Extended Green Pepper Shelf Life under Evaporative Cooling System

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Abstract.

Green peppers are perishable without cold storage, and studies have focused on measuring the shelf-life of crops during cold storage. However, our study was interested in extending the shelf life of green peppers by at least 7 days using evaporative cooling. The evaporative cooling system was compared with a non- cooling method, which is widely used in local markets. The objectives of this study were to determine the temperature, relative humidity (RH), weight loss (WLP), shelf-life days (SLD), and Brix. Initially, the dimensions of the wooden box were 46 by 95 centimetres. Holes were drilled into the top and bottom of each cabinet to ensure that air could flow freely across the green peppers. The air cooler and the box were linked using a duct. Temperature and relative humidity were measured inside and outside the box using sensors. The findings indicated that the average duration of usability for the evaporative cooler exceeded that of the sustainability approaches across all three speeds. The evaporative cooler accomplished these characteristics by extended the green peppers shelf life to an average 12 days and maintaining their overall quality. The weight loss was reduced when evaporative cooling was employed and increased when zero energy was utilized. A robust connection was seen between the reduction in weight loss and the Brix measurements. Subsequent research should explore the utilization of solar panels as energy providers for running evaporative cooling systems or relying on natural ventilation.

Keywords: air flow, food losses, sensors, sustainability, zero energy.

1. Introduction

The growing desire among consumers for ripe fruits has surged in recent years due to their delectable taste (Villaseñor-Aguilar, et al., 2020), abundant nutritional content (Kim, et al., 2019; Abou-Sreea, et al., 2021), and high vitamin C content (Muhamad, Y. H. & Al-Badri,, 2021). The Brix is a measure of fruit maturity and sweetness, and can be used to estimate harvest, sales, and processing times. The shelf life of most fruits and vegetables is short after harvesting owing to the lack of cooling methods. This may have caused changes in the weight, and Brix values (AL-Sammarraie, et al., 2022). A cooling method can reduce weight loss. An air cooler is commonly used in Iraq to reduce the temperature during the summer (Al-Badri & AL-Makhul, 2019); and increase the relative humidity (Abdul-Munaim A. , 2006; Al-Badri & Abdul-Abass, 2014). Alternative power such as wind (Mthethwa, Workneh, Kassim, & , 2022) is used instead of electrical power (Al-Badri & AL-Makhul, 2019). Other techniques, such as cold water use (Abdul-Munaim & Al-Badri, 2014), alternative pads (Al-Badri S. B., 2009), fan speed (Peter, Adeshina, & Uswat, 2023), may be used to improve cooling efficiency and treatment of fruits with ginger to extend the shelf life (Al-Hajani, Haded, & AL Bamarny, 2022) and increase the air flow rate (Ndukwu, et al., 2023). Sustainable materials such as charcoal cooler (Jude, Nwaeze, Nnaemeka, & Chimezie, 2023) and packaging (Alfraji, Thamer, & Manhal, 2014) can be used.

1.1. Temperature (T C) and relative humidity (RH%)

Optimizing the temperature slows undesirable metabolic changes, such as softening and textural and color changes. Bell peppers are sensitive to chilling injury when stored at a lower temperature of 7°C (45 °F) (Watada, Kim, Kim, & Harris, 1987). Temperature fluctuations cause 25-50% of postharvest losses. The optimal temperature delay deterioration; can be expressed physiologically, pathologically, and physically. Red peppers develop faster in color change during storage, which was 4.7 - 5.2 days greater than that of yellow peppers, which was double that to 10.7 days (Molinari, 1999). Kissinger, et al (2005) studied the physiological and biochemical fundamentals of pepper water loss, and 10 peppers were chosen for evaluating the water loss rate in ripe pepper during storage.

The peppers were stored at 20°C and 85% RH. Furthermore, after the storage of Bellboy green peppers for 6 days at 20°C, the color changed to yellow when the weight loss reached 11.0%. Hruschka (1977) described deterioration in the commercial shape of green bell peppers accompanied by moderate shriveling symptoms, which appeared when weight loss was 12.0%.

2.1.1 Weight loss (WL)

Green peppers are hollow, and a small amount of water loss from the peppers is reflected in the loss of freshness, which decreases their shelf life, quality, and marketability (Kissinger, et al., 2005). As weight loss increases during storage, the firmness of the produce decreases, and wilting, shriveling, or browning increases (Ramjan & Ansari, 2018). Hruschka (1977) described deterioration in the commercial shape of green bell peppers accompanied by moderate shriveling symptoms, which appeared when weight loss was12%. In another study, the flaccidity of green pepper was associated with water loss (Lownds, Banaras, & Bosland, 1993).Green peppers lose marketability when they reach 7.0 % weight loss (Robinson, Browne, & Burton, 1975). The Mexican peppers became flaccid after 3- 5 days of storage at 20°C, and the weight loss reached 7- 10%. The signs of shriveling started to appear, when green paper lost 5% of its weight (González & Tiznado, 1993). The relationship between weight loss and visual quality decreased as weight decreased. The samples were stored at 20, 25, and 37°C. In addition, the delay in storage plays an important role in the decrease in weight loss, which was 1.9 on day 7 when the samples were stored at a temperature of 7.5°C (Cantwell & Thangaiah, 2001). The suitable weight loss of green pepper was 5-12% before the loss of marketability, which depended on the type of cultivar.

3.1.1 Shelf-Life Days (SLD)

The shelf-life of fruits and vegetables is short because of their susceptibility to microbial spoilage, which increases their respiration rate, and ethylene production. A cool chamber helped keep the vegetables cooler and extend their shelf life. The ability of a chamber to increase shelf life varies depending on the vegetable and its location (Piloo & Vida, 2014). The shelf-life of green paper was 28 days when it was stored at 14°C and 83% RH, when it was stored in an evaporative cooling system (Samir, Woldetsadik, & Workneh, 2013), and 22 days when it was stored under evaporative cooler conditions at 23°C and RH greater than 90% (Antonio & Acedo, 1997). The shelf-life day affects the maturity stage of green peppers (Kasampalis, et al., 2022). The shelf-life is influenced by relative humidity (Byeon, et al., 2023),whereas other researchers have confirmed that shelf life is affected by temperature. Over the last few decades, as health by eating habits has increased, the consumption of fresh produce has also increased. Cool storage via an evaporative cooling system can be implemented to extend the shelf life of fruits and vegetables (Sangeeta, et al., 2022).

4.1.1 Brix

The consumer demand for ripened fruits has increased in recent years because of their sweet flavor and high nutritional value. The sweet flavor is related to the sugar content of fruits and vegetables (Molinari, 1999). Bell peppers were green at the unripe stage, and their color changed to red, gold, purple, orange, or brown as they were immature owing to the increase in sugar content. The color bell peppers tended to be sweeter than the green peppers. The pepper flavor was the most notable (Hardenburg, Watada , & Wang, 1986) characteristic and could be sweet, mild, or strongly nippy. Brix is associated with color change in green peppers. The color sensor was used to classify green pepper and the results were compared with those of the Pixy2 camera via image processing. The results illustrated that the camera recorded the best sorting method (AL-Sammarraie & Özbek, 2021). SCiO was used to measure sweetness (AL-Sammarraie, et al., 2022) and pepper content (Muhamad, Y. H. & Al-Badri,, 2021). Cost for each work need consider that help to understand the benefits (Jassam, Abd Al-majeed, & Ali, 2022),

The storage of fruits and vegetables in local markets in Iraq considered to be a sustainable method involving zero energy; however, the quality of these fruits and vegetables is declining rapidly, and weight loss is increasing because a cooling method is needed to prolong their shelf life. Evaporative cooling is friendly to the environment, requires low energy and has a low cost.

Equations

1.1 Using equation (1) a digital scale was used to obtain measurements every other day, and the data were recorded. The weight loss percentage (WLP) was calculated using the following equation: (Kamorudeen, Ismaila, Aderonmu, Teslim, & Mutiu, 2013).

$$\text{Weight loss (\%)} = \frac{\text{Initial weigh– final weight}}{\text{Initial weight}} \text{X100} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

1.2 Equation (2) Correlation between WLP% and Brix:

The equation below was used to calculate the correlation between WLP% and Brix

$$r_{12} = \frac{\sum(Y_1 - \bar{Y}_1)(Y_2 - \bar{Y}_2)}{\sqrt{\sum(Y_1 - \bar{Y}_1)^2 \sum(Y_2 - \bar{Y}_2)^2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

2.Materials and Methods

In a cold storage cabinet with 4 layers, holes exist in each layer that allow air to pass through to the next layer. This will help move air over crops to decrease temperature and increase relative humidity. A plastic tube was used to connect the air cooler and the cabinet.

The cooler performance was tested and verified using an evaporative air cooler with ambient relative humidity and temperature, cooler relative humidity, and temperature, and inside the box data collection and recording were performed using an Arduino. The air speed was measured using a Kestrel- 300. All of these characteristics were tested at each cooler speed.

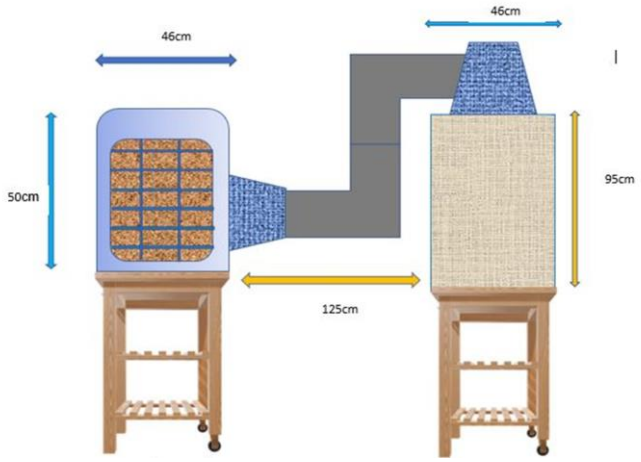

Figure -1-Air cooler and storage box.

The air cooler had three speeds (1400 rpm), a water tank capacity of 50 L, and a power consumption of 190 W. Three sensors were used to record T◦C and RH% daily, and the average temperature each day was calculated as ±. The sensors were placed inside the air cooler and inside and outside the storage box. The data were recorded daily using Ardoin software.

Temperature and relative humidity sensor

Air speed

Figure 2 Sensors used in the experiment.

2.1 Brix: Brix was measured for each sample at three different locations on each bell paper every other day**.** Each replicate had 2 green bell peppers and a plus sign symbol with two arrows on each green bell paper, as shown in Fig. 3a. The SCiO spectrometer was used to measure Brix (Donis-González, Valero, Abdul Momin, Kaur, & Slaughter, 2020) at each arrow and in the center of the plus sign to ensure that accurate measurements were taken at the same spot every other day, as shown in Fig 3b.

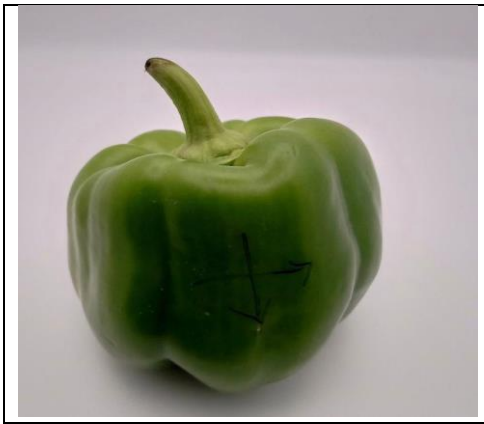

Fig 3a Green bell peppers and a plus sign symbol with two arrows were marked on every green bell pepper, as shown in the picture.

Fig 3b SCiO spectrometer was used to measure Brix at each arrow and in the center of the plus sign.

Figure 3 Green peppers and SCiO spectrometer

3. Results and Discussion: The maximum SLD was 15 days for speed 1, the average temperature was 21 ±0.0°C and the average relative humidity was 75 ± 0.577, which was recorded as 10.81±0.97 WLP%. The minimum SLD was 8.33±1.15 at speed 3, the average temperature was 26 ± 0.0°C, and the relative humidity was 62 ± 1.00, which was recorded as 12.00±0.0WLP%. This may be related to the air speed, which increases the contact time between water and air, leading to an increase in the relative humidity and decrease in the temperature, as shown in the recorded data (Al-Badri & AL-Makhul, 2019; Abdul-Munaim & Al-Badri, 2014).

On the other hand, the SLD was lower for the sustainability method for all experiments, which was 4.33±0.57 - 5±0.00 owing to the high average temperature, which was 31 ± 00 -32 ± 0.577 and lower relative humidity, which was 25% – 44% that work on increased weight loss.

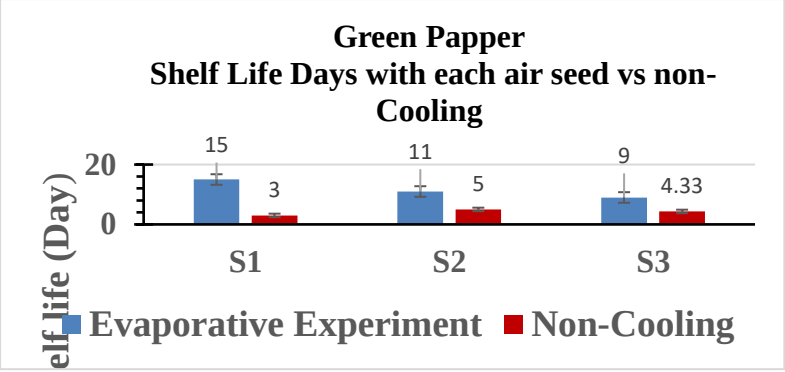

Figure 4 Green Papper shelf-life day with each air speed versus non-cooling

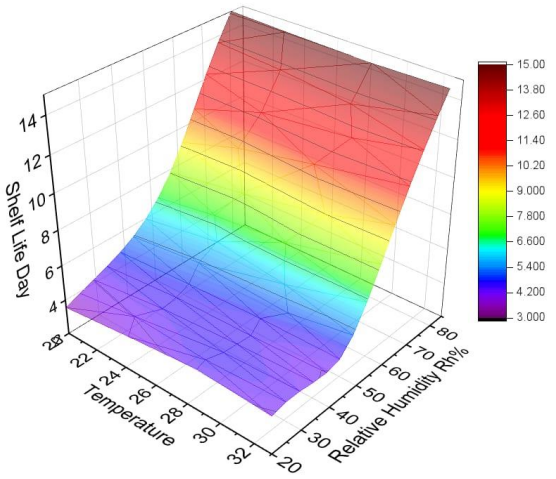

Figure 5The 3D model illustrates the relationship between temperature, relative humidity, and shelf-life..

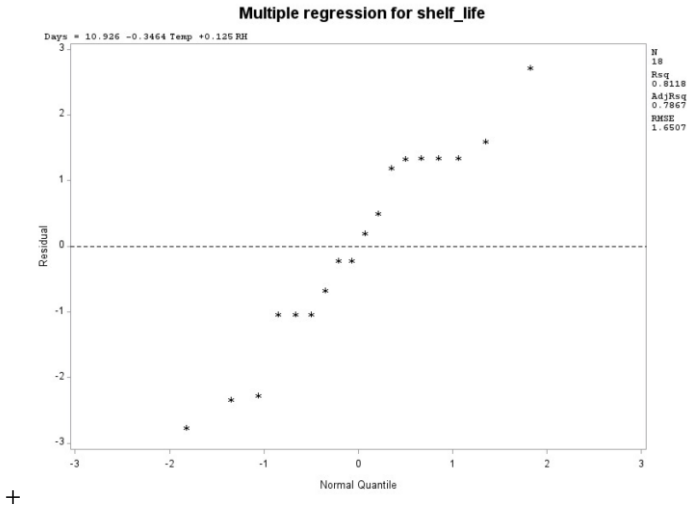

Figure 6 Multiple regression for the shelf life

The 3D model shows the relationship between relative humidity (RH), and temperature, and their influence on the shelf-life days of storage, depending on the data for all the experiments. The overall model was highly significant ($df_{(2,17)}$=***32.34***, $p<0.0001$). The coefficient of temperature was – 0.34637, which was lower than the coefficient of relative humidity, which was 0.12495. This means that temperature had a greater influence on the extended shelf life of green pepper than relative humidity. The mathematical model explained most of the data because Reg = 0.82, AdjReg= 0.79 and RMS= 1.65.

Table 1 Overall results of the shelf-life days, The Reg Procedure, MODLEI, Dependent

Source	DF	Sum of Squares	Mean Square	F Value		Pr>F	
Model	**2**	**176.24053**	88.12026	32.34		**<.0001**	
Error	**15**	**40.87058**	2.72471				
Corrected Total	**17**	**217.11111**					

Root MSE	**1.65067**	**R-Square**	**0.8118**
Dependent Mean	**7.777778**	**Adj R-Sq**	**0.7867**
Coeff Var	**21.22288**		

Variable	DF	Parameter Estimate	Standard Erro	T Value	Pr > t	Standardized Estimate	Tolerance	95% Condidence Limits	
Intercept	1	10.92563	5.94191	1.84	0	0	.	-1.73925	23.59051
Temp	1	-0.34637	0.15679	-2.21	-0.38049	-0.38049	0.42304	-0.68056	-0.01218
RH	1	0.12495	0.03728	0.004 4	0.57730	0.57730	0.42304	0.04549	0.20441

Correlation between WLP and Brix

Figure 7 shows that there was a highly significant correlation between WLP and Brix, which was 0.9893, (P-Value <0.0001). The data show a correlation only for the cooling method and the data for no-cooling were neglected because of the short life of the day, which averaged 4.33 days.

Table 2 Correlations between WLP and Brix

Simple Statistics						
Variable	**N**	**Mean**	**Std Dev**	**Median**	**Minimum**	**Maximum**
WL	8	7.70750	4.22577	9.50500	0	11.80000
Brix	8	4.09875	0.31935	4.18500	3.52000	4.44000

Pearson Correlation Coefficients, N = 8 Prob > |r| under H0: Rho=0		
	WL	**Brix**
WL	**1.00000**	**0.98927 <.0001**
Brix	**0.98927 <.0001**	**1.00000**

Spearman Correlation Coefficients, N = 8 Prob > |r| under H0: Rho=0		
	WL	**Brix**
WL	**1.00000**	**0.97619 <.0001**
Brix	**0.97619 <.0001**	**1.00000**

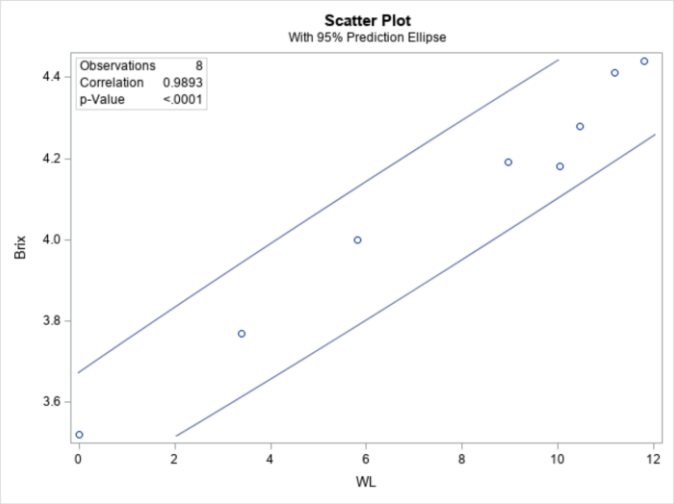

Figure 7 Scatter plot

Since there was a correlation, regression was applied, and the results showed that the impact of WLP on Brix was highly significant ($F_{1,7}$=*275.01, P< 0.0001)*. The R-Square was 0.978648, indicating that 97.8% of the data were explained by the regression model. The root MSE was 0.050,

Table 3 Linear regression

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	0.69864481	0.69864481	275.01	<.0001
Error	6	0.01524269	0.00254045		
Corrected Total	7	0.71388750			

R-Square	Coeff Var	Root MSE	y Mean
0.978648	1.229713	0.050403	4.098750

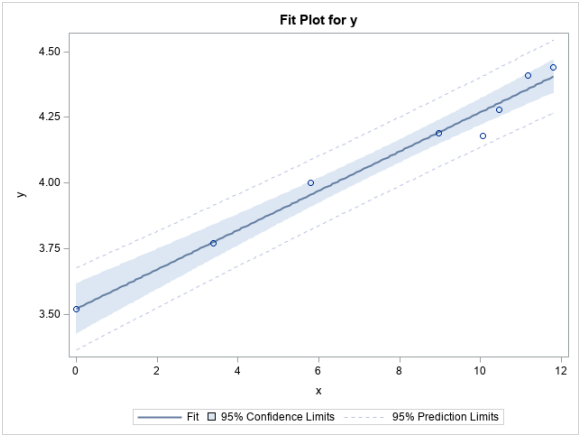

Figure 8 Fit plot for y (Brix)

Cost

Cost calculation was based on 1 ton of green pepper and the dollar price is 100 $ =1320 Iraqi Dinnar according to the National Bank of Iraq.

Table 4 cost analysis

	Evaporative cooling	Suitability
	Vibrable cost	Vibrable cost
Desk work	38 $	38 $
Seeds	11 $	11 $
Fertilizer	16 $	16 $
Pesticides	11 $	11 $
Laber work	75 $	75 $
Fuel and matinee	15$	15$
Cost of product	168 $	168 $
Income	378 $	378 $
Net profit	210 $	210 $
When using Evaporative cooling techniques		
Marketing Cost (transportation, Storage,..etc)	35 $	15 $
Income	378 $	329 $
Net profit	177 $	146 $
Marketing margin	340$	242$
Marketing efficiency	89%	81%

Conclusion

Yes, the results of this study answered the following research question. Does evaporative cooling prolong the shelf life of green peppers at least 7 days? The average shelf life was 12 days, and the shelf life did not affect quality. A higher air speed decreased the shelf-life of vegetables and increased the WL%, whereas a lower air speed increased the shelf-life and decreased the WL%. This difference may be related to the lower relative humidity obtained from the evaporative cooling system when using the high air speed, which decreases the relative humidity and increases the temperature.

The speed one treatment extended the shelf-life days, led to low temperature and higher relative humidity, and extended the shelf-life days of the green paper with a minimum WL% because of the long contact time between the water and the pads.

Speed two recorded the middle shelf-life days and the middle temperature, and finally, Speed three recorded the highest temperature and lowest shelf-life days. On the other hand, when using sustainability methods, in which the bell pepper was mimicked by the local retail market, the shelf-life days decreased to a minimum of 4 days and a maximum of 5 days because the

higher temperature and lower relative humidity increased the respiration rate, which was reflected in the WL%, and was recorded to be greater than 10% after 4-5 days. Under the sustainability method, the fruits begin to shrink and/or wilt faster than samples stored under evaporative cooling. The results illustrated a strong positive correlation between WLP% and Brix as weight loss decreased during storage and Brix increased. Finally, cost analysis is recommended to use evaporative cooling in market and farm that help to improve the quality and benefit.

Recommendations and future work

Research has recommended using packaging via both methods to help extend the shelf-life and decrease the WL. Future research needs to investigate in the suitability of this method for storing fruit and veganises with zero energy. Further research needs to apply a control air speed lower than 3.4 m/sec, which is the minimum air speed for the speed one that may provide a new result.

Conflicts of interest

The authors declare that there are no conflicts of interest.

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