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Effect of Hot Water Treatment and Evaporative Cooling on Some Postharvest Characteristics of Sweet Pepper (*Capsicum annuum* cv. 'Sweet Cayenne')

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Abstract

Sweet pepper is an economically important vegetable crop that is widely cultivated in many countries. However, sweet pepper incurs considerable postharvest losses due to its high perishability as manifested by shriveling and disease development. This study evaluated the effects of hot water spray treatment (55 °C) and evaporative cooling (25.6±1.31 °C, 98.87±2.07% relative humidity [RH]) as storage option on some physico-chemical attributes of 'Sweet Cayenne' sweet pepper. The evaporative cooler (EC) provided a microclimate with 27.96% higher RH and a temperature that was 0.41 °C lower compared to ambient storage conditions. Temperature reduction was very slight but the conditions in the EC resulted in reduced weight loss and shriveling, better visual quality, delayed color development and generally longer period of acceptable quality compared to the control fruit stored in ambient. Hot water treatment alone did not pose any significant effect in maintaining the quality of sweet pepper but tended to slightly maintain quality when combined with storage in the EC. Total soluble solids were affected only at nine days after treatment. Results showed the potential of evaporative cooling in maintaining the postharvest quality of sweet pepper and extending its shelf life by three days compared to storage in ambient conditions. The EC design may be improved to prevent surface moisture in the stored produce in order to reduce decay.

***Keywords**:* evaporative cooling, hot water treatment, shelf life, visual quality, sweet pepper

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1. Introduction

Sweet pepper (*Capsicum annuum* L.) is an extensively grown vegetable crop in many countries because of its high nutritive and culinary value (Samira *et al.*, 2013). It is a balanced source of most essential nutrients including high contents of vitamins A, C and E and has antioxidant properties as it is rich in phytochemicals and flavonoids (Deepa *et al.*, 2006). However, sweet pepper is highly perishable with a short shelf life. It is prone to water loss and shriveling which affect the overall visual quality (González-Aguilar *et al.*, 1999).

To maintain its quality and minimize postharvest losses, rapid cooling after harvest is considered as the most effective method (Ilić *et al.*, 2012) followed by storage in low temperature. However, sweet pepper is sensitive to chilling injury wherein upon storage in temperatures below 7 °C, symptoms such as severe pitting, calyx darkening, weight loss and decay development are observed (Lim *et al.,* 2007). In tropical countries, a cheaper alternative to refrigeration is through evaporative cooling which can provide a storage environment with lower temperature and higher RH (Samira *et al.,* 2013) than ambient conditions. A previous study on the storage of sweet pepper in a cabinet evaporative cooler (EC) in Davao City, Philippines, a tropical region, found that the cabinet EC made of jute sack that was continuously moistened with water, can maintain an average temperature and relative humidity (RH) of 23.91±3.85 °C, 93.84±9.33% , respectively. The difference between the two storage conditions were 4.820C and 26.78% RH. Sweet pepper stored in the EC had reduced weight loss and longer retention of firmness (Bayogan *et al.*, 2017). Samira *et al.* (2013) reported that hot peppers stored in the EC had reduced weight loss and maintained higher levels of ascorbic acid, pH, and marketability. Furthermore, fruit stored in EC were marketable up to 28 days while those stored in ambient were already unmarketable after 16 days. In tomatoes, a simple brick-walled EC with moistened sawdust or sand effectively reduced weight loss and improved shelf life (Vanndy *et al.*, 2008).

Another factor that limits the marketability and storage life of sweet pepper is pathological deterioration. This crop is highly susceptible to fungal infections such as those caused by *Botrytis cinerea* and *Alternaria alternata* (Halfon-Meiri and Rylski, 1983; González-Aguilar *et al.*, 1999). To minimize the use of chemicals, there has been a growing interest in the application of hot water as a postharvest treatment to control pests and prevent fungal rots in fruits and vegetables (Lurie, 1998). Fallik *et al.* (1999) reported that a hot water rinse for 12 seconds (55 °C) significantly reduced decay incidence in sweet peppers while maintaining marketable fruit quality.

The resulting lower temperature and higher RH in an evaporative cooling system with the combination of heat treatment could prolong the shelf life of sweet pepper. This study evaluated the effectiveness of hot water spraying (55

°C) and evaporative cooling, alone or in combination, in improving the postharvest attributes and prolonging the shelf life of sweet pepper.

2. Methodology

2.1 Sample Preparation

Freshly harvested, uniformly-sized and blemish-free mature green 'Sweet Cayenne' peppers grown under traditional cultural practices were procured from Bankerohan Market in Davao City, Philippines. Fruit were transported to the Postharvest Biology Laboratory at the University of the Philippines Mindanao where the experiment was conducted. Pretreatment was done by dipping the fruit in sodium hypochlorite (200 mg L^{-1}) solution for three minutes followed by air-drying.

2.2 Postharvest Treatment

Treatments consisted of a control; spraying with warm water (55 °C) until dipping wet and air drying then storing at ambient conditions; storing of untreated sample in cabinet EC; and spraying of hot water (55 °C) and air drying then storing in the EC. The EC (99 cm x 70 cm x 150 cm) was covered with two layers of jute sack as cabinet walling with three racks. Its door is burlap-covered. The sack walls were continuously moistened with water from a container placed on top of the EC cabinet. The water system was designed to wet all the sides of the jute sack. The EC cabinet was installed with horizontal pipe that was connected to the water source, and water moved gravitationally along the sides of the cabinet. A total of 30 samples per treatment in which ten fruit per replicate were evaluated for the non-destructive parameters at each evaluation period. For total soluble solids (TSS), 20 samples per replication were prepared for the whole duration of the experiment, using five fruit per evaluation.

2.3 Temperature and RH

The RH and temperature of the ambient and EC conditions were measured daily using two digital data loggers (HOBO UX 100-003). One data logger was attached inside the EC while the other was inside the laboratory where fruit kept in ambient condition were stored.

2.4 Evaluation of Postharvest Attributes

2.4.1 Weight Loss

Thirty samples from each treatment were initially weighed and monitored at a three-day interval for nine days. Weight loss percentage was calculated using the Equation 1:

$$\textit{Weight loss (\%)} = \frac{\textit{Initial weight - Final weight}}{\textit{Initial weight}} \times 100 \qquad (1)$$

2.4.2 Quality Assessment

The following parameters were evaluated using quality rating scales: visual quality rating (1=excellent, fresh appearance; 2=very good, slight defects; 3=good, limit of saleability, defects progressing; 4=fair, usable but not saleable; 5=poor), shriveling (1=no shriveling; 2=slight, 1-15% shriveling; 3=moderate, 16-30% shriveling; 4=severe, 31-49% shriveling; 5=extreme, ≥50% shrivelling), peel color (1=mature green; 2=breaker; 3=turning; 4=orange; 5=light red; 6=dark red), degree of decay (1=no decay; 2=1-10% decay/slight; 3=11-25% decay/moderate; 4=26-50% decay/moderately severe; 5=more than 50% decay/severe). Percentage of postharvest decay was determined by counting the number of samples showing decay and deducting this from the total number of peppers in each replication. Samples with a visual quality rating exceeding 3 were deemed as non-marketable and have reached the end of shelf life.

2.4.3 Total Soluble Solids

The juice was extracted using a slow fruit juice extractor (Hurom Slow Juicer). One or two drops of the juice was placed on the prism surface of an Atago PAL-1 digital refractometer to measure the TSS.

2.4.4 Statistical Analysis

Analysis of variance using one-way ANOVA was used to analyze data while Fisher's least significant difference (LSD, $p \leq 0.05$) test was used for comparing treatment means.

3. Results and Discussion

3.1 Reduced Weight Loss in Sweet Pepper Stored in Evaporative Cooler (EC)

Figure 1a shows that sweet pepper (*Capsicum annuum* L. cv. 'Sweet Cayenne') samples stored in the evaporative cooler (EC, 25.3±1.2 °C, 98.9±2.1% RH) had a significantly lower percentage of weight loss compared to those stored in ambient conditions (25.7±1.3 °C±1.2 °C, 70.9±4.0% RH). Hot water sprayed on sweet pepper did not show any advantage when stored in EC in terms of weight loss relative to the samples in EC alone. At six days after treatment (DAT), some samples were no longer acceptable due to deterioration in quality (extreme shriveling or development of decay) and were, thus, not included for data recording at nine DAT. This explains the slight drop in weight loss and visual quality at nine DAT.

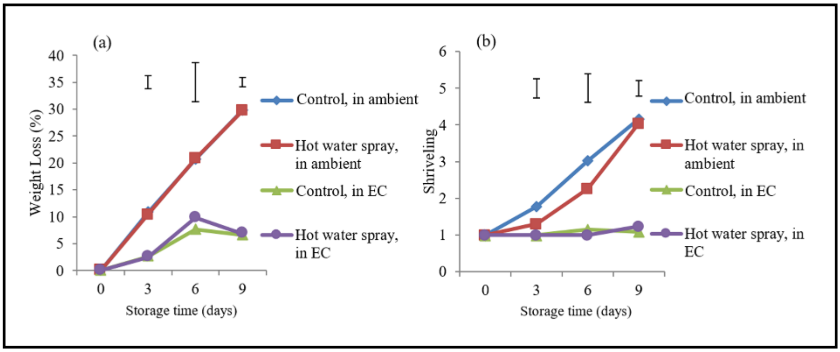

Figure 1. Effect of hot water spray treatment and storage in cabinet EC on the weight loss (a) and shriveling (b) of sweet pepper. Vertical bars indicate LSD value at $p \leq 0.05$.

The total weight of sweet pepper is mainly due to its water content. Weight loss is primarily due to water loss which can be reduced by EC as a result of lower temperature and higher RH in the storage chamber (Acedo, 1997). The slightly lower temperature and higher RH conditions provided by the EC in the present study appeared to have slowed down the rate of transpiration resulting in reduced weight loss as compared to those stored in ambient conditions. The EC provided a microclimate with an RH and temperature that were 27.96% higher and 0.410 °C lower, respectively, compared to ambient conditions. The differences in weight loss in sweet pepper could be attributed to the higher RH in EC. In another study, green pepper stored in low RH like in 60 and 80% RH resulted in higher weight loss (15% and 10%) while only 6 and 4% weight loss were recorded in fruit stored in 90 and 95% RH, respectively (Nunes *et al.*, 2012). In the present study, fruit stored in EC with higher RH had 10% lower weight loss than the fruit stored in ambient with lower RH at six DAT. This indicates that RH has a greater effect on the differences in weight loss in sweet pepper than the temperature. In lettuce and cranberry, storage of the produce in the same temperature with varying RH resulted in differences of weight loss (Nunes and Emond, 2007; Forney, 2008). In both produce, higher RH reduced weight loss.

3.2 Evaporative Cooling Reduced Shriveling in Sweet Pepper

Sweet peppers held in ambient condition shriveled faster than those stored in evaporative cooling conditions (Figure 1b). At nine DAT, only slight (1-15% of the surface area) shriveling was observed in EC treatments while those that were stored in ambient exhibited severe (31-49% of the surface area) shriveling. Furthermore, at three and nine DAT, spraying of hot water tended to reduce shriveling as compared to untreated fruit in both storage conditions. After nine days of storage, 100% and 90% of the samples for the control and hot water spray treatments, respectively, have reached the end of shelf life because of extreme shriveling.

Shriveling is one of the effects of excessive water loss leading to higher weight loss. Fruit with higher weight loss also showed higher degree of shriveling as shown in fruit stored at ambient conditions where RH was lower. In this study, though the temperature in EC was only 0.41 °C lower than in ambient, excessive shriveling of fruit was prevented due to the RH that was higher by 27.96%. Shriveling tended to be reduced in hot water-treated sweet pepper in ambient conditions. As reported by Wang *et al.* (2000), hot water treatment could increase the transcript levels of heat shock proteins in a fruit, thereby protecting other proteins from breaking down and maintain the integrity of the cells.

3.3 Evaporative Cooling Maintained Better Quality of Sweet Pepper

Visual quality of the sweet pepper samples varied among treatments at nine DAT but not earlier (Figure 2a). Although hot water-sprayed fruit stored in EC maintained the best visual quality, untreated fruit in EC also retained an acceptable quality at nine DAT. On the other hand, all fruit stored in ambient were found unmarketable.

Since water loss is a primary physiological factor that affects the quality of sweet pepper during storage (Dumville and Fry, 2000), the reduction of percentage of water loss of stored fruit in EC helped maintain marketable quality. Although, hot water treatment combined with storage in ambient condition did lead to deterioration of fruit quality, but when stored in EC, fruit maintained slightly better overall visual quality characteristics. This was opposite in hot water-treated fruit when stored in EC.

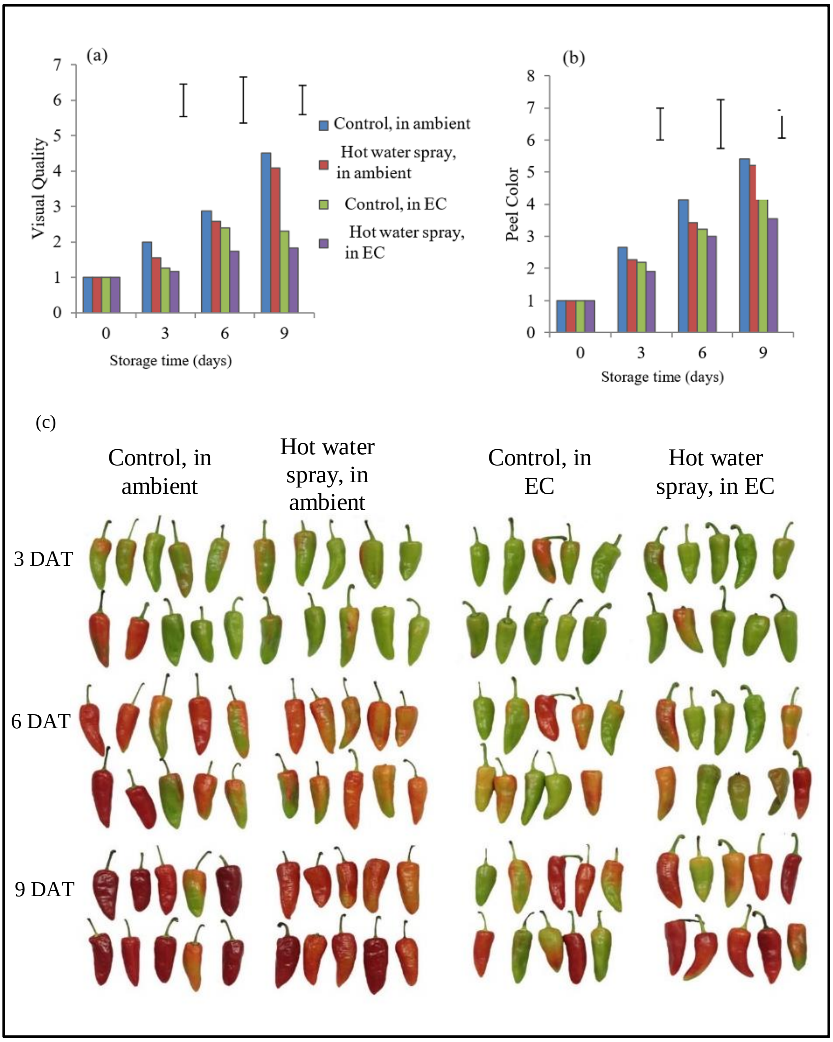

Figure 2. Effect of hot water spray treatment and storage in cabinet EC on the visual quality (a, c) and peel color (b, c) of sweet pepper. Vertical bars indicate LSD value at $p \leq 0.05$.

The optimum storage temperature and RH for green and red capsicums range from 1-5 °C at 90-95% RH (Ekman *et al.*, 2016). In the present study, despite the slight difference of temperature between EC and ambient condition, better visual quality was still maintained. This was due to higher RH in EC than in ambient condition signifying the greater effect of RH in maintaining better quality of fruit compared to temperature. During the dry season where high temperature is a limiting factor in quality maintenance of fruit, increasing the storage RH of fresh produce can effectively maintain fruit quality.

3.4 Evaporative Cooling and Hot Water Treatment Delayed Color Change

Peel color change from mature green to full red was slowest for hot water-treated fruit when stored in EC, whereas those stored in ambient conditions without hot water treatment showed the fastest color change from green to full red (Figures 2b). In addition, both treatments in the EC have significantly slower rate of peel color change compared to fruit stored in ambient condition. Figure 2c shows differences in visual quality and peel color changes of fruit.

The change in peel color is a visible sign of ripening along with other physico-chemical and metabolic changes (Chaki *et al.*, 2015). Color change in sweet pepper, from green to orange or full red, is accompanied by chlorophyll degradation with simultaneous synthesis of carotenoids (Tadesse, 1998). According to Lurie (1998), exposing fruit to high temperature may enhance some of its ripening processes while it slows down the process in other fruits. Alteration of normal protein synthesis and cellular metabolism in fruit may disrupt the normal process of ripening. Heat treatment may have retarded the breakdown of chlorophyll as reported in lime fruit in which color change was also delayed (Kaewsuksaeng *et al.*, 2015) which slowed down the color change. Inhibition of ripening modulated by heat treatments may persist for a period when the produce is stored in low temperature (Lurie and Pedreschi, 2014). This may explain the delayed color change of heat-treated samples in EC compared to treated samples in ambient room conditions where the former had slightly low temperature. Storing under evaporative cooling conditions can slow down the ripening process of sweet pepper, which resulted in prolonged shelf life. This agrees with the results of González-Aguilar *et al.* (1999) in which sweet peppers treated with hot water (50 °C) followed by packing in polyethylene film exhibited reduced color development.

3.5 Hot Water Treatment Reduced Decay in Ambient Room Conditions but not in EC

All treatments started showing symptoms of slight decay at three DAT (Figures 3a and 3b). In ambient conditions, hot water treatment showed lower decay at six DAT. However, in evaporative cooling conditions, hot water treatment showed higher decay incidence at nine DAT while there was no decay in sweet pepper stored in ambient conditions both in treated and control fruit. There was a lower incidence of diseases in EC alone at nine DAT compared to six DAT because decayed fruit observed in the previous evaluation were discarded to avoid cross contamination.

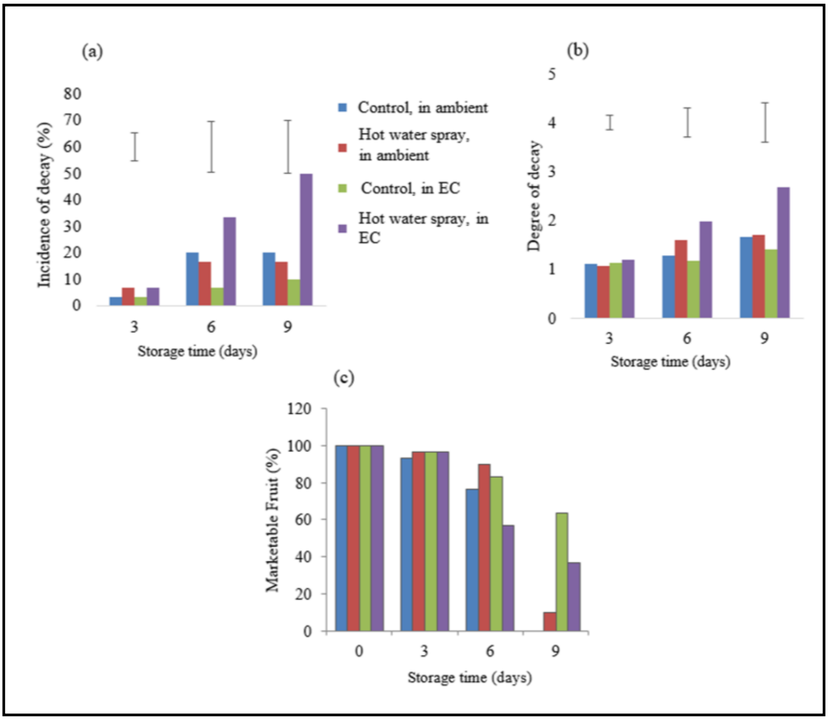

Figure 3. Effect of hot water treatment and evaporative cooling on sweet pepper fruit (a), decay incidence (b), and marketable fruit (c) during storage. Vertical bars show LSD value at $p \leq 0.05$.

The development of soft rot in hot water sprayed fruit was probably the major limiting factor for the shelf life of the fruit stored in EC. This result is contradictory with the findings of Shehata *et al.* (2013) that indicated dipping in hot water (55 °C) for one minute followed by film packaging showed no signs of development of decay for 28 days of storage at 8 °C and 95% RH. One factor that may have contributed to the development of decay would be the presence of surface moisture on some samples inside the EC that promoted microbial development. The presence of surface moisture was due to the very high RH, 98.9±2.1%, compared to the recommended RH storage condition for pepper which is 90-95%. Therefore, it is recommended to ensure that free water should not be in contact with the fruit during storage since this would enhance disease development.

3.6 Evaporative Cooling Maintained the Marketability of Sweet Pepper

Although 77% and 90% of the fruit samples of the control and hot water spraying stored in ambient, respectively, remained marketable at six DAT (Figure 3c), moderate to extreme shriveling occurred in the drier environment (70.9±4.0% RH) under ambient conditions. Since fruit continued to shrivel, the remaining samples were discarded by day six and day seven. Hence, at nine DAT, 0 and 10% of the fruit remained marketable in the control and hot water-sprayed treatments followed by those stored in ambient conditions, respectively. Higher percentage of marketable fruit was noted in EC at nine DAT although losses still occurred due to decay. This result was also observed in some hot pepper varieties stored in EC in which fruit remained marketable for an extended period but with losses associated with decay (Samira *et al*., 2013). It is suggested to keep the RH within the recommended conditions as excessively high RH during the storage may result in surface moisture on the stored product. It is also necessary to use other disinfection methods as hot water spray was not sufficient to control the diseases.

3.7 TSS was not Affected by Evaporative Cooling and Hot Water Treatment

There was a decline in TSS from zero to nine DAT, except at six DAT where there was an increase in TSS in control. However, TSS was not affected and did not significantly vary among treatments (Figure 4). At nine DAT, there was no TSS recorded in all samples stored in ambient as fruit had already reached the end of shelf life.

The study of González-Aguilar (1999) reported only minor differences in the values for TSS observed after 14 days of storage of hot water-sprayed sweet peppers. Samira *et al.* (2013) also noticed an increase of TSS during storage in some sweet pepper varieties especially in ambient than in evaporative cooling. The authors explained that the increase could be due to loss of moisture as the fruit convert the organic acids to sugar which then declined with storage time as fruit cells use the soluble solids.

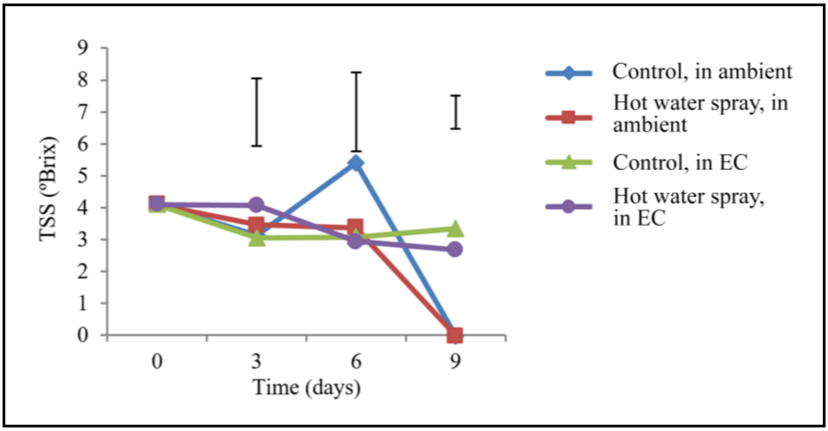

Figure 4. Effect of hot water spray treatment and storage in cabinet EC on the TSS of sweet pepper. Vertical bars indicate LSD value at $p \leq 0.05$.

4. Conclusion and Recommendation

This study evaluated the effectiveness of hot water spraying (55 °C) and evaporative cooling, individually or in combination, in improving the postharvest attributes and prolonging the shelf life of sweet pepper fruit. The EC provided a microclimate with 27.96% higher RH and 0.41 °C lower temperature compared to ambient conditions. Temperature reduction was slight but the conditions in the EC resulted in reduced weight loss and shriveling, better visual quality, slower color changes and more acceptable fruit indicating a longer shelf life compared to the control fruit stored in ambient conditions. This indicates that RH had a greater effect on the quality of sweet pepper stored in the EC. Although hot water treatment alone did not have a significant effect in maintaining quality and prolonging fruit market acceptability, combining it with storage in EC showed positive results in terms of slowing the rate of peel color change. While severe shriveling and dull color were the major indicators for the end of shelf life of sweet pepper in ambient conditions at nine DAT, development of soft rot was the limiting factor for sweet peppers in EC. Nevertheless, fruit without decay symptoms remained to have good quality until nine days in EC. Overall, storing non-hot water treated sweet pepper fruit in EC resulted in 63.33% more marketable fruit compared to the control, and 26.66% more good fruit than the application of hot water spraying combined with storage in EC at nine DAT. Storing in EC alone can reduce postharvest losses in sweet pepper. Further studies are recommended to improve design of the cabinet EC to reduce surface moisture in stored produce that can lead to diseases. Other heat treatment temperatures may be studied further.

5. Acknowledgement

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