this trial was Galilea 39, a widely grown fresh market-type which is a hybrid, and it's known for its extended shelf life (2-3 weeks in room storage) [13]. Tomatoes at the breaker stage of maturity were used for both experiments.

Experimental Set-up

The experiment comprised five treatments:
1). Plastic crates in ZECC with precooling
2). Plastic crates in ZECC without precooling
3). Plastic container in ZECC with precooling
4). Plastic container in ZECC without precooling, and
5). Plastic crate in room storage (Control).

The experiment design used was a completely randomized design (CRD) with three replications. Two storage environments were used: a) ZECC and b) room storage (control). Two types of storage devices were used: plastic crates, which had a vent, and plastic containers, which were not vented and equipped with a lid. Before storage, vegetables were sorted, cleaned, and weighed. Each storage device contained 500 g of kale and 1kg of tomatoes. Portions of 250 g of kale and 500 g of tomatoes were marked for physiological loss of weight (PLW) determination (Figure 1). Monitoring of stored vegetables occurred at one and two-day intervals for kale and tomato, respectively. Thermo-hygrometers were placed in each storage environment and outdoors to track changes in temperature and RH throughout the storage period. The sand between the brick walls of the ZECC was watered daily to maintain cooling through evapotranspiration. The kale storage experiment took place from May 11 to May 19, 2022, at AA, and from May 13 to May 21, 2022, at

Woliso. The tomato experiment was conducted from May 24 to June 16, 2022, at AA and from May 26 to June 17, 2022, at Woliso.

Data collected

Temperature and Relative Humidity

Figure 1: Kale and tomato treatments in storage devices in ZECC

Temperature and RH readings were taken every three hours: at 9:00 AM, 12:00 PM, 3:00 PM, and 6:00 PM. In addition, daily minimum and maximum temperatures, as well as RH, were recorded each day at 9:00 AM. Daily averages were calculated by summing the minimum and maximum and dividing by 2. Temperature measurements were recorded in degrees Celsius (°C), while RH was expressed as a percentage.

Physiological loss of weight

The cumulative weight loss was recorded using a digital weight balance and expressed as a percentage of the initial weight. The formula used for calculating cumulative weight loss (%) is as follows:

$$\text{PLW}(\%) = \frac{\text{Weight of the initial sample (g)} - \text{Weight of a sample at a specific sampling date (g)}}{\text{Weight of the initial sample (g)}} x\ 100$$

Wilting index

The degree of wilting in kale was evaluated using a 7-point hedonic scale, where each point corresponds to a specific level of wilting:

1 = extreme wilting
2 = very severe wilting
3 = severe wilting
4 = moderate wilting
5 = slight wilting
6 = very slight wilting, and
7 = no wilting[14].

A wilting index of five was used as a cut-off for the marketability of kale.

Visual quality

The visual quality of the stored tomatoes was assessed using a rating scale:
9 = excellent
7 = very good
5 = good
3 = fair, and
1 = poor, as used in [14] at each PLW data collection day.

The evaluation was conducted by a panel consisting of researchers, agricultural experts, and farmers. The rating was based on the overall visual appearance of the vegetable samples. Tomatoes rated seven or above were deemed marketable, while those rated below seven were considered unmarketable.

Total soluble solids

Measurement of total soluble solids (TSS) of the tomatoes (°Brix) was done using a digital refractometer Atago (APAL-1) Japan. The refractometer determines TSS by comparing the speed of light in a vacuum to its speed through the sample; higher solute concentration results in slower light speed, hence higher °Brix [15].

Breakeven analysis

The cost-benefit analysis focused on recovering the construction expenses for the ZECC. Calculating the breakeven point involved various factors, including the extended shelf life provided by the ZECC, the number of production seasons annually, and the storage rounds per season. Additionally, the prices of the products at each location were considered in the analysis. Specifically, for tomatoes, two production seasons in a year and two storage rounds per production season were considered. The estimated storage capacity of the ZECC was 120 kg, equivalent to six plastic crates of tomatoes[12]. The construction cost of the ZECC was estimated at USD 439.

Data analysis

The analysis of variance (ANOVA) was conducted separately for each location and parameter using SAS Studio[16]. Whenever a significant difference between treatment effects was observed at a significance level of $P < 0.01$, the Tukey Honestly Significant Difference (HSD) test was employed for post-hoc comparisons. In addition, the SAS/GRAPH capabilities were utilized to generate scatter plots and bar graphs [16].

RESULTS AND DISSCUSION

Temperature and Relative Humidity

Relative to room storage, the mean maximum temperature inside ZECC was 5.66°C and 6.82°C lower at AA and Woliso, respectively. Similarly, during the tomato storage periods, compared to room storage, the mean maximum temperature in the ZECC was 2.15°C and 6.15°C lower at AA and Woliso, respectively. The average daily temperature over the storage periods of tomatoes at AA in figure 2 demonstrated a consistent decrease in temperature within the ZECC.

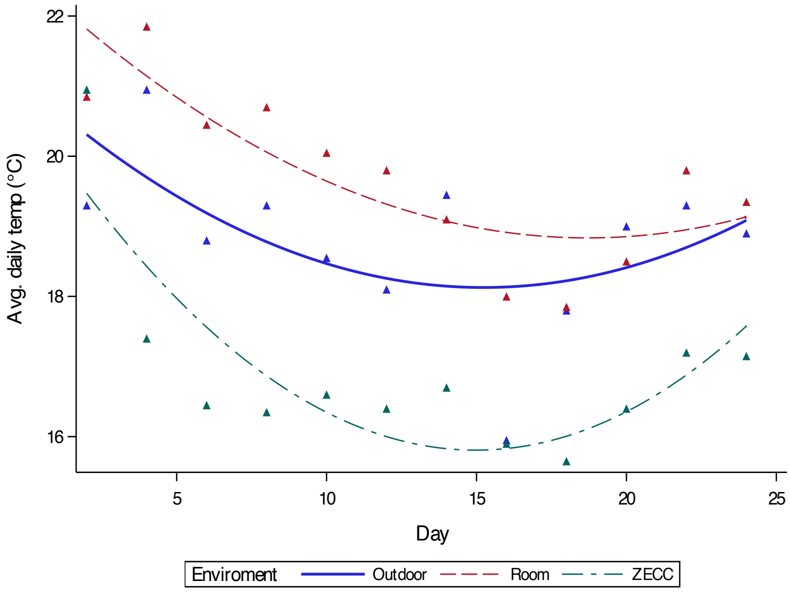

Figure 2: **Average daily temperatures (°C) at AA during the tomato storage period; degree of polynomial regression line =1**

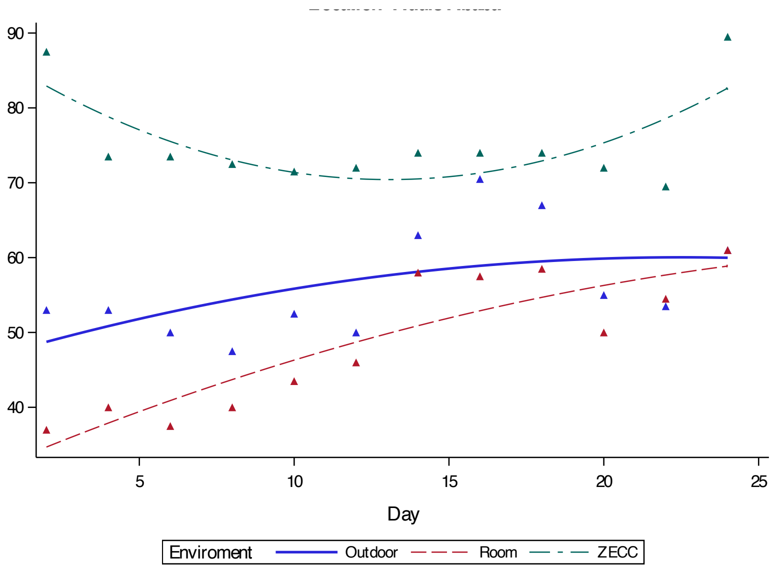

Figure 3: **Average daily RH (%) at AA during the tomato storage period; degree of polynomial regression line =1**

As shown in figure 3, the average daily relative humidity (RH) was markedly higher in the ZECC compared to both the room and outdoor RH. During the kale storage period, RH in the ZECC reached up to 85 % at both locations. However, in-room storage, the highest RH observed during the storage period was 40.50 % at AA and 44.50 % at Woliso. Similarly, during the tomato storage phase, compared to room storage, the mean maximum RH inside the ZECC was 40.00% and 29.52% higher at AA and Woliso, respectively. The result is consistent with research conducted by Singh and Satapathy [17]. They reported a significant reduction in the mean maximum temperature and an increase in RH inside the ZECC. Furthermore, these findings aligned with research by Dirpan *et al.* [17], who reported that surface ZECC, like the one used in this experiment, exhibited lower temperatures and higher RH compared to underground ZECC.

Physiological loss of weight

Physiological loss of weight of kale differed significantly between treatments on all days of the storage period at AA ($p<0.001$), and all days except day 1 in Woliso ($p<0.01$). Throughout the storage period, PLW was higher for kale stored in the room compared to the ZECC treatments. Although differences between storage materials in ZECC were mostly not significant, PLW in both locations on the 4th day was lower in plastic containers with pre-cooling of produce. Particularly, at AA, PLW in room storage reached 56.5 % on the 4th day compared to 17.1-22.9 % for the ZECC treatments (table 1). Likewise, at Woliso, on the 4th day, PLW reached 68.0 % for room storage, contrasting with 36.3-52.0 % in the ZECC. These results align with previous research on leafy vegetables [19], where room storage resulted in a weight loss of 47.6%, contrasting with the 10.05 % observed in the ZECC.

The PLW on tomatoes differed significantly ($p<0.001$) between treatments on all observation days, except on day 4 in AA. The PLW in room storage reached 9.3% and 30.7%, whereas, in ZECC, it ranged from 0.4% to 1.6% in AA and from 4.7% to 5.7% in Woliso (tables 2 & 3). Regarding storage devices, particularly in AA, the plastic container exhibited lower PLW in contrast to the plastic crate. Like kale, PLW in tomatoes at Woliso was higher than at AA. This was attributed to the higher temperature and lower RH at Woliso during the storage period, in contrast to AA. The reduction in PLW in tomatoes when stored in ZECC has been documented by numerous studies [20, 21]. Similarly, low PLW in ZECC storage has been reported in other vegetables, and spices including pointed gourd and okra [22], mango [23], capsicum, brinjal, amaranthus, cabbage, and onion leaf [17], and ginger [24].

Total soluble solids

No Significant differences ($p<0.01$; $F=6.60$) were observed among treatments when the TSS of tomatoes was measured on day 24 of the experiment in AA. The highest °Brix was recorded for the plastic crate treatments in ZECC (8.73 and 8.50) (figure 2). Despite the higher PLW of the room-stored tomatoes, the mean TSS of the plastic container in ZECC treatments was slightly lower than that of the room-stored tomatoes. Although TSS was only measured on day 24 of the trial, the fact that the highest readings were obtained from the ZECC-stored tomatoes indicates that ZECC maintained the physicochemical quality of the stored tomatoes.

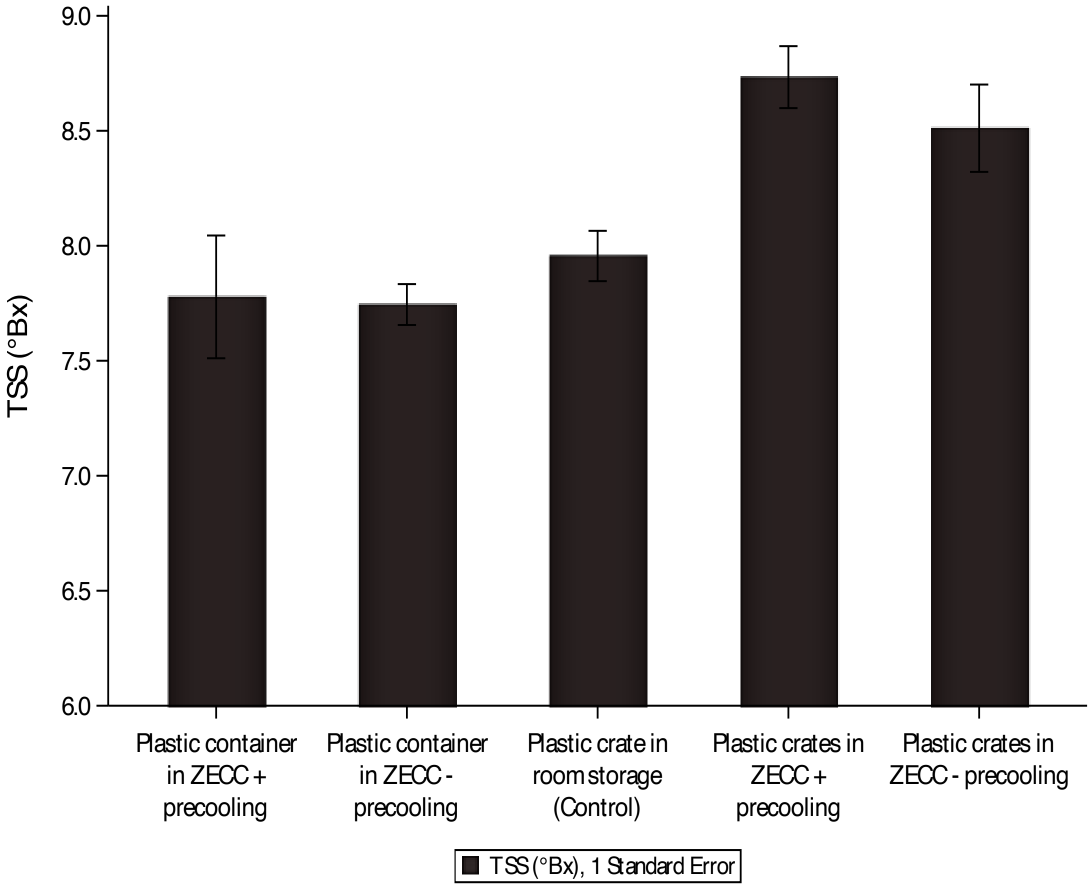

Figure 4: TSS of stored tomatoes on day 24 at AA; SE as error bar

Wilting Index

The wilting index for kale was used to determine marketability. According to the evaluation conducted by the panel, a mean wilting index of five and above was considered indicative of salable produce. In both locations, the kale stored in the room remained within the marketable limit for slightly more than one day. However, for the treatments in the ZECC, kale leaves remained salable for up to 3 ½ and 2 ½ days in AA and Woliso, respectively (figures 5 & 6).The relatively rapid wilting of kale at Woliso compared to AA was attributed to the higher temperature and lower RH at Woliso. The findings agree with a report by Ghosal *et al*. and Kumari and Kamal [25, 26] in which leafy greens such as amaranth, spinach, cabbage, and coriander can be stored in ZECC without significant wilting for several days.

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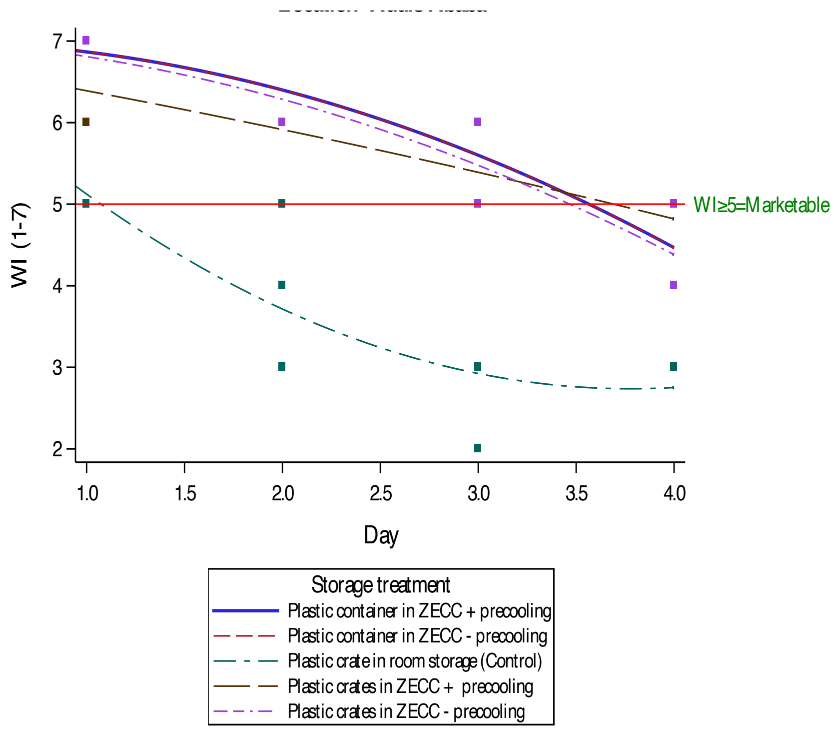

Figure 5: Wilting index of Kale at AA; degree of polynomial regression line=2

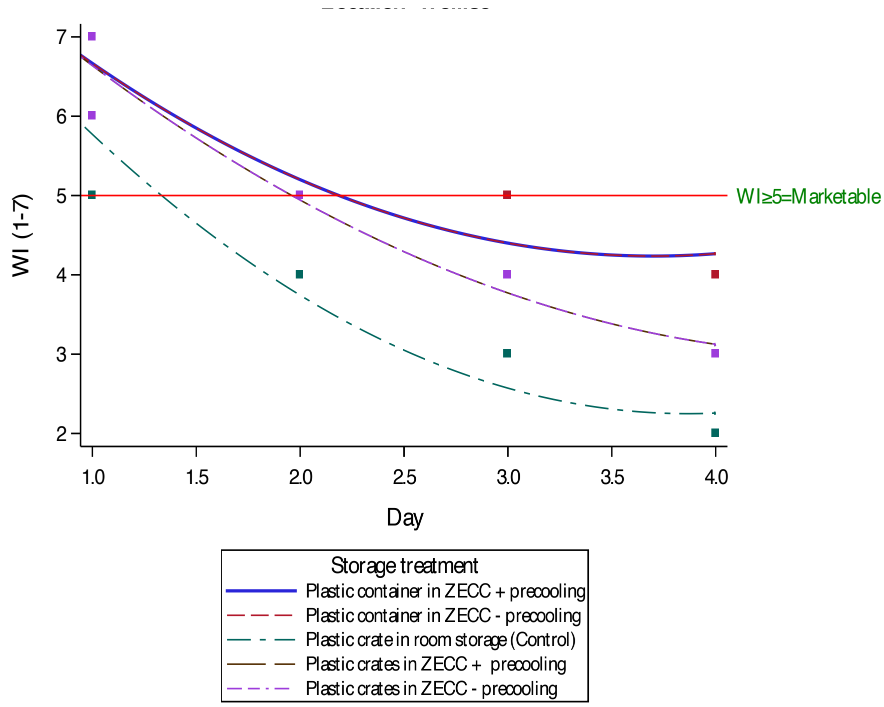

Figure 6: Wilting index of Kale at Woliso; degree of polynomial regression line=2

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Visual Quality

For tomatoes, the visual quality is often influenced by maturity and storage period [21, 27]. To this end, the evaluating panel set a cutoff point of ≥ 7 on the visual quality scale, which corresponds to a rating of 'very good' according to Kader and Cantwell [15]. In both locations, the treatments in ZECC followed a similar pattern; thus, the four treatments in the ZECC were represented by the same line on the graphs (figures 7 & 8). Based on the visual quality, at AA, the tomatoes stored in the room remained marketable for 16 days, but for the ZECC treatments, it remained marketable until the 24th day. Similarly, at Woliso, tomatoes stored in the room remained marketable for up to 12 days, whereas the ZECC treatments remained marketable for 22 days. This highlights the benefit of storing tomatoes in the ZECC, as the data showed that the shelf-life was extended by 10 days in both locations. The effect of ZECC on maintaining the visual quality of tomatoes was also reported by other studies [7].

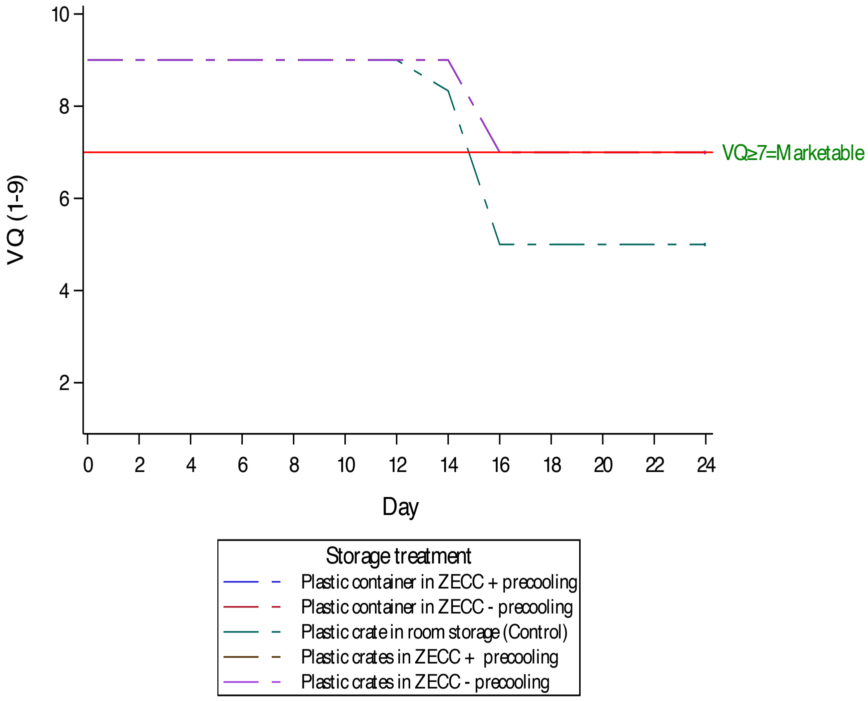

Figure 7: **Visual quality of tomato at AA**

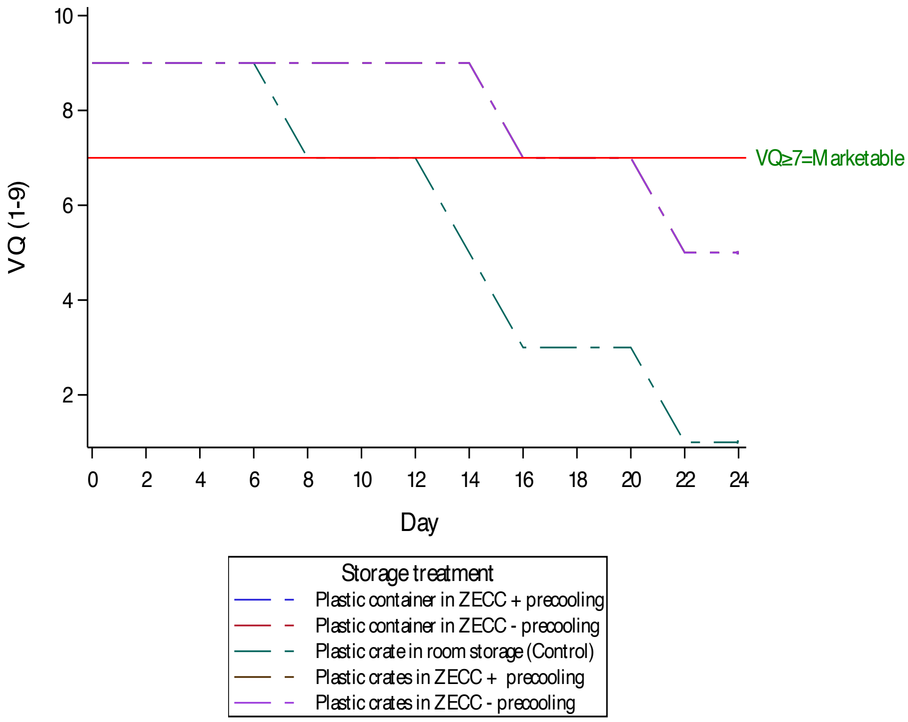

Figure 8: **Visual quality of tomato at Woliso**

Breakeven Analysis

In AA, the ZECC intervention enabled farmers to extend the shelf life of tomatoes from 16 to 24 days (50 %). However, the shelf-life extension of ZECC has been more pronounced in Woliso, and this improved the shelf-life of tomatoes by 83.3% (figures 7 & 8). As a result, the ZEEC helped to generate an extra income of USD 158 in AA and USD 226 in Woliso. Given the ZEEC establishment cost of USD 439, it will take at least 2.8 years (33.6 months in AA) to recover the cost of investment with an extra income earned from ZECC intervention. However, the cost recovery period and the number of years required to breakeven with the extra income are shorter in Woliso, which is 1.9 years (22.8 months).

As indicated in figures 5 & 6, the establishment of ZEEC can extend the shelf-life of kale from 1.5 days to 3.5 days (133.3%) in AA. On the other hand, in Woliso, ZEEC extends the shelf-life of kale by 1.5 days, that is, from 1 day to 2.5 days (150%). Due to the intervention, farmers could be able to generate an extra income of USD 241 in AA and USD 204 in Woliso, and the income difference is attributed to the high price of kale in AA (*See Annex for details*). With this extra income, it will take a farmer around 1.8 years (22 months) in AA and 2.2 years (26 months) in Woliso to recover the cost of investment in ZEEC establishment.

CONCLUSION AND RECOMMENDATIONS FOR DEVELOPMENT

The extended shelf life observed in vegetables stored in ZECC can be attributed to its ability to reduce temperature and increase RH compared to room storage conditions. Based on this trial, it is reasonable to conclude that ZECC significantly enhances the shelf life of vegetables in two locations of Ethiopia, particularly benefiting tomatoes. Moreover, the effectiveness of ZECC appears to be more pronounced in warmer areas compared to cooler environments. From the Veggies 4 Planet & People project in the intervention districts, it became evident that the initial cost of implementing ZECC posed a barrier to adoption among small-scale farmers. However, upon calculating the breakeven period, it became apparent that ZECC is a worthwhile investment, offering a potential solution to the post-harvest challenges faced by vegetable producers in the country. Furthermore, there is a potential benefit in expanding the use of ZECC to small-scale retailers who sell vegetables along roadsides and in permanent markets in smaller towns.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

Table 1: **PLW of kale at AA and Woliso**

	AA				*Woliso*			
	Day				Day			
	1	2	3	4	1	2	3	4
Plastic crates in ZECC + precooling	13.33b	17.33b	20.26b	22.93b	12.00b	28.00b	37.33b	44.00b
Plastic crates in ZECC - precooling	12.67b	14.13b	18.93b	21.46b	27.33ab	38.66ab	46.66ab	52.00ab
Plastic container in ZECC + precooling	12.00b	10.26b	15.46b	17.06b	14.00b	24.00b	32.00b	36.33b
Plastic container in ZECC - precooling	9.333b	13.33b	15.46b	19.46b	15.33b	25.33b	35.33b	39.33b
Plastic crate in room storage (Control)	26.67a	37.86a	48.00a	56.53a	30.66a	48.66a	61.33a	68.00a
F-value	32.56	65.37	91.40	153.7	6.95	13.82	19.95	23.21
P-value	***	***	***	***	ns	**	**	**
CV (%)	12.29	13.31	10.68	9.20	28.23	14.87	11.55	9.75

Note:

- Means followed by the same letter within a column are not significantly different according to Tukey's HSD test at the specified significance level
- Statistical significance: *** indicates P < 0.001; ** indicates P < 0.01; and "ns" denotes not significant (P > 0.01)

Table 2: **PLW in tomatoes at AA**

	Day					
	4	8	12	16	20	24
Plastic crates in ZECC + precooling	0.40a	0.80b	1.06b	1.20b	1.20bc	1.60b
Plastic crates in ZECC - precooling	0.40a	0.53b	1.20b	1.20b	1.22b	1.60b
Plastic container in ZECC + precooling	0.40a	0.53b	0.67b	0.93b	0.93bc	0.93bc
Plastic container in ZECC - precooling	0.00a	0.00b	0.00b	0.27b	0.27c	0.40c
Plastic crate in room storage (Control)	1.06a	3.46a	5.20a	6.67a	7.73a	9.33a
F-value	4.15	35.33	45.52	106.20	105.90	148.20
P-value	ns	***	***	***	***	***
CV (%)	66.4	33	29.05	15.57	14.89	13.00

Note:

- Means followed by the same letter within a column are not significantly different according to Tukey's HSD test at the specified significance level
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Table 3: PLW in tomatoes at Woliso

	Day					
	4	**8**	**12**	**16**	**20**	**24**
Plastic crates in ZECC + precooling	0.00b	1.00b	1.33b	1.67b	2.33b	5.67b
Plastic crates in ZECC - precooling	0.00b	0.33b	0.67b	1.33b	2.33b	5.00b
Plastic container in ZECC + precooling	0.00b	0.67b	1.33b	1.33b	1.67b	5.67b
Plastic container in ZECC - precooling	0.00b	0.33b	1.00b	1.67b	2.33b	4.67b
Plastic crate in room storage (Control)	2.00a	8.67a	15.00a	19.33a	25.33a	30.66a
F-value	∞	22.46	145.5	109.10	604.20	118.8
P-value	***	***	***	***	***	***
CV (%)	0.00	68.24	25.64	30.67	11.77	9.54

Note:
- Means followed by the same letter within a column are not significantly different according to Tukey's HSD test at the specified significance level
- Statistical significance: *** indicates P < 0.001; ** indicates P < 0.01; and "ns" denotes not significant (P > 0.01)

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Appendix 1

Table A: Cost-Benefit Analysis and Breakeven Determination for ZEEC investment in Kale

Crop	Season	Round	Shelf life of kale inside ZECC		Shelf life of kale outside ZECC		Extended shelf-life due to ZECC		Shelf-life Extension in %		Quantity stored inside ZECC (Kg)	Price in Birr per Kg		Extra income earned due to ZECC (in USD)	
			AA	Woliso	AA	Woliso	AA	Woliso	AA	Woliso		AA	Woliso	AA	Woliso
Kale	**One**	1	3.5	2.5	1.5	1	2	1.5	133.3%	150%	120	0.35	0.26	56.1	47.4
		2	3.5	2.5	1.5	1	2	1.5	133.3%	150%	120	0.35	0.26	56.1	47.4
	Two	1	3.5	2.5	1.5	1	2	1.5	133.3%	150%	120	0.40	0.30	64.6	54.5
		2	3.5	2.5	1.5	1	2	1.5	133.3%	150%	120	0.40	0.30	64.6	54.5
Total														241.4	203.7
Number of years required to breakeven with the extra income alone														1.82	2.15

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Appendix 2

Table B: Cost-Benefit Analysis and Breakeven Determination for ZEEC investment in Tomato

Crop	Season	Round	Shelf life of tomato inside ZECC		Shelf life of tomato outside ZECC		Extended shelf-life due to ZECC		Shelf-life Extension in %		Quantity stored inside ZECC (Kg)	Price in Birr per Kg		Extra income earned due to ZECC (in USD)	
			AA	Woliso	AA	Woliso	AA	Woliso	AA	Woliso		AA	Woliso	AA	Woliso
Tomato	**One**	1	24	22	16	12	8	10	50%	83.3%	120	0.61	0.53	36.8	52.6
		2	24	22	16	12	8	10	50%	83.3%	120	0.61	0.53	36.8	52.6
	Two	1	24	22	16	12	8	10	50%	83.3%	120	0.71	0.61	42.4	60.5
		2	24	22	16	12	8	10	50%	83.3%	120	0.71	0.61	42.4	60.5
Total														158.4	226.3
Number of years required to breakeven with the extra income alone														2.77	1.94