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Analysis of quality changes in bell pepper cultivars in response to delayed cooling in a controlled chamber

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Abstract

The effect of 24-h greenhouse cooling delay on the quality characteristics of four bell pepper cultivars during storage in a controlled chamber was investigated. Four bell pepper cultivars (Ferrari-red, Ferrari-yellow, Vine sweet-mini, and Raon-mini) were immediately transferred to storage after harvest (IS), delayed storage without cover (DS), and delayed storage with cover (DSC). In both delayed conditions, bell pepper cultivars were left separately in a greenhouse for 1 d. In all treatments, the bell pepper cultivars were stored in a controlled chamber. Vine sweet-mini treated with DS showed the greatest loss in weight and firmness, with losses of 21.4 and 64.1%, respectively, after 15 d of storage. Vine sweet-mini treated with DS also showed the greatest change in total soluble solids content (10.9 to 13.7 °Bx) over the storage period. Less degradation in the lightness (L^*), hue angle ($h°$), and chroma (C^*) values was observed in Ferrari-red treated with IS during storage for 15 d. Overall, the changes were smaller in the bell pepper cultivars treated with IS than in those treated with the delayed-cooling treatments. Results revealed that minimising delays from harvest to cooling could reduce the quality loss and improve the storage life of harvested bell peppers.

Introduction

Bell pepper (*Capsicum annuum* L.) is one of the most popular horticultural commodities cultivated throughout the world (Sharma *et al.,* 2018). Over the years, production and consumption of bell pepper have been steadily increasing worldwide (Biswas *et al.,* 2018; Li *et al.,* 2018), a trend that is driven by its rich nutritional contents including vitamins, minerals, and carotenoids (Ilić *et al.,* 2012; Wang *et al.,* 2018; Chen *et al.,* 2018). However, the quality of bell pepper fruit rapidly deteriorates following poor post-harvest handling, leading to large losses (Nyanjage *et al.,* 2005). Therefore, proper post-harvest handling and management techniques are required for the reduction of post-harvest losses of bell pepper (Faqeerzada *et al.,* 2018; Yahia, 2019; Ge *et al.,* 2019).

Appropriate handling between harvest and consumption can play a significant role in reducing such losses of harvested fruits and vegetables (Prusky, 2011; Kabir *et al.,* 2019; Jung *et al.,* 2019). In developing countries, the post-harvest losses of fresh fruit can be as high as 20 - 50% (Kader, 2005). Therefore, reducing these losses remains a major goal, mainly due to food security issues that need to be rectified worldwide, especially in developing countries (Pila *et al.,* 2010; Kusumaningrum *et al.,* 2015).

Temperature and humidity are critical factors for maintaining the quality of harvested bell pepper (O'Donoghue *et al.,* 2017). The recommended post-harvest storage temperature and humidity for bell pepper are 7 - 10°C and 90 - 98%, respectively (El-Ramady *et al.,* 2015). The exposure of harvested horticultural produce between harvest and storage to adverse environmental conditions, such as extremely high or low temperatures, rain, and extremely low humidity can be highly detrimental to the harvested commodity (Ajita and Jha, 2017). However, higher humidity prevents moisture loss and maintains the firmness of stored fruits (Lurie *et al.,* 1986).

Delayed cooling can result in post-harvest qualitative or qualitative losses of fruits and vegetables;

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thus, shortening post-harvest shelf life (Thompson *et al.,* 2001; Kader and Barrett, 2005). Even a 1-h cooling delay after harvesting can lead to a ~10% loss in the marketing of some horticultural produce (Kader and Rolle, 2004). Hence, appropriate post-harvest handling of horticultural commodities is crucial for maintaining the post-harvest quality of fresh or processed products (Bosland and Votava, 2012).

Many studies have reported the influences of harvesting stage, post-harvest treatment, and post-harvest storage environment on the post-harvest quality of fruits and vegetables, including bell peppers (Díaz-Pérez, 2013; O'Donoghue *et al.,* 2013; Tsegay *et al.,* 2013; Belović *et al.,* 2014; Shim *et al.,* 2016; Qin *et al.,* 2017; Lee, 2018; Jung *et al.,* 2019). However, there are few studies on the consequences of cooling delays on the post-harvest quality of bell pepper.

Large-sized Ferrari (red and yellow) and mini bell (Vine sweet and Raon) peppers are among the popular bell pepper cultivars consumed in the Republic of Korea. After harvest, generally, growers place their bell peppers unattended in greenhouses for approximately 1 d before transporting them to storage and processing centres. During this cooling delay, harvested bell peppers can be exposed to various environmental conditions that potentially influence their storage quality. Therefore, the present work aimed to investigate the effects of delayed cooling (24-h) on post-harvest quality characteristics such as weight loss, total soluble solids, firmness, and colour values of four bell pepper cultivars during post-harvest storage in a controlled chamber.

Materials and methods

Fruit samples and treatments

Four bell pepper cultivars (Ferrari-red, Ferrari-yellow, Vine sweet-mini, and Raon-mini) were harvested from the middle region of the Republic of Korea, and immediately transported from the field to storage facilities. These varieties were selected after discussion with horticultural scientists, because of their cultivation popularity and physical variations (e.g., size and firmness). The post-harvest quality of the stored bell peppers was assessed under three storage conditions: immediate storage in a controlled chamber without any cooling delay (IS), delayed storage in a greenhouse without cover (DS) for 1 d followed by storage in a controlled chamber, and delayed storage in a greenhouse under cover (DSC) with a greenhouse shade cloth of 1.0 mm thickness for 1 d followed by storage in a controlled chamber (the latter two treatments represented 24-h delayed cooling treatments).

Storage conditions

The IS treatment was applied in a controlled chamber (CC) with dimensions of 6.5 × 4.5 × 3.0 m, where the bell pepper fruit samples were continuously stored for 15 d. The delayed cooling treatments were carried out separately in a greenhouse (GH) with dimensions of 7.5 × 5.5 × 3.5 m, where the fruit samples treated with DS and DSC were maintained for 1 d to simulate the cooling delay practice of farmers. The fruits were then stored in the controlled chamber for 14 d. For each cultivar on the harvest day (day 0), one group of fruits was immediately stored inside the controlled chamber (IS), and the other two groups of fruits were placed inside the greenhouse, one with cover (DSC) and the other without cover (DS).

During the 24-h delayed cooling of fruit samples in the greenhouse, sensor nodes consisted of temperature and humidity sensors (AM2315, Aosong Electronics Co., Ltd., Guangzhou, China) were placed in the DS and DSC storage boxes, inside and outside of the greenhouse to monitor the environmental conditions. During the delayed cooling period, the temperature and relative humidity inside the greenhouse were 18 ~ 39°C and 40 ~ 85%, respectively, and outside of the greenhouse, these values were 18 ~ 28°C and 55 ~ 75%, respectively. In contrast, the temperature and relative humidity inside the controlled chamber was maintained at 10 ± 1°C and 90 ± 3%, respectively (Figure 1).

Measurement of quality characteristics

Weight loss

The bell pepper samples were weighed at harvest day and at each storage interval. The total weight loss (WL) of the bell pepper samples was considered as the difference between initial weight (IW) and final weight (FW) on the observation day at each storage interval, and expressed as a percentage using Eq. 1 (Gharezi *et al.,* 2012):

$$WL\ (\%) = \frac{IW - FW}{IW} \times 100 \qquad \text{(Eq. 1)}$$

Firmness

The bell pepper samples' firmness was measured using a penetrometer (TMS-Pro, Food Technology Corporation, Virginia, USA). The fruits were compressed at a penetration depth of 5 mm by the penetrometer probe at a speed of 50 mm/min using a conical plate, and the results were expressed in Newton (N).

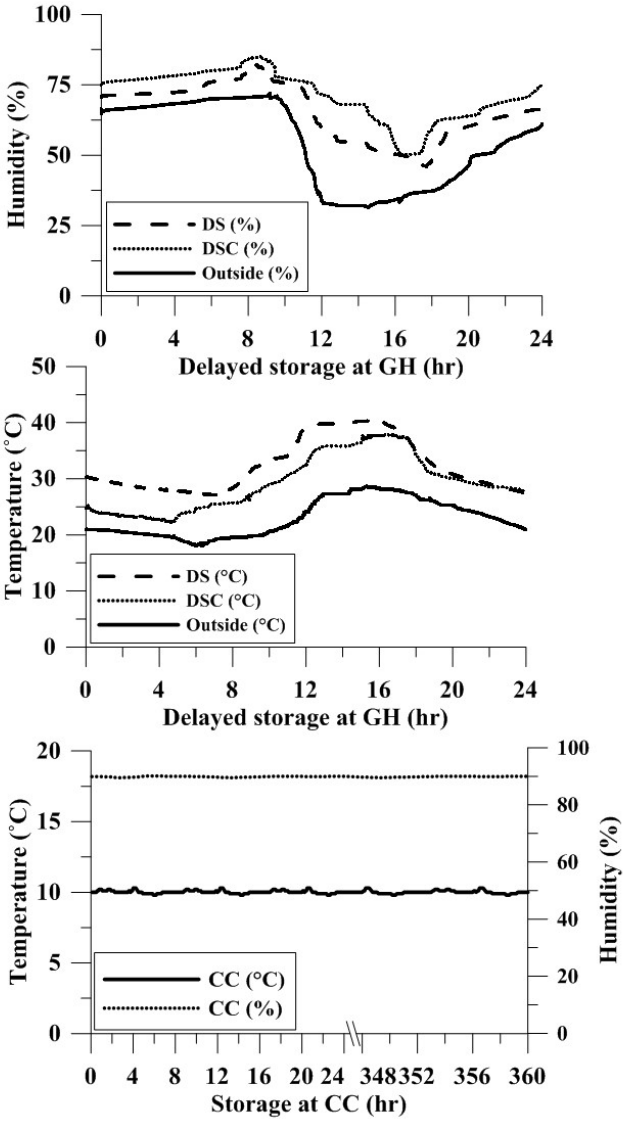

Figure 1. Temperature and humidity status during 24-h of delayed cooling in a greenhouse (GH) for DS- and DSC-treated bell pepper cultivars (a) and (b), respectively, and inside a controlled chamber (CC) for bell pepper cultivars treated with IS, DS, and DSC (c). IS = immediate storage, DS = 24-h delayed storage without cover, and DSC = 24-h delayed storage under cover.

Total soluble solids (TSS)

The bell pepper samples were diced, and a juice extractor (FruX80, Goojung Engineering Co. Ltd., Seoul, Korea) was used to extract the juice. Each sample was thoroughly mixed, and a handheld digital refractometer (PR-32a, Atago Co. Ltd., Tokyo, Japan) was used to measure the TSS content. The results were expressed in degree Brix (°Bx).

Colour

The skin colour of the bell pepper samples was measured from the middle part of the fruits with a colorimeter (CR-400; Konica Minolta Inc., Tokyo, Japan) to obtain lightness (L^*), redness/greenness (a^*), and yellowness/blueness (b^*) colour values according to the approach of Khairi *et al.* (2015). The measured a^* and b^* values of the bell pepper samples were converted to hue angles ($h°$), calculated as $h° = tan\text{-}1\ (b^*/a^*)$, and chroma ($C^*$) values were calculated as $C^* = (a^{*2} + b^{*2})^{0.5}$ following the procedures of Topuz *et al.* (2009).

Experimental and analytical procedures

Ten bell pepper samples of each cultivar were allocated to each of the storage treatments (IS, DS, and DSC), with three replications per treatment. A total of 360 fruit samples were evaluated under these storage treatments (10 samples × 4 cultivars × 3 storage × 3 replicates). The quality characteristics of the samples were measured at harvest (day 0) and immediately subjected to their corresponding storage treatments (IS, DS, and DSC). After 24-h, the DS- and DSC-treated samples were placed in the controlled chamber for continuous storage. Measurements of each of the quality characteristics of the fruits were performed at days 5, 10, and 15 of storage. The experimental data were statistically analysed, applying a three-way analysis of variance (ANOVA) with three main factors: storage treatment, cultivar, and storage period. The ANOVA was performed using the SAS software package (version 9; SAS Corporation, Cary, NC, USA). Duncan's multiple range test was used to compare the means at a 5% significance level. The experimental design of the present work is detailed in Table 1.

Results and discussion

Properties of the bell pepper cultivars at harvest

The properties of the bell pepper cultivars at harvest are shown in Table 2. Significant differences were found in the diameter and weight among the bell pepper cultivars and treatments. Among the cultivars, Ferrari-yellow exhibited the highest difference, and Raon-mini exhibited the smallest difference. TSS, firmness, and colour values (L^*, $h°$, and C^*) generally differed among the bell pepper cultivars. No significant differences were observed in the properties among the storage treatments, except TSS in Raon-mini and C^* in Ferrari-red.

Among the cultivars, the average fruit weight of Ferrari-yellow was the highest (196.57 ± 4.94) at harvest. The average fruit firmness values were higher in Vine sweet-mini (16.71 ± 0.45) and Ferrari-red (9.43 ± 0.62) as compared to the other two cultivars. As compared to the other two bell

Table 1. Experimental design of the present work.

Bell pepper cultivar	Four (Ferrari-red, Ferrari-yellow, Vine sweet-mini, and Raon-mini)	
Treatment	IS (Immediate storage) DS (24-h delayed storage without cover) DSC (24-h delayed storage under cover)	Three replications
Storage period	IS: 15 d in controlled chamber DS and DSC: 1 d (delayed cooling) in GH and 14 d in CC	
Main factor and their interaction	Treatment	3
	Storage period (interval)	4
	Cultivar	4
Environmental factor	Greenhouse (GH) (variable conditions): 18 ~ 39°C and 40 ~ 85% Controlled chamber (CC) (constant conditions): 10 ± 1°C and 90 ± 3%	

Table 2. Properties of the bell pepper cultivars at harvest.

Property		**Treatment**	**Bell pepper cultivar**			
			Ferrari-red	**Ferrari-yellow**	**Vine sweet-mini**	**Raon-mini**
Diameter (cm)		IS	8.10 ± 0.02^{Cb}	9.23 ± 0.04^{Aa}	2.61 ± 0.02^{Ac}	2.14 ± 0.03^{Bd}
		DS	8.84 ± 0.02^{Ab}	9.25 ± 0.03^{Aa}	2.55 ± 0.03^{Bc}	2.08 ± 0.06^{Bd}
		DSC	8.59 ± 0.07^{Bb}	9.25 ± 0.01^{Aa}	2.45 ± 0.01^{Cc}	2.25 ± 0.01^{Ad}
Weight (g)		IS	161.26 ± 1.85^{Bb}	203.07 ± 4.02^{Aa}	18.39 ± 1.69^{Ad}	28.59 ± 3.01^{Ac}
		DS	165.30 ± 1.55^{Ab}	195.60 ± 7.91^{ABa}	18.09 ± 1.38^{Ad}	28.20 ± 2.88^{Ac}
		DSC	163.92 ± 2.00^{Ab}	191.05 ± 2.90^{Ba}	15.09 ± 0.69^{Bd}	28.00 ± 0.30^{Ac}
Firmness (N)		IS	9.31 ± 0.35^{Aab}	7.48 ± 0.17^{Ac}	9.65 ± 0.97^{Aa}	8.52 ± 0.38^{Abc}
		DS	9.24 ± 1.10^{Aab}	7.29 ± 0.02^{Ac}	10.13 ± 0.31^{Aa}	7.94 ± 0.94^{Abc}
		DSC	9.74 ± 0.43^{Ab}	7.41 ± 0.35^{Ad}	10.68 ± 0.10^{Aa}	8.63 ± 0.34^{Ac}
TSS (°Brix)		IS	6.89 ± 0.15^{Ab}	6.46 ± 0.02^{Ab}	11.69 ± 0.71^{Aa}	10.90 ± 0.57^{Aa}
		DS	6.88 ± 0.14^{Ac}	6.58 ± 0.41^{Ac}	10.96 ± 0.25^{Aa}	10.05 ± 0.37^{ABb}
		DSC	6.67 ± 0.10^{Ac}	6.57 ± 0.13^{Ac}	11.22 ± 0.15^{Aa}	9.75 ± 0.31^{Bb}
Color	L^*	IS	33.55 ± 0.37^{Ac}	44.91 ± 1.37^{Ab}	35.43 ± 4.76^{Ac}	50.73 ± 2.57^{Aa}
		DS	33.42 ± 0.82^{Ac}	44.91 ± 1.37^{Ab}	30.67 ± 2.35^{Ac}	48.62 ± 0.98^{Aa}
		DSC	44.08 ± 0.45^{Ab}	45.32 ± 1.48^{Aa}	35.35 ± 0.13^{Ab}	35.38 ± 0.12^{Aa}
	C^*	IS	34.97 ± 0.25^{Ac}	58.12 ± 1.83^{Aa}	48.31 ± 1.58^{Ab}	44.66 ± 3.27^{Ab}
		DS	32.67 ± 0.55^{Bc}	55.82 ± 2.68^{Aa}	46.37 ± 2.57^{Ab}	44.80 ± 2.29^{Ab}
		DSC	34.05 ± 1.01^{Ac}	57.08 ± 1.99^{Aa}	45.07 ± 1.87^{Ab}	47.30 ± 3.00^{Ab}
	$h°$	IS	28.97 ± 1.07^{Ad}	88.32 ± 0.17^{Aa}	40.31 ± 0.68^{Ac}	61.36 ± 2.47^{Ab}
		DS	28.31 ± 2.48^{Ad}	88.01 ± 1.02^{Aa}	39.79 ± 1.45^{Ac}	61.76 ± 2.94^{Ab}
		DSC	28.44 ± 1.28^{Ad}	87.36 ± 0.63^{Aa}	39.20 ± 0.65^{Ac}	58.96 ± 3.38^{Ab}

Means ± SD within a column followed by similar uppercase are not significantly different ($p < 0.05$) among the treatments for each cultivar. Means ± SD within a row followed by similar lowercase are not significantly different ($p < 0.05$) among cultivars for each quality characteristics. IS = immediate storage, DS = 24-h delayed storage without cover, and DSC = 24-h delayed storage under cover.

pepper cultivars at harvest day, higher TSS contents were observed in Vine sweet-mini and Raon-mini, with average values of 11.29 ± 0.37°Bx and 10.23 ± 0.42°Bx, respectively. Higher L^* and $h°$ colour values were also recorded for Vine sweet-mini and Raon-mini, whereas slightly higher C^* colour values were recorded in Ferrari-yellow and Vine sweet-mini (57.01 ± 2.16 and 46.58 ± 2.01, respectively).

Weight loss

A general increase in weight loss over the storage period was observed in all the treated bell pepper cultivars, although the changes after 15 d of storage were smaller in the IS treatment than in the other treatments. All of the main factors (treatment, storage duration, and cultivar) had highly significant ($p < 0.001$) influences on weight loss in the bell pepper cultivars (Table 3). The two-way interaction of treatment and cultivar had significant effect on weight loss ($p < 0.05$), and that storage period and cultivar had highly significant ($p < 0.001$) effect on weight loss. No significant effect of the two-way interaction of treatment and storage period or of the three-way interaction of treatment, storage period, and cultivar was observed.

After 15 d of storage, as compared to other treatments, Vine sweet-mini, Raon-mini, Ferrari-red, and Ferrari-yellow had the highest weight losses under the DS treatment: 20.51, 17.19, 3.23, and 3.05%, respectively (Figure 2a). These increases in weight loss in the samples might have been due to moisture loss, respiration, and trans-evaporation (Patel *et al.,* 2019). Ben-Yehoshua and Rodov (2003) reported that the vapour pressure deficit (DVP), which is the difference in water vapour pressure between the tissue of the fruit and the atmosphere accelerates weight loss. After 15 d of storage,

Table 3. Effects of delayed cooling treatment (Tr), cultivar (C), and storage period (SP) on quality characteristics of stored bell pepper cultivars.

ANOVA	Weight loss	TSS	Firmness	*L**	*h°*	*C**
Tr	< 0.001**	0.035**	0.001**	0.095*	0.129*	0.308*
SP	< 0.001**	< 0.001**	< 0.001**	0.016**	< 0.001**	0.015**
C	< 0.001**	< 0.001**	< 0.001**	< 0.001**	< 0.001**	< 0.001**
Tr × C	0.004**	0.246*	0.282*	0.015**	0.191*	0.001**
Tr × SP	0.125*	0.267*	0.298*	0.159*	0.963*	0.036**
SP × C	< 0.001**	< 0.001**	< 0.001**	< 0.001**	0.625*	< 0.001**
Tr × SP × C	0.689*	0.307*	0.963*	0.642*	0.987*	0.203*

*indicates insignificant differences ($p > 0.05$), and **indicates significant differences ($p < 0.05$).

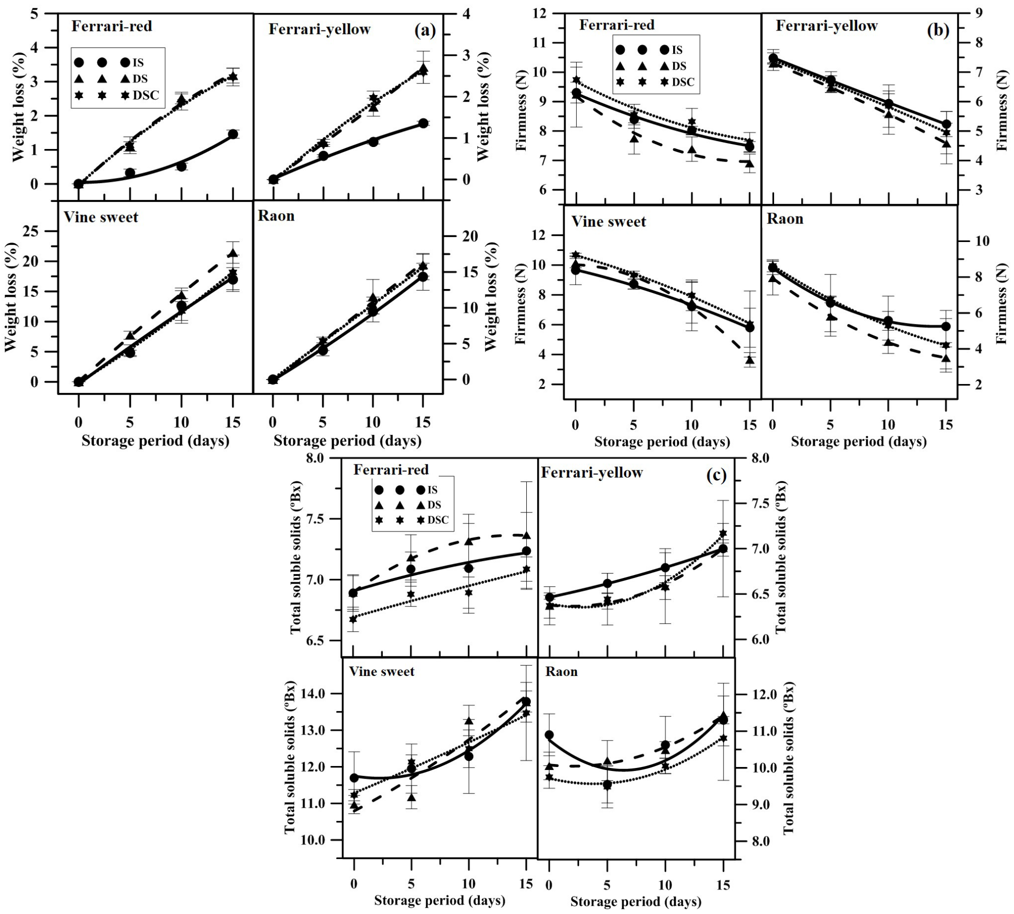

Figure 2. Weight loss (a), firmness (b), and changes in TSS content (c) of four bell pepper cultivars during storage of 15 d under the IS, DS, and DSC treatments. IS = immediate storage, DS = 24-h delayed storage without cover, and DSC = 24-h delayed storage under cover.

Ferrari-yellow under the IS treatment showed the minimum weight loss, 1.40%, thus indicating that this cultivar had lower metabolic and respiration rates than the other cultivars.

Firmness

A general decreasing trend was observed in the firmness of the bell pepper cultivars of each cultivar over the storage duration under the IS, DS, and DSC conditions (Figure 2b). Statistical analysis indicated that the main effects of treatment, storage period, and cultivar on the firmness of the stored bell pepper cultivars were significant ($p < 0.05$, $p < 0.001$, and $p < 0.001$, respectively) (Table 3). The two-way interactions (excluding storage period and cultivar) and three-way interaction among treatments, cultivars, and storage days had no significant effects ($p > 0.05$) on firmness.

Among the treatments, the DS treatment yielded the highest rate of decrease in firmness, with Ferrari-red, Ferrari-yellow, Vine sweet-mini, and Raon-mini exhibiting decreases of 9.24 to 6.90, 7.29 to 4.58, 10.13 to 3.65, and 7.94 to 3.50 N, respectively. However, cultivars treated with IS showed a lower rate of decrease in firmness, while among the cultivars, Ferrari-red showed the lowest decrease in firmness, with firmness in this cultivar decreasing from 9.31 to 7.46 N over 15 d of storage. The firmness losses of fruits are associated with the degradation of tissue due to enzymatic activities in the cell wall (Yousuf *et al.,* 2018). Results obtained in the present work show that post-harvest delayed cooling has negative influences on the firmness of stored bell peppers.

Total soluble solids (TSS)

The changes in TSS of the cultivars under the three storage treatments over the storage period are shown in Figure 2c. Treatment, storage period, and cultivar had significant ($p < 0.05$, $p < 0.001$, and $p < 0.001$, respectively) influences on the changes in TSS of the stored bell pepper cultivars (Table 3). However, the two- and three-way interactions of treatment, cultivar, and storage period did not have significant influences on the changes in TSS, except for storage duration and cultivar, which had significant ($p < 0.001$) influence on the changes in TSS.

Lower changes in TSS content were observed in the IS-treated cultivars than in those treated with DS or DSC. The TSS contents in IS-treated Ferrari-red, Ferrari-yellow, Vine sweet-mini, and Raon-mini increased by 5.09, 8.32, 18.07, and 3.83%, respectively, over the 15 d of storage. This delayed increase in TSS content in the IS-treated cultivars could have been due to lower levels of metabolic activity and respiration under IS than under the delayed-cooling treatments (Ali *et al.,* 2011). Among the different combinations of cultivar and treatment, the greatest change in TSS content over the storage period was observed for Vine sweet-mini treated with DS. Ferrari-red treated with IS experienced the lowest TSS change from 6.89 to 7.24°Bx. The DSC-treated bell peppers showed smaller increases in TSS content as compared to those treated with DS, possibly because of the lowering effects of cover on the temperature of the cultivars inside the greenhouse (Abdel-Ghany *et al.,* 2015).

Colour

The degradation in colour values (L^*, $h°$, and C^*) of the stored bell pepper cultivars of the IS, DS, and DSC treatments during the storage period are shown in Figure 3. The two-way interactions of treatment and cultivar, and storage period and cultivar showed significant influences on the L^* and C^* values of the stored bell pepper cultivars, whereas no two-way interaction had significant effect on the $h°$ values. The three-way interaction among treatment, storage period, and cultivar had no significant influence on L^*, $h°$, or C^* values in the treated cultivars (Table 3). Among the various combinations of cultivar and treatment, Vine sweet-mini subjected to the DS treatment experienced the largest increase in L^* (30.6 - 37.9), whereas Ferrari-yellow treated with DS showed the smallest increase (55.4 - 55.1). The largest changes in the hue angle were observed in Ferrari-red, with the largest decrease (28.3 - 21.6) observed in the DS-treated samples, and the smallest decrease (28.9 - 23.5) observed in the IS-treated samples.

Among the cultivars, Ferrari-yellow showed the smallest decrease in $h°$ values over the 15 d of storage; among the treatments, the largest decrease (88.1 - 85.8) in this cultivar was observed in the DS treatment, and the smallest (87.6 - 85.7) was observed in the IS treatment. The C^* in Ferrari-red increased throughout the storage period, with the DS-treated Ferrari-red showing the largest increase (32.6 - 35.1), and the IS-treated samples showing the smallest (34.9 - 36.1). Among the cultivars, Ferrari-yellow exhibited the largest decrease in C^*, with the largest (58.1 - 43.2) and smallest decreases (55.8 - 49.8) in this cultivar were observed in the IS and DS treatments, respectively. Changes in the colour parameters of fruits are associated with the ripening stage, and indicate physiological changes

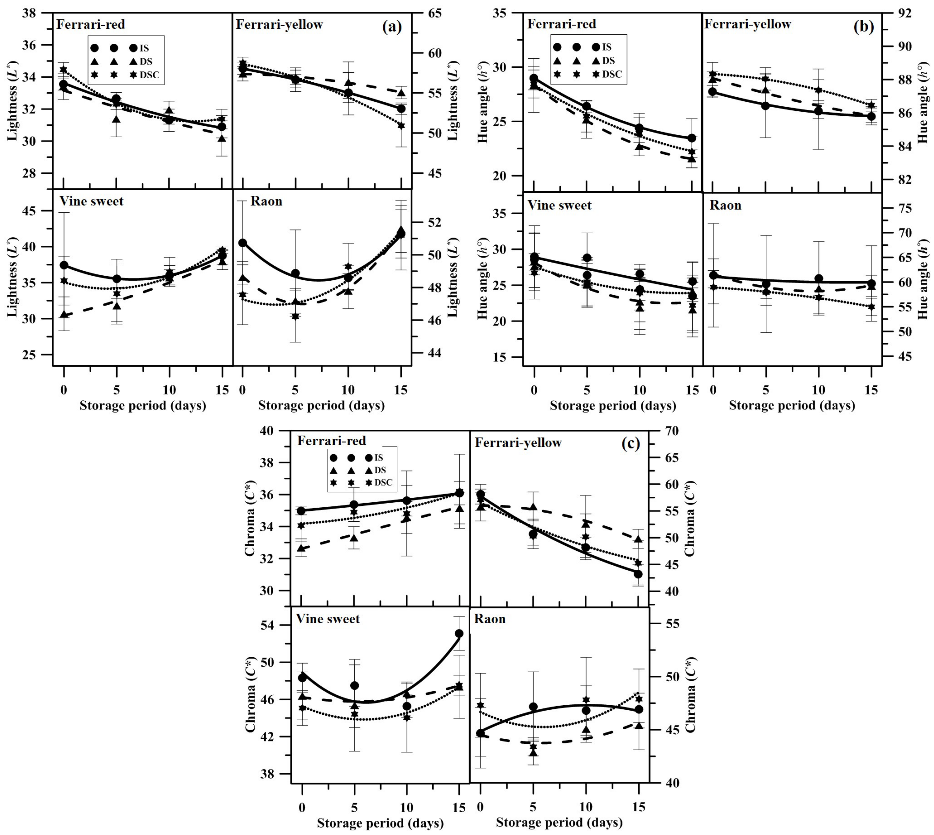

Figure 3. Changes in the L^* (a), $h°$ (b), and C^* (c) values of the four bell pepper cultivars over 15 days of storage under the IS, DS, and DSC treatments. IS = immediate storage, DS = 24-h delayed storage without cover, and DSC = 24-h delayed storage under cover.

(Tigist *et al.,* 2013). The colour of the IS-treated bell pepper cultivars was better maintained than those of the delayed cooling-treated fruits, which might have been due to the elevated temperature and lower relative humidity experienced by the DS- and DSC-treated bell pepper cultivars during the delayed cooling period (Gil and Tudela, 2012). The measurements of the colour values in the present work showed that post-harvest cooling delay strongly influenced colour retention in the stored bell peppers, while having negative effects on the colour values.

Conclusion

Delayed cooling (leaving bell peppers unattended up to one or two days inside the greenhouse) can affect the post-harvest quality of bell peppers. Therefore, we investigated the effect of delayed cooling on changes in the quality of bell peppers during storage. The DS- and DSC-treated bell peppers resulted in rapid weight and firmness losses, large changes in TSS content, and rapid decreases in hue angle relative to those of the IS-treated fruit samples. The overall changes in the examined quality parameters were slower for the bell peppers treated with IS than other delayed cooling treatments. The present work demonstrated the consequences of delayed cooling in post-harvest storage of bell peppers and highlighted the importance of immediate cooling to maintain post-harvest quality and prolong the storage of harvested bell peppers.

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