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Fennel Essential Oil as Safe Natural Compound Maintains Quality of Cold Stored Bell Pepper at Low Temperature

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THIS study investigated the effect of fennel essential oils at 0, 250, 500 and 750 µLL-1 on bell pepper during cold storage for 7, 14, 21 and 28 days at 5°C and 28 days plus 3 days at room conditions. The aim was to maintain quality and reduce the chilling injury of bell pepper. Weight loss, appearance, decay, taste, color, total chlorophyll, chilling injury (CI), seed discoloration, electrolyte leakage (EL), soluble solids content (SSC), ascorbic acid, total phenols were measured. The results indicated that 750 µLL-1 of fennel essential oil was effective in maintaining the quality of bell pepper where had the lowest weight loss, decay, CI, seed discoloration, EL and SSC, and had the highest value of appearance, color, chlorophyll, taste, ascorbic acid and phenols during cold storage and shelf life at room conditions. Thus, these results indicate that fennel essential oils could be used as a safe treatment to preserve quality, alleviate CI and prolong postharvest life of stored bell pepper under low temperature and room conditions.

Keywords: *Capsicum annuum*, Chilling injury, Seed discoloration, Essential oils, Quality, Low temperature.

Introduction

Sweet pepper (*Capsicum annuum* L.) is one of the important vegetables in Egypt. It is a perishable vegetable with a high susceptibility to postharvest diseases (Hardenburg et al., 1990). Pepper fruit encounter many problems during postharvest period, such as weight loss, quality deterioration and chilling injury when were stored below 10 °C (Seo et al., 2020). Various postharvest treatments, such as chemicals (Ding and Wang, 2018), ultra-violet radiation (Vicente et al., 2005), edible coatings (Abad Ullah et al., 2017), intermittent warming (Liu et al., 2015), hot water (Gonzalez-Aguilar et al., 2000) and methyl jasmonate (Seo et al., 2020), were used to maintain quality and reduce chilling injury of pepper. Recently, natural compounds such as essential oils have been used to reduce decay and chilling injury and to maintain quality of many horticultural crops like strawberry (Zamani-Zadeh et al., 2014), table grapes (Valero et al., 2006), tomato (Tzortzakis, 2007), peach (Cindi et al., 2016), leafy vegetables (Ponce et al., 2004) and fresh-cut produce (Scollard et al., 2016). Many investigators reported that fennel essential oils have several biological activities, such as antioxidant activity (Singh et al., 2006), hepatoprotective effect (Özbek et al., 2003), anti-inflammatory activity (Choi and Hwang, 2004), antithrombotic activity (Tognolini et al., 2007), antidiabetic activity (El-Soud et al., 2011), acaricidal activity (Lee, 2004), and antitumour activity (Pradhan et al., 2008). Additionally, fennel essential oils have antifungal activity (Singh et al., 2006), and antibacterial activity (Diao et al., 2014). Now, few studies investigated the effect of essential oils on bell pepper during storage such as cinnamon oil (Xing et al., 2011). However, no information available about effect of fennel essential oils on bell pepper. Therefore, the objective of this study was to test the hypothesis that the fennel essential oils could be used to reduce the decay, alleviate chilling injury, maintain the quality and prolong the storage period of bell pepper in 5 °C and shelf life at room conditions.

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Materials and Methods

Plant materials and essential fennel oil extraction

Greenhouse bell pepper fruits cv. Top Star were harvested on April 2, 2019 in the first season and on April 8, 2020 in the second season from a farm of the Faculty of Agriculture, Suez Canal University, Ismailia, Egypt. Fennel (*Foeniculum vulgare* L.) seeds were purchased from a local market in Ismailia city. Essential seeds oil was extracted by hydrodistillation using a glass Clevenger-type apparatus for three hours. The extracted oil was dried using anhydrous sodium sulfate and stored in dark bottle of glass at 4 °C until use.

Treatments

At the laboratory, bell pepper fruit were visually checked for blemishes and defects. The chosen fruit were divided into four groups, the first group was sprayed with distilled water as control while the second, third and fourth were sprayed with 250, 500 and 750 µLL^{-1} of fennel essential oil using a spray bottle, respectively. Directly after treating, the four treatments were removed to ambient room conditions for drying the moisture of surface, and each four bell pepper fruits (as one replicate) were placed into polystyrene foam dish, and then were covered by film of highly perforated polypropylene. All treatments were stored at 5 °C and 85-90 % of relative humidity for 7, 14, 21 and 28 d as cold storage and 28 at 5 °C plus 3 days at room conditions as shelf life. The used essential fennel oil was prepared by dissolving in Tween 20 (1%; v/v).

Measurements

Weight loss

The weight loss of four sweet pepper fruits in each replicate were weighted before the storage as an initial weight and then were weighed during cold storage and shelf life at room conditions. The weight loss was calculated as a percentage from the initial weight.

Appearance, decay and taste

Selected five panelists had experience in sensory evaluation valued bell pepper fruit quality during storage periods and shelf life. Appearance was scored based on a 1 – 9 scale, where: 9= excellent appearance, 7= very good, 5= good, 3= fair and 1= poor; inedible (Nasef, 2018). Decay was measured according to Kader et al. (1973) on 5 - 1 scale, where: 5 refer to severe, 4 to moderately severe, 3 to moderate, 2 to slight and 1 to none decay. This scaling depends on percentage of decay on bell pepper. The taste of bell pepper fruit was rated on a scale of 5–1, where 5 = fully typical, 4 = moderately full, 3 = moderate, 2 = slight and 1 = none (Nasef, 2018).

Color

Color was estimated by a Hunter colorimeter (Hunter Instrument DP-9000, Japan) which measures L* indicate lightness ('0L' indicates black, '100L' indicates white), a* (-a* indicates greenness, +a* indicates redness) b* (-b* indicates blue, +b* indicates yellow) (Manjunatha and Anurag, 2014). The hue angle was calculated by the following equation: $h= \tan^{-1} (b^*/a^*) +180$, while chroma: $c= (a^2 + b^2)^{1/2}$ (Trail et al., 1992).

Total chlorophyll content

Total chlorophylls were extracted from bell pepper by acetone (80%) and assessed spectrophotometrically according to Lichenthaler and Wellburn (1983), and expressed as mg/100 g fresh weight.

Chilling injury

Chilling injury was assessed by the extent of surface pitting, valued as percentage of affected area of surface on 1-5 scale, where: 1 refer to no injury, 2 to slight (up to 20 % of the fruit were injured), 3 to moderate (21–40 % of the fruit were injured), 4 to moderately severe (61–80 % of the fruit were injured),, 5 to severe (81–100 % of the fruit were injured) as mentioned in Imahori et al., 2008.

Seed discoloration

Seed discoloration were scored on 1 to 5 scales, where 1= none, 2= slight, 3= moderate, 4= moderately severe, and 5= severe discoloration.

Electrolyte leakage

Five disks of mesocarp tissue (7-mm diameter and weigh about 3g) of bell pepper were removed from fruit using a cork borer (Hakim et al., 1999). The disks were dipped in 50 mL of distilled water in glass conical flask for one hour at 25°C, and then the electrical conductivity was measured to determine initial conductivity (EC1) using a digital electrical conductivity meter (CD-4301, Lutron Inst.Co. UK), and then the disks were boiled for 10 min to reach 100 % electrolyte leakage, and total conductivity was measured (EC2). Relative electrolyte leakage (%) was calculated as (EC1/EC2) ×100 (Nasef, 2018).

Soluble solids content (SSC)

Soluble solids content was measured by a hand refractometer (Atago N1, Japan) and expressed as % (AOAC, 1996).

Ascorbic acid

Ascorbic acid was determined by 2,6 dichlorophenolindophenol method according to Pearson (1970), and expressed as mg/100 g fresh weight.

Total phenols

Total phenols were assessed according to Folin-Ciocalteu method using a spectrophotometer (UNICO UV/Visible 2100, USA), as described by Sadasivam and Manickam (1991).

Statistical analysis

The experiment was designed in a completely randomized block design (CRBD) with a split plot, with three replicates. Fennel essential oils were dispersed in the main plots while the periods of storage were randomly distributed in sub plots. The data analysis was performed by analysis of variance (ANOVA) by Co Stat version6.303 1998-2004, Co Hort software,798 Lighthouse Ave, PMP320, Monterey, CA 93940, USA. The significance differences between means were estimated by Duncan's test. The figures were achieved using Sigma Plot10.0 software (Systat Software Inc., Hounslow, UK).

Results

Weight loss

The effect of fennel oil, storage periods and their interaction on the weight loss of sweet pepper during cold storage and shelf life in both seasons were presented in Figure 1. As shown in Fig. 1, the fennel oil reduced the weight loss of sweet pepper. The lowest weight loss was recorded with 750 μLL^{-1} while the highest value was recorded with the control treatment during the both seasons. Weight loss increased with extending the storage period at 5 °C and shelf life at the room conditions.

Appearance

The effect of fennel oil, storage period and their interaction on visual quality of bell pepper are recorded in Table 1. There is no significant difference between bell pepper treated with 500 μLL^{-1} and 750 μLL^{-1} of fennel oil in visual quality parameter in the first season, however, pepper treated with 750 μLL^{-1} had the highest value in the second season. The visual quality of pepper reduced with increasing the storage period. Concerning the interaction between fennel oil and storage period, at 28 days of storage at 5 °C, 750 μLL^{-1} level of fennel oil was very good compared to the others. During shelf life for 3 days after 28 days at 5 °C, both 500 μLL^{-1} and 750 μLL^{-1} of fennel oil was good.

Decay

As shown in Table 1, the control treatment had the highest decay in both seasons. No significant differences were detected between the three concentrations of fennel oil in the first season, however, no significant difference was detected between control and 250 μLL^{-1} of fennel oil in the second season. Decay increased with prolonging the storage period. At the end of storage plus shelf life, the decay in untreated pepper was moderate while was slight in bell pepper treated with 500 μLL^{-1} and 750 μLL^{-1} of fennel oil.

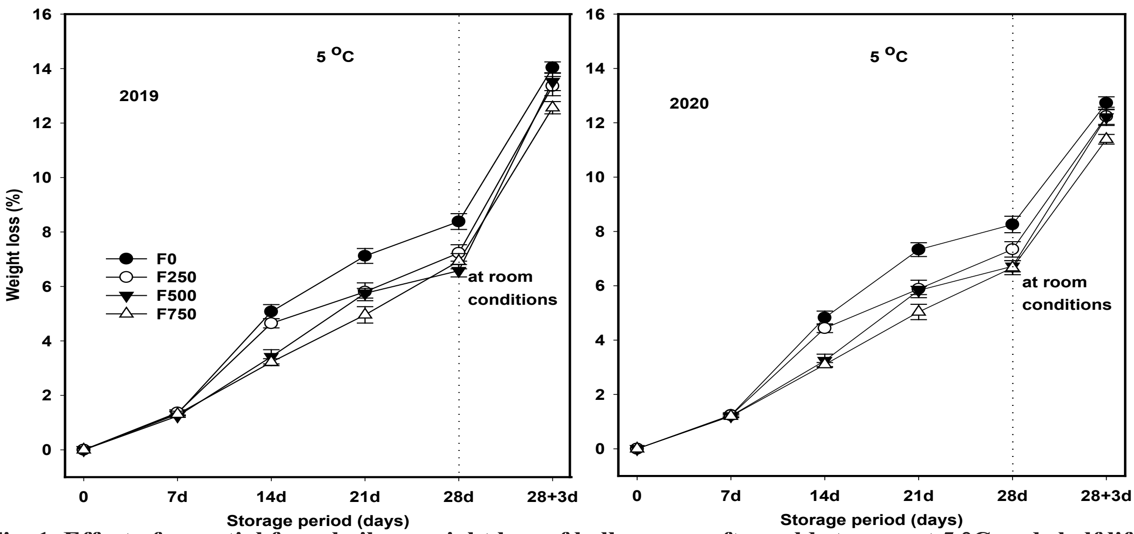

Fig. 1. Effect of essential fennel oil on weight loss of bell pepper after cold storage at 5 °C and shelf life at room conditions. Values are the mean of n=3 and vertical bars indicate the standard error. F0= control, F250= 250 μLL^{-1}, F500= 500 μLL^{-1}, F750= 750 μLL^{-1} of essential fennel oil sprayed on fruits before storage.

TABLE 1. Main effects of fennel essential oil, storage periods and their interactions on appearance, decay, taste, chilling injury and seed discoloration of bell pepper.

Storage period (days)	2019					2020				
	Fennel oil (µLL^{-1})				Mean	Fennel oil (µLL^{-1})				Mean
	0	250	500	750		0	250	500	750	
					Appearance					
0	9	9	9	9		9	9	9	9	
7	9.00a	9.00a	9.00a	9.00a	9.00A	9.00a	9.00a	9.00a	9.00a	9.00A
14	9.00a	9.00a	9.00a	9.00a	9.00A	8.33a	8.33a	9.00a	9.00a	8.67A
21	7.00b	7.00b	7.00b	7.00b	7.00B	7.00b	7.00b	7.00b	7.00b	7.00B
28	5.00c	5.00c	6.33b	7.00b	5.83C	5.00c	5.00c	5.00c	7.00b	5.50C
28+3	3.67d	4.33cd	5.00c	5.00c	4.50D	3.67d	4.33cd	5.00c	5.00c	4.50D
Mean	6.73B	6.87B	7.27A	7.40A		6.60B	6.73B	7.00AB	7.40A	
					Decay					
0	1	1	1	1		1	1	1	1	
7	1.00d	1.00d	1.00d	1.00d	1.00C	1.00d	1.00d	1.00d	1.00d	1.00C
14	1.00d	1.00d	1.00d	1.00d	1.00C	1.00d	1.00d	1.00d	1.00d	1.00C
21	1.00d	1.00d	1.00d	1.00d	1.00C	1.00d	1.00d	1.00d	1.00d	1.00C
28	2.00c	2.00c	2.00c	2.00c	2.00B	2.00c	2.00c	2.00c	2.00c	2.00B
28+3	3.00a	2.33b	2.00c	2.00c	2.33A	3.00a	2.67b	2.00c	2.00c	2.42A
Mean	1.60A	1.47B	1.40B	1.40B		1.60A	1.53A	1.40B	1.40B	
					Taste					
0	5	5	5	5		5	5	5	5	
7	5.00a	5.00a	5.00a	5.00a	5.00A	5.00a	5.00a	5.00a	5.00a	5.00A
14	5.00a	5.00a	5.00a	5.00a	5.00A	5.00a	5.00a	5.00a	5.00a	5.00A
21	4.00b	4.00b	4.00b	4.00b	4.00B	4.00b	4.00b	4.00b	4.00b	4.00B
28	3.00c	3.00c	3.67b	4.00b	3.42C	3.00c	3.00c	3.67b	3.67b	3.33C
28+3	2.33d	2.33d	3.00c	3.00c	2.67D	2.00d	2.00d	2.67c	3.00c	2.42D
Mean	3.87B	3.87B	4.13A	4.20A		3.80B	3.80B	4.07A	4.13A	
					Chilling injury (Pitting)					
0	1	1	1	1		1	1	1	1	
7	1.00d	1.00d	1.00d	1.00d	1.00D	1.00d	1.00d	1.00d	1.00d	1.00D
14	1.00d	1.00d	1.00d	1.00d	1.00D	1.00d	1.00d	1.00d	1.00d	1.00D
21	2.00c	2.00c	2.00c	2.00c	2.00C	2.00c	2.00c	2.00c	2.00c	2.00C
28	3.00b	3.00b	2.67b	2.00c	2.67B	3.00b	3.00b	3.00b	2.00c	2.75B
28+3	3.67a	3.67a	3.67a	3.00b	3.50A	3.67a	3.67a	3.67a	3.00b	3.50A
Mean	2.13A	2.13A	2.07A	1.80B		2.13A	2.13A	2.13A	1.80B	
					Seed discoloration					
0	1	1	1	1		1	1	1	1	
7	1.00f	1.00f	1.00f	1.00f	1.00D	1.00e	1.00e	1.00e	1.00e	1.00D
14	1.00f	1.00f	1.00f	1.00f	1.00D	1.00e	1.00e	1.00e	1.00e	1.00D
21	2.00e	2.00e	2.00e	2.00e	2.00C	2.00d	2.00d	2.00d	2.00d	2.00C
28	3.67bc	3.33cd	3.00d	2.33e	3.08B	3.67ab	3.33bc	3.00c	2.33d	3.08B
28+3	4.33a	4.33a	4.00ab	3.33cd	4.00A	4.00a	4.00a	4.00a	3.00c	3.75A
Mean	2.40A	2.33A	2.20A	1.93B		2.33A	2.27A	2.20A	1.87B	

Values are the means of three replicates. Values followed by the same letters within a column for each genus are not significantly different at the 5% level of probability according to Duncan's multiple range test.

Taste

The taste of bell pepper is shown in Table 1. No significant difference was detected between control and 250 μLL^{-1} of fennel oil or 500 μLL^{-1} and 750 μLL^{-1} in both seasons. With the increase of storage time, the taste of bell pepper decreased. With respect to the interaction between fennel oil and storage time, the taste was moderate in bell pepper treated with 500 μLL^{-1} and 750 μLL^{-1} of fennel oil, while was slight in control and bell pepper treated with 250 μLL^{-1} at the end of storage.

Color

The results of effects of different concentrations of fennel oil, storage period and their interaction on L, -a, b, c and h value of bell pepper fruit are presented in figure 2. L, b and c values were the lowest while -a and h values were the highest in bell pepper fruit treated with 750 μLL^{-1}. The all parameters of color changed during periods of cold storage and shelf life. Regarding to the interaction, at the end of storage, L, b and c of control fruit was the highest compared with fruit treated with the three concentrations of fennel oil. No significant difference was observed between control and 250 μLL^{-1} concentration in -a of fruit in both seasons. However, h value is the lowest in untreated fruit after 28 days at 5 °C plus 3 days at room conditions.

Total Chlorophyll content

The three levels (250, 500 and 750 μLL^{-1}) of fennel oil showed significant differences compared to control treatment in total chlorophyll content (Fig. 3). However, no significant difference was detected between 500 and 750 μLL^{-1} in both seasons. The prolonging of storage time resulted in reducing the total chlorophyll content in bell pepper fruit. With regard to the interaction between fennel oil and period of storage, untreated fruit recorded the lowest content of chlorophyll during storage time except at 7 days at 5 °C in the first season.

Chilling injury (pitting)

The lowest score of pitting was observed in bell pepper treated with 750 μLL^{-1} of fennel oil (Table 1). No significant differences were recorded among control, 250 and 500 μLL^{-1} of fennel oil. Pitting increased by prolonging the storage time and after shelf life. Regarding to the interaction, after 28 days of storage at 5 °C, the pitting score was slight in bell pepper treated with 750 μLL^{-1} of fennel oil in both seasons, then became moderate when bell pepper was transferred into the room conditions as shelf life.

Seed discoloration

Seed discoloration revealed significant differences between 750 μLL^{-1} and other treatments. Seed discoloration gradually increased with extending the storage period. Concerning the interaction, at the end of storage, bell pepper treated with 750 μLL^{-1} concentration had the lowest seed discoloration compared with the others (Table 1).

Electrolyte leakage

Figure 4 shows the effects of fennel oil, storage periods and their interaction on electrolyte leakage of bell pepper fruit. The lowest electrolyte leakage was in fruit treated with 750 μLL^{-1} compared with the others and there was no significant difference between control and 250 μLL^{-1}. During the storage, electrolyte leakage sharply increased at 7 days at 5 °C in untreated fruit, and at 14 days in fruit treated with 250 and 500 μLL^{-1} in the first season. Fruit treated with 750 μLL^{-1} recorded the lowest EL during storage periods in the second season. However, the differences between 500 and 750 μLL^{-1} is non-significant after 28 days at 5 °C plus 3 days of shelf life at room conditions in both seasons.

Soluble solids content (SSC)

Figure 5 shows that the untreated fruit recorded the highest SSC and no significant differences between the three concentrations of fennel oil. SSC sharply increased in untreated fruit after 14 days at 5 °C then gradually decreased until the end of storage. At the three days at room conditions after 28 days at 5 °C, the lowest SSC was found in untreated fruit in both seasons. However, no significant differences were detected between the three concentrations of fennel oil in the second season.

Ascorbic acid

Ascorbic acid was highest in bell pepper treated with 750 μLL^{-1} compared with the others. Ascorbic acid significantly decreased throughout storage at 5 °C and shelf life. Concerning the interaction, fennel oil at 750 μLL^{-1} significantly maintained ascorbic acid throughout storage periods at 5 °C and at room conditions as shelf life in both seasons (Fig. 6).

Total phenols

Total phenols increased with the increase of fennel oil concentration, and the highest content of phenol was detected in bell pepper treated with 750 μLL^{-1} in both seasons. Total phenols of fruit treated with 750 μLL^{-1} sharply increased after 7 days then decreased. At the end of storage, the highest phenols content was observed with 750 μLL^{-1} compared the others (Fig. 7).

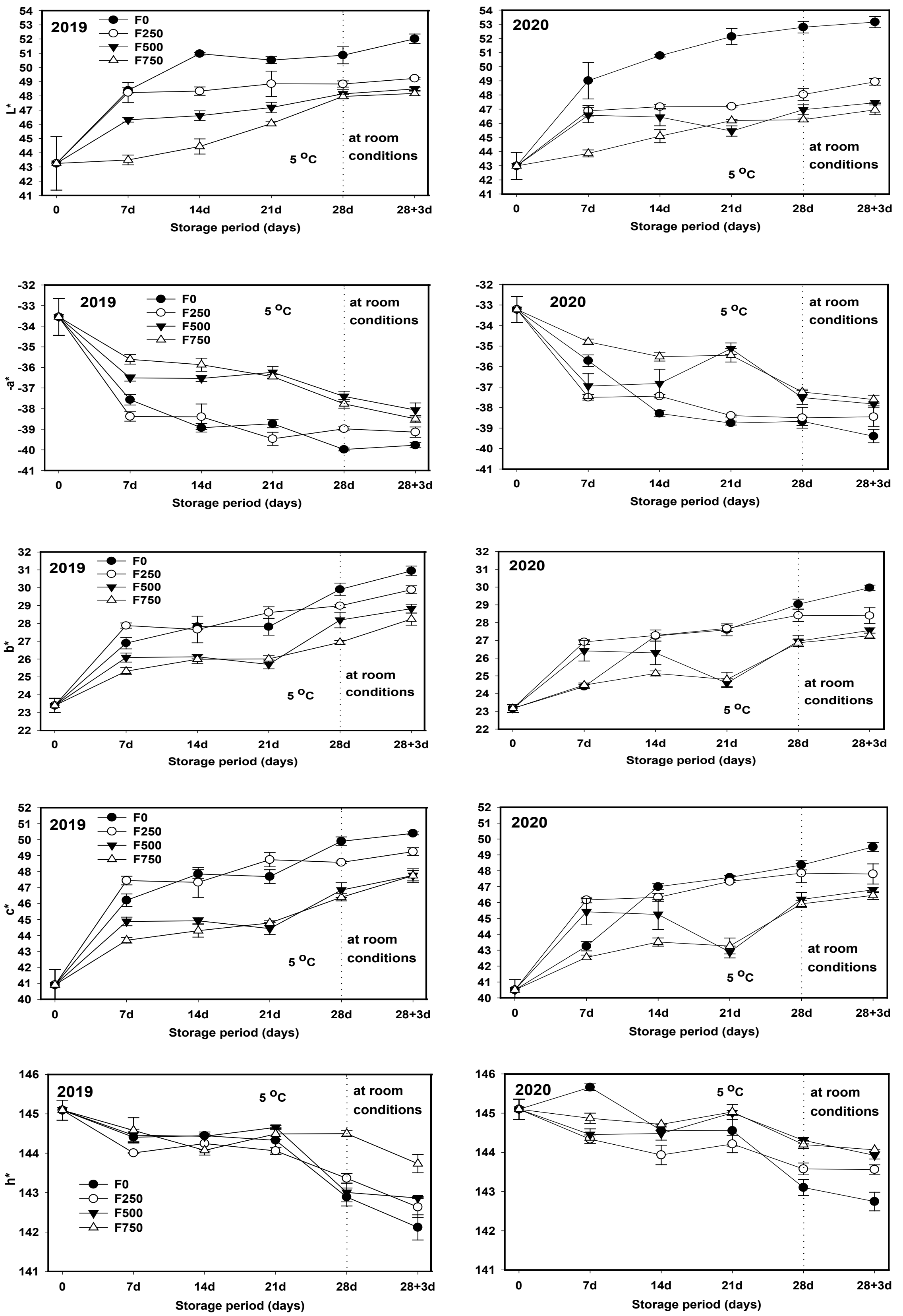

Fig. 2. Effect of essential fennel oil on color of bell pepper after cold storage at 5 °C and shelf life at room conditions. Values are the mean of n=3 and vertical bars indicate the standard error. F0= control, F250= 250 µLL^{-1}, F500= 500 µLL^{-1}, F750= 750 µLL^{-1} of fennel essential oil.

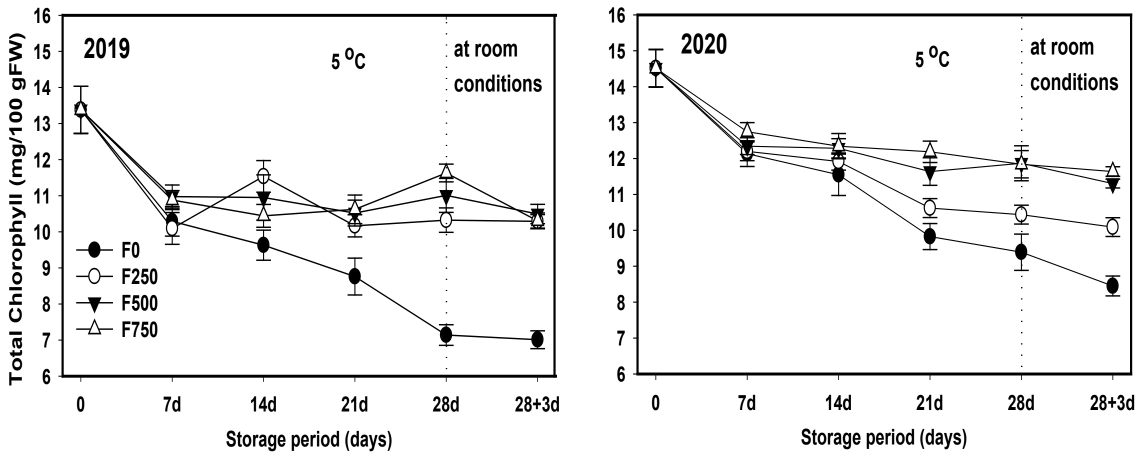

Fig. 3. Effect of essential fennel oil on total chlorophyll of bell pepper after cold storage at 5 °C and shelf life at room conditions. Values are the mean of n=3 and vertical bars indicate the standard error. F0= control, F250= 250 µLL^{-1}, F500= 500 µLL^{-1}, F750= 750 µLL^{-1} of fennel essential oil.

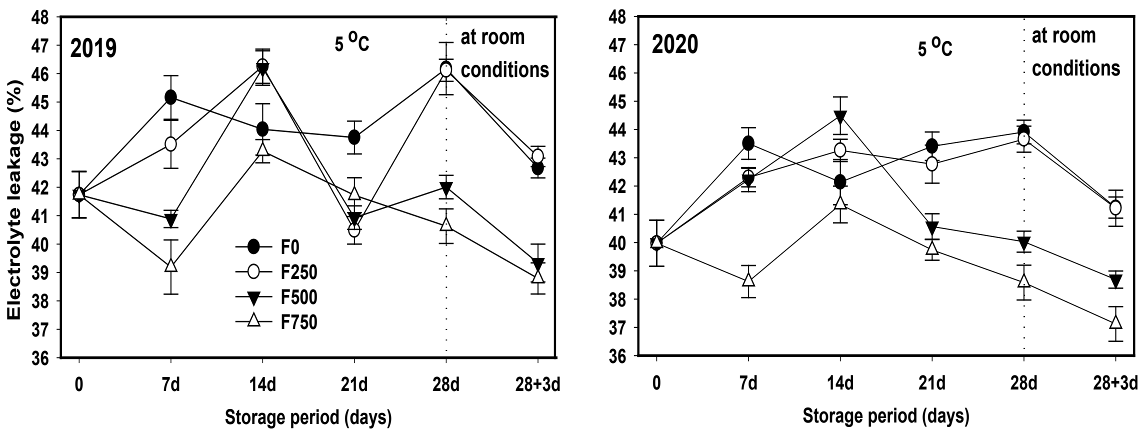

Fig. 4. Effect of essential fennel oil on electrolyate leakage of bell pepper after cold storage at 5 °C and shelf life at room conditions. Values are the mean of n=3 and vertical bars indicate the standard error. F0= control, F250= 250 µLL^{-1}, F500= 500 µLL^{-1}, F750= 750 µLL^{-1} of fennel essential oil.

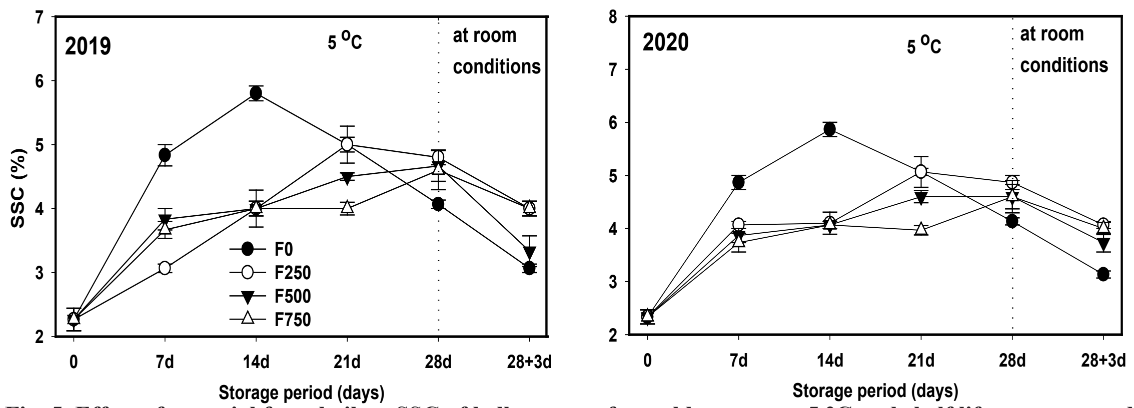

Fig. 5. Effect of essential fennel oil on SSC of bell pepper after cold storage at 5 °C and shelf life at room conditions. Values are the mean of n=3 and vertical bars indicate the standard error. F0= control, F250= 250 µLL^{-1}, F500= 500 µLL^{-1}, F750= 750 µLL^{-1} of fennel essential oil.

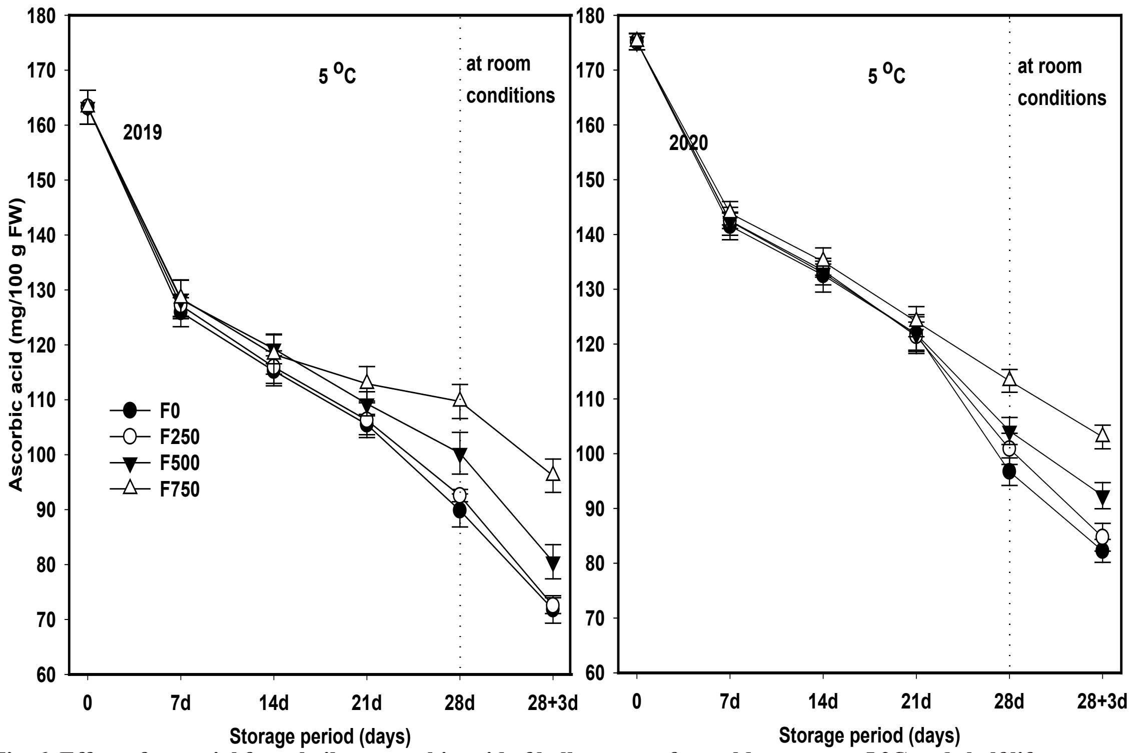

Fig. 6. Effect of essential fennel oil on ascorbic acid of bell pepper after cold storage at 5 °C and shelf life at room conditions. Values are the mean of n=3 and vertical bars indicate the standard error. F0= control, F250= 250 µLL^{-1}, F500= 500 µLL^{-1}, F750= 750 µLL^{-1} of fennel essential oil.

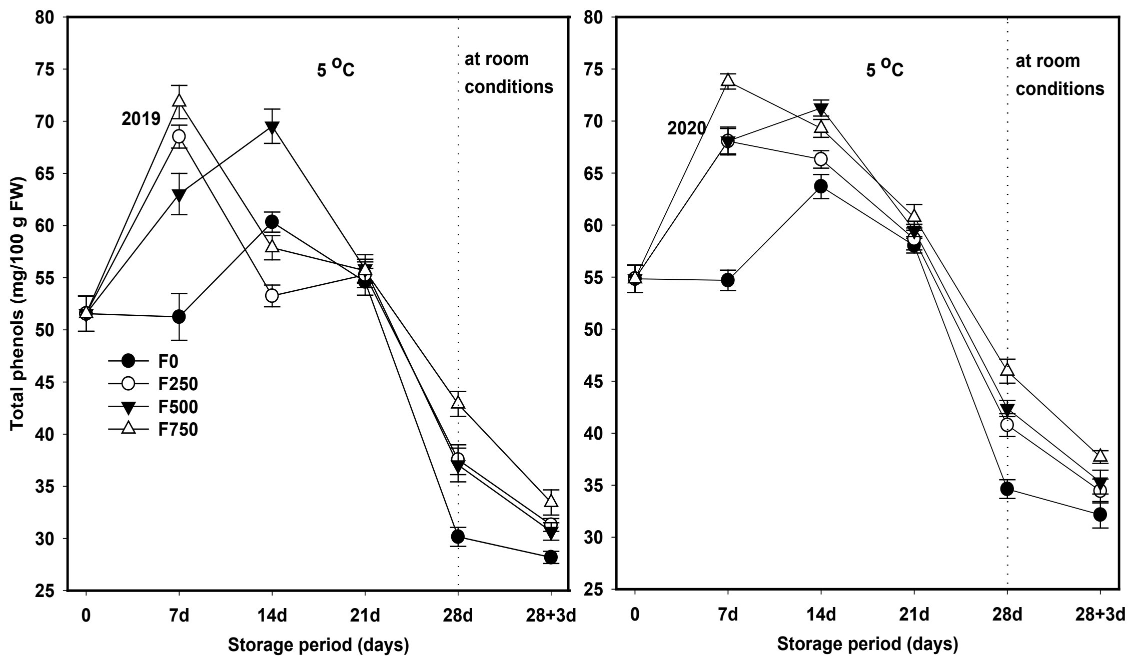

Fig. 7. Effect of essential fennel oil on total phenols of bell pepper after cold storage at 5 °C and shelf life at room conditions. Values are the mean of n=3 and vertical bars indicate the standard error. F0= control, F250= 250 µLL^{-1}, F500= 500 µLL^{-1}, F750= 750 µLL^{-1} of fennel essential oil.

Discussion

The natural essential oils such as fennel oil are safe eco-friendly compounds can be used to maintain the quality of horticultural crops as an alternative to synthetic chemicals. Using many essential oils in edible products were approved by the Food and Drug Administration (Scollard et al., 2016). In this study, fennel oil was effective in maintaining quality and prolonging shelf life of bell pepper. Weight loss of bell pepper was less by 750 μLL^{-1} of fennel oil. Similarly, fennel oil resulted in reducing the weight loss of table grape (Abdolahi et al., 2010), and tomato during storage (Mohammad and Aminifard, 2013). This may be attributed to reduce the dehydration process (Valero et al., 2006), and might reduce the respiration rate (Jhalegar et al., 2015), thus inhibiting the loss of water from fruit.

Fennel oil maintained bell pepper appearance. The beneficial effects of fennel essential oil on the bell pepper appearance were observed during cold storage and shelf life. In consistent with this result, treated table grape with fennel oil had good appearance (Abdolahi et al., 2010). The great appearance of bell pepper may be due to the reduction of weight loss.

Fennel essential oils have antifungal and antimicrobial activity against Gram positive and Gram negative bacteria (Shahat et al., 2011). In this study, the addition of fennel essential oil to bell pepper resulted in reducing the decay. Previous reports indicated that eucalyptus and cinnamon essential oils decreased the decay on strawberry and tomato fruit (Tzortzakis, 2007). The mechanism of action of fennel essential oils may be due to their hydrophobicity and components, which accumulate in the cell membranes of microorganisms (food-borne pathogens), disturbing the structure and triggering an increase of permeability, leading to the electrolytes leakage ($K^+$and Na^+), besides losses of reducing sugars, proteins and 260 nm absorbing materials, Impairing the microbial enzyme systems, thereby causing the cell death (Diao et al., 2014).

Fennel essential oils had no negative effects on bell pepper taste. Previous findings showed that treated strawberry with cumin essential oil had the better taste (Zamani-Zadeh et al., 2014). This result may be attributed to the low weight loss of bell pepper fruits during storage.

Skin color parameters and total chlorophyll content of bell pepper treated with 750 μLL^{-1} of fennel essential oil were the best in comparison with others. These results indicated that fennel essential oil reduced the degradation of chlorophyll. This might be attributed to the inhibition of enzymes activity such as peroxidase (Ponce et al., 2004) and chlorophyll oxidase.

Bell pepper is a sensitive vegetable crop to cool temperatures. Fennel essential oil at 750 μLL^{-1} was more effective in alleviating the chilling injury of bell pepper compared to other concentrations and control. Fruit water status plays a significant role in developing the pitting during storage (Alferez and Burns, 2004), this may explain the reducing chilling injury of bell pepper which had lower weight loss when was treated with 750 μLL^{-1} of fennel oil. Furthermore, Wang, (2006) reported that natural volatile compounds such as methyl jasmonate can reduce chilling injury in tomatoes, mango, pepper and zucchini squash by elevating the expression of gene of heat shock proteins. Also, natural volatile compounds can promote the antioxidant enzyme activities which alleviate the stress of oxidative (Chanjirakul et al., 2006), and may increase the tissues resistance against chilling injury (Nasef, 2018). One of the chilling injury symptoms in pepper is seed discoloration (Boonsiri et al., 2007). The lowest seed discoloration was observed in bell pepper treated with 750 μLL^{-1} of fennel oil, suggesting the role of fennel oil in reducing seed discoloration. In recent study, seed discoloration of hot pepper was inhibited by methyl jasmonate treatment (Seo et al., 2020).

Electrolyte leakage (EL) of bell pepper have been used as an indicator of cell membrane injury. The concentration of 750 μLL^{-1} fennel essential oil was more effective in reducing EL of bell pepper, indicating that a higher integrity of membrane was done. In the same line, using cinnamon oil maintained the membrane permeability of sweet pepper (Xing et al., 2011).

Control fruit had higher SSC while those treated with fennel essential oil had lower SSC. These results suggest that fennel essential oils may delay the deterioration of bell pepper fruit. Similarly, SSC was lowest in grape fruit treated with anise, chamomile and black caraway essential oils compared to untreated fruit (Behshti et al., 2020).

Fennel essential oils at 750 μLL^{-1} was the most effective concentration in reducing the reduction of ascorbic acid during storage of bell pepper.

In a similar study, ascorbic acid was highest in tomato treated with fennel oils (Mohammad and Aminifard, 2013). Also, essential oil treatments such as thyme and cumin maintained ascorbic acid of strawberry during storage (Zamani-Zadeh et al., 2014). The accumulation of ascorbic acid may reduce the activity of polyphenol oxidase enzyme (Remorini et al., 2015), maintaining the phenols content, this is supported by the results of this study where the highest concentration of phenols was recorded in bell pepper treated with 750 μLL^{-1} of fennel essential oils. In addition, phenols of essential oils enhance the antioxidants and scavenging activity in fruit tissues (Cindi et al., 2016), and induce the defense system (Tzortzakis et al., 2011). This may indicate that fennel essential oils maintain the quality of bell pepper during storage at 5C for 28 day and during 3 days of display simulation at room temperature.

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Conflicts of interest

The author declares that he has no conflicts of interest related to the publication of this study.

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زيت الشمر العطري كمركب طبيعي آمن يحافظ على جودة الفلفل المخزن تخزيناً مبرداً فى درجة الحرارة المنخفضة

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هذه الدراسة بحثت تأثير زيت الشمر العطري بتركيز ٠، ٢٥٠، ٥٠٠ و ٧٥٠ ميكرو/لتر على الفلفل خلال التخزين البارد لمدة ٧، ١٤، ٢١، و٢٨ يوماً على درجة حرارة ٥ درجة مئوي و ٢٨ يوماً بالإضافة ٣ أيام فى ظروف الغرفة العادية. كان الهدف من الدراسة هو الحفاظ على جودة وتقليل أضرار البرودة فى الفلفل. تم قياس فقد الوزن، والمظهر، والتالف، والطعم، واللون، والكلورفيل، وأضرار البرودة، وتلون البذور، والتسريب الكهربي، ومحتوى المواد الصلبة الذائبة، وحامض الأسكوربيك، والفينولات. أوضحت النتائج أن زيت الشمر العطري بتركيز ٧٥٠ ميكرو/لتر كان أكثر فاعلية فى الحفاظ على جودة الفلفل حيث أعطى أقل فقد وزن وتلف وأضرار برودة ولون للبذور وتسريب كهربي و محتوى مواد صلبة ذائبة، و أعلى قيمة للمظهر واللون والطعم وحامض الأسكوربيك والفينولات خلال فترة التخزين وفترة الصلاحية للعرض فى ظروف الغرفة العادية. هذه النتائج تدل على أن زيت الشمر العطري يمكن أن يستخدم كمعاملة آمنة لحفظ الجودة و تخفيف أضرار البرودة وإطالة حياة ثمار الفلفل بعد الحصاد فى درجة الحرارة المنخفضة وظروف الغرفة العادية.