RESEARCH ARTICLE https://doi.org/10.7235/HORT.20230038

Seasonal Difference of Fruit Quality Attributes and Physiological Disorders in Paprika Cultivars under a Simulated Export System

Si-Eun Byeon[1], Sangyo Jeong[1], Hnin Phyu Lwin[1], Jinhee Lee[1], Theint Thandar Latt[1], Hyowon Park[1], Yeo Eun Yun[2], Jung-Soo Lee[3], and Jinwook Lee[1]*

[1]Department of Plant Science and Technology, Chung-Ang University, Anseong 17546, Korea
[2]Postharvest Technology Division, National Institute of Horticultural and Herbal Science, RDA, Wanju 55365, Korea
[3]Technology Services Division, National Institute of Horticultural and Herbal Science, RDA, Wanju 55365, Korea

*Corresponding author: JL425@cau.ac.kr

Received: March 13, 2023
Revised: April 12, 2023
Accepted: May 10, 2023

OPEN ACCESS

HORTICULTURAL SCIENCE and TECHNOLOGY
41(4):414-428, 2023
URL: http://www.hst-j.org

pISSN : 1226-8763
eISSN : 2465-8588

This study was financially supported by a grant from the 2021 Research Fund (PJ015652022022) of the Rural Development Administration (RDA), Republic of Korea. Mr. Sangyo Jeong was also supported by the Chung-Ang University Graduate Research Scholarship (Academic Scholarship for College of Biotechnology and Natural Resources) in 2022 for his M.S. program.

Conflicts of Interest
The authors declare that there are no conflicts of interest.

Abstract

This study evaluated seasonal changes in various fruit quality attributes and the incidence of physiological disorders in the blocky and conical types of paprika cultivars using a simulated export system. The effects of three different pericarp colors were also investigated. ‘Scirocco’, ‘DSP 7054’, and ‘Volante’ cultivars were used as a blocky type, while ‘Raon red’, ‘Raon orange’, and ‘Raon yellow’ cultivars were used as a conical type with red, orange, and yellow pericarp color, respectively. The fruit was shipped at 10°C for two weeks, stored at 10°C for one week, and then transferred at 22°C for one week to simulate export by shipping. Storage temperatures and relative humidity levels greatly fluctuated in the winter season as compared to the summer season. Thus, fruit weight loss was higher in the winter season than in the summer season regardless of the cultivar type. However, the pericarp firmness was lower in the winter season. The soluble solids content and titratable acidity were higher in conical type than in the blocky type of paprika cultivar and highest in the ‘Raon red’ cultivar. The pericarp lightness and hue angle responded differently during the export season, depending on the pericarp color and fruit type. The incidence and severity of fruit shriveling were higher in the winter season than in the summer season, irrespective of the cultivar. Fruit shriveling was less severe in the conical type than in the blocky type, regardless of the pericarp color. Moreover, the incidence and severity of fruit softening, pedicel wilting, and pedicel browning were higher in the winter season than in the summer season. Therefore, the results indicate that the storage humidity levels likely play a pivotal role in the postharvest handling of paprika fruit quality during the seasonal export period. Thus, careful consideration of various techniques that are contingent upon the season of export and the specific type of fruit is required.

Additional key words: correlation network, fruit quality parameters, pedicel, storage disorders, storage humidity, storage temperature

Introduction

Since the paprika (*Capsicum annuum* L.) fruit, also known as sweet pepper or bell pepper, was introduced into Korea, its cultivation and consumption have grown exponentially (Lim et al., 2007, 2008a). Along with the consistent and continuous production and export of the blocky type of paprika, the conical type of paprika also has great attractive value due to its fruit size and high soluble solids content (SSC) (Kim et al., 2016; Kye et al., 2022). Thus, numerous conical types of paprika cultivars are being actively bred and developed through both public and private breeding projects for commercial use (Baek and Shin, 2020; Kye et al., 2022). In addition, the antioxidant activity, specifically the free radical scavenging activity, is much higher in the conical type of paprika fruit than in the blocky type, regardless of the pericarp color (Luitel and Kang, 2013; Kye et al., 2022). However, it was reported that consumer preference for paprika fruit was based on their pericarp color rather than on the retail price or vitamin C content (Frank et al., 2001).

Immediately after harvest, paprika fruit are sorted using a fruit quality grading system that takes into account the pericarp color coverage and fruit size (or fruit weight) (Fox et al., 2005; Díaz-Pérez et al., 2007; Lim et al., 2007; Mohi-Alden et al., 2022). The fruit are packed into suitable packaging materials and then directly distributed into wholesale and retail markets or shipped for export (Singh et al., 2014; Seo et al., 2019; Lwin et al., 2022). During their distribution and shelf life period, paprika fruit are exposed to various types of biotic and abiotic stress under unfavorable environmental conditions, such as high temperatures and low relative humidity levels (Lwin et al., 2022). Thus, the overall fruit quality could deteriorate during storage (Choi et al., 2015). Typically, paprika fruit lose water through the various physiological processes associated with respiration and transpiration from the fruit surface during storage and shelf life, which reduce the fresh weight of the fruit (Taheri et al., 2020). Under such conditions, the fruit begin to wilt and/or shrivel (Manolopoulou et al., 2010). In addition, the reduced fresh weight of paprika fruit is directly associated with a reduction in the pericarp firmness (Liu et al., 2015; Taheri et al., 2020). SSC, as a fruit quality parameter, is affected during both cold storage and distribution (Lim et al., 2008b) and is highly sensitive to the fruit maturity stage (Kasampalis et al., 2022). The fruit quality parameters of paprika are greatly influenced by the cultivar type and postharvest handling practices as well (Smith et al., 2006; Frans et al., 2021; Lwin et al., 2022). However, the effects of various fruit quality parameters on different paprika cultivars during different seasons have not been adequately investigated. Therefore, we attempt to test the hypothesis that the fruit quality of paprika cultivars depending on the export stage is affected differently during the two contrasting export seasons. Thus, the objective of this study aimed to evaluate various fruit quality attributes of six paprika cultivars during the winter and summer seasons and to assess the phenotypic responses to physiological disorders under a simulated export system from the harvest to the final distribution stages.

Materials and Methods

Plant Materials and Storage Conditions

Two types of paprika (*Capsicum annuum* L.) fruit, blocky and conical types, were harvested in two seasons. The first harvest occurred on 17 February 2022 for the winter season and the second was on 9 June 2022 for the summer season. Red 'Scirocco', orange 'DSP 7054', and yellow 'Volante' blocky types of paprika cultivars were cultivated in Yeongam, Jeollanam-do, while red 'Raon red', orange 'Raon orange', and yellow 'Raon yellow' conical types of paprika cultivars were produced in Jinju, Gyeongsangnam-do, Republic of Korea. All cultivars were cultivated according to the standard agronomic practices of each region and were harvested at commercial maturity (RDA, 2023). They were then immediately transported to the National Institute of Horticultural and Herbal Science (NIHHS), Rural Development Administration (RDA) in Wanju, Korea, where they were randomly arranged into four groups of 15 fruits each. One group was used to assess the fruit quality characteristics at harvest on the same day. The other three groups were stored in a refrigerated container maintained at 10°C at the NIHHS facility for the simulated shipping treatment. Two weeks later, three groups of six cultivars each were transferred to a laboratory at Chung-Ang University, Anseong, Gyeonggi-do, Republic of Korea, which took 2 h at 22°C. The fruit quality parameters of one of the three groups were directly evaluated as was done at harvest time. The other two groups were immediately stored at 10°C for one additional week. Next, the wholesale distribution system involved in exporting the paprika fruit was mimicked to determine the fruit quality attributes of one group of packed fruit during this entire process. The last group was stored at ambient temperature for one additional week in order to mimic the paprika fruit quality under shelf life conditions. The temperature and relative humidity during storage were recorded during a simulated export period using a data logger (TR-72wf, T&D Co., Nagano, Japan).

Assessment of Fruit Quality Attributes

Each cultivar was packed into four boxes. Each box contained 15 fruits on a paper tray (three replicates, five fruits per replicate). The fruit quality attributes were evaluated at four simulated export steps: at harvest, two weeks after the ‘Shipping’ period, three weeks an additional week following a mimicked wholesale ‘Storage’ and distribution period, and then upon an additional week after a mimicked ‘Shelf life’ period (Fig. 1). The weight loss of each individual fruit was evaluated using a previously published method (Byeon and Lee, 2020). The results were expressed as the percentage of the initial weight that was lost (Latt et al., 2023). The color of the fruit was measured at three points on the equatorial region of each fruit using a colorimeter (Minolta CR-400, Minolta Co., Osaka, Japan) after calibration with a standard white plate ($Y = 93.8$, $X = 0.3130$, $y = 0.3191$). Lightness (L^*), chroma (C^*), hue angle (h^o), greenness to redness (a^*), and blueness to yellowness (b^*) were expressed as average values using a previously developed CIE system (McGuire, 1992; Lee et al., 2022b; Lwin et al., 2022). The color coverage was expressed as a percentage and represents the change from immature green to a mature color.

Physiological disorders, in this case, shriveling, softening, pitting, pedicel wilting, and pedicel browning, were evaluated throughout the experimental period. The incidence rate (%) was calculated as the ratio of damaged fruit to the total number of fruit examined (Lee et al., 2013). The severity of the physiological disorders was expressed using the method proposed by (Lee et al., 2019), in which the damaged area of a fruit is depicted as follows: 0 = 0%, 1 = 1 − 10%, 2 = 11 − 25%, 3 = 26 − 50%, 4 = 51 − 75%, and 5 = 76 − 100% of the fruit area being damaged.

To ascertain the rates of fruit respiration and ethylene production, paprika fruit were sealed in an enclosed container (1.9 L) for 2 h, after which 1 mL each of the sample gas was collected from the headspace of the container. One gas sample was injected into a gas chromatograph (YL6500GC, YL Instrument Co., Ltd., Anyang, Korea) to measure fruit respiration in each case. The chromatograph was activated with an 80/100 Porapak Q column (Supelco Inc., Supelco Park, Bellefonte, PA, USA). The temperatures of the injector and thermal conductivity detector were set to 200°C and 150°C, respectively, and the oven was set to 50°C. The other gas sample for determining the ethylene production rate was assessed using a gas

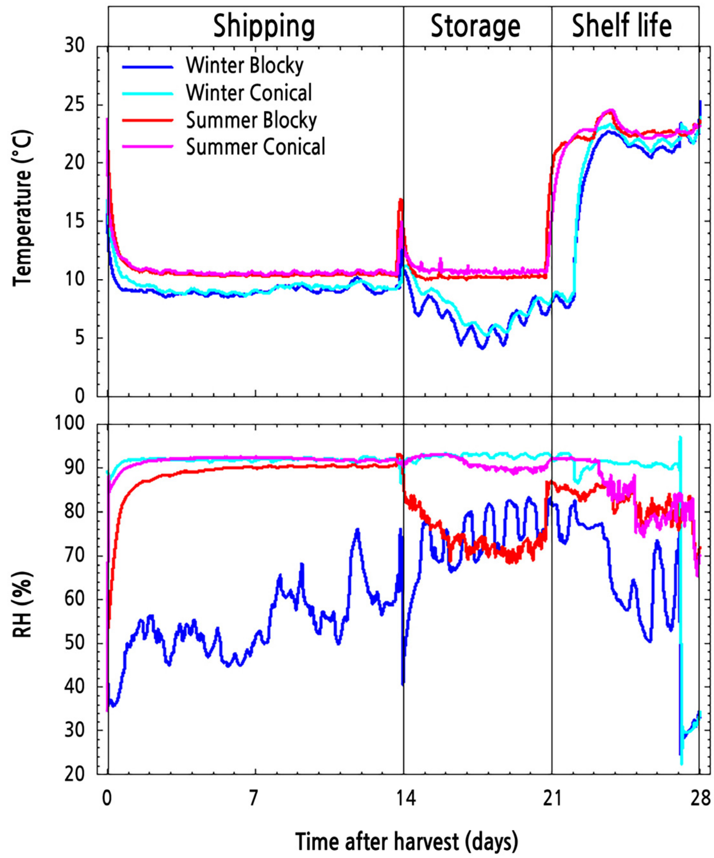

Fig. 1. Responses to storage temperature and relative humidity levels by blocky and conical types of paprika fruit shipped in a container maintained at 10°C for two weeks, transferred at 10°C for one week, and then stored at 22°C for one week of additional shelf life in the winter and summer seasons.

chromatography system (Agilent 8890 GC, Agilent Technologies Inc., Santa Clara, CA, USA) with a CP-Al_2O_3/Na_2SO_4 deactivated column (50 m × 0.53 mm i.d. × 10 μm film thickness, Agilent J&W PLOT column, Agilent Technologies Inc., Santa Clara, CA, USA). The temperatures of the injector, oven, and flame ionization detector were set to 200°C, 70°C, and 250°C, respectively. Helium (He) was used as the carrier gas at a flow rate of 30 mL min^{-1} for both GC analysis conditions (Byeon et al., 2022; Latt et al., 2023). Fruit firmness was measured using a Brookfield texture analyzer (CT3 4500, AMETEK Brookfield, Inc., Middleborough, MA, USA). A 2 mm plunger was inserted on opposite sides of each fruit. The pre-test speed, post-test speed, and sample rate were 2 mm·s^{-1}, 10 mm·s^{-1}, and 100 point·s^{-1}, respectively. The results were expressed in Newton (N). The SSC was determined using a digital hand-held pocket reflectometer (Model PAL-1, Atago Co., Ltd., Tokyo, Japan) and the titratable acidity (TA) was determined by titrating 5 mL of juice squeezed from paprika to an endpoint of pH 8.2 with 0.1 N NaOH using a Titrette (Titrette® bottle-top burette, BrandTech® Scientific, Inc., Wertheim, Germany). Both SSC and TA were expressed as percentages (Lee et al., 2022a; Lwin and Lee, 2022).

Statistical Analyses

A completely randomized design was adopted to evaluate the fruit quality attributes and physiological disorders in the two types (blocky vs conical) of paprika cultivars with three different pericarp colors (red, orange, and yellow) during a simulated export period comprising two contrasting seasons. A completely randomized design was assigned to each cultivar with three replications, with five fruits per replicate. Weight loss, firmness, and physiological storage disorders were determined by using 15 paprika fruits as replicates. However, fruit respiration and ethylene production rates were investigated using six replicates (or fruits). The data were used to form a general linear model (GLM) for statistical analyses. SSC, TA, and SSC/TA data were obtained using three replicates with five fruits per replicate. The GLM procedure was utilized to determine the statistical significance of each variable through an analysis of variance (ANOVA) using SAS 9.3 (SAS Institute Inc., Cary, NC, USA). The least significant difference (LSD) test was applied to examine the significance of any difference in the means among the cultivars ($p < 0.05$). The correlation coefficient network was obtained with the MetScape (Version 3.1.3) plugin for Cytoscape (Version 3.8.2; https://cytoscape.org/), as described previously (Basu et al., 2017; Lwin et al., 2022).

Results

Storage Air Temperature and Relative Humidity Responses

The storage air temperature was slightly lower in the winter season than in the summer season regardless of the cultivar and fruit type. The storage air temperature remained stable in the summer season during the simulated export and wholesale market storage period, irrespective of the fruit type. However, in the winter season, although the storage air temperature remained relatively constant during the shipping period, it fluctuated daily during the wholesale market storage period. During the shelf life, the storage air temperature changed daily, regardless of the fruit type or export season (Fig. 1).

The relative humidity was approximately 90% during the simulated shipping period, except for the blocky type in the winter season. The relative humidity of the conical types of paprika cultivars showed less fluctuation during wholesale market storage, in contrast to that for the blocky type of paprika cultivar, regardless of the export season. In addition, during the shelf life, the relative humidity changed inconsistently relative to the fruit type in winter, whereas it showed consistent changes in summer (Fig. 1).

Physiological Responses of Fruit Quality Attributes

The fruit appearance outcomes in the form of phenotypic responses are shown in Fig. 2, based on the fruit type (blocky vs conical type), fruit pericarp color (yellow, orange, and red peel), and simulated export period (harvest, shipping, wholesale market storage, and shelf life). In the winter season, the fruit rapidly lost weight during the shipping period, but the weight then remained consistent during the wholesale market storage and shelf life periods, regardless of the fruit type or cultivar. In contrast, weight loss according to the fruit type gradually increased during the simulated export period overall regardless of the fruit pericarp color. The weight loss was greater in the blocky type of paprika fruit than in the conical type (Fig. 3). Firmness of the fruit pericarp was also inconsistent in the winter season, irrespective of the cultivar type. Firmness of the fruit pericarp was higher in the conical type of paprika cultivar than in the blocky type in the summer season. Furthermore, the fruit pericarp firmness tended to decrease gradually throughout the simulated export period,

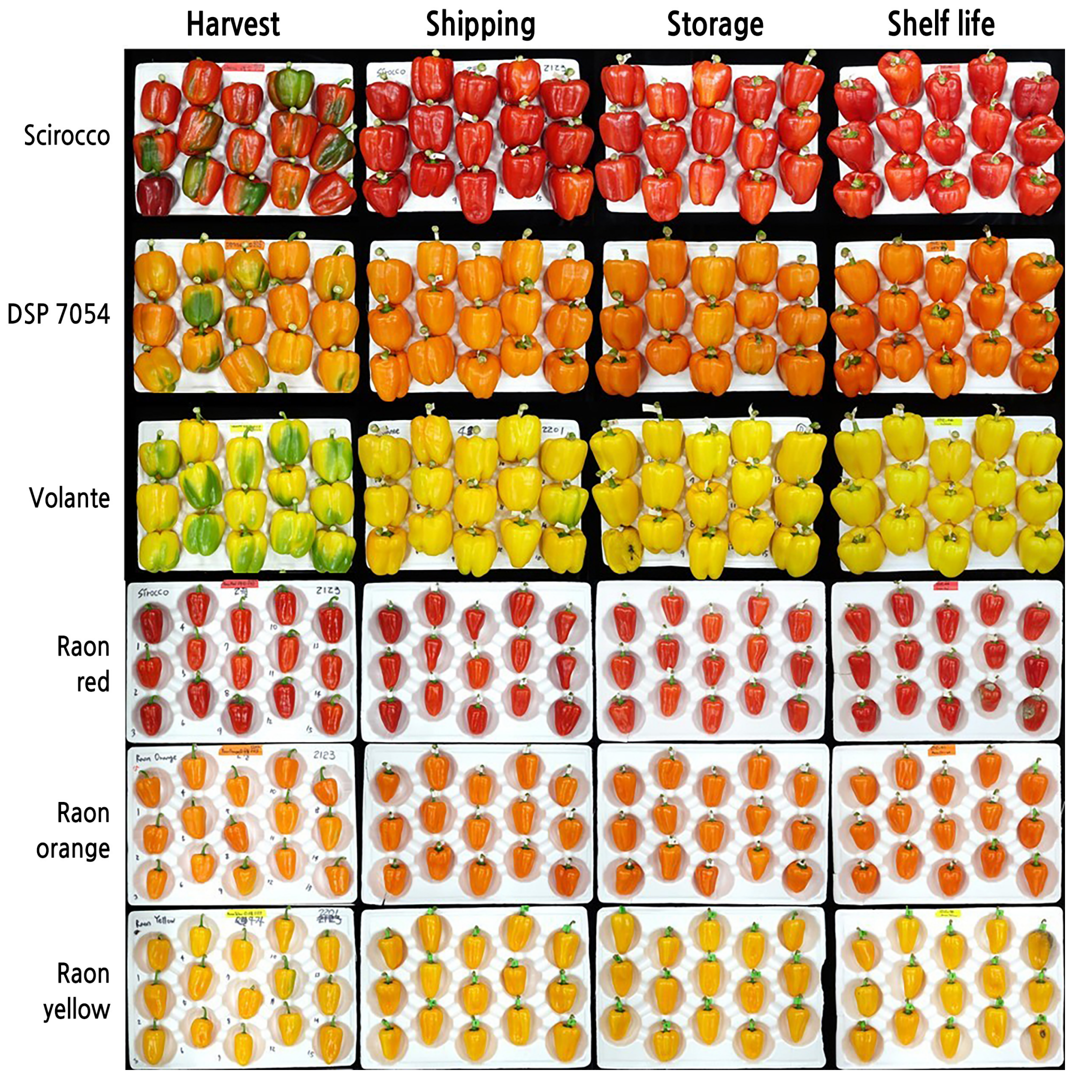

Fig. 2. Fruit phenotypic responses of paprika cultivars classified as blocky ('Scirocco', 'DSP 7054', and 'Volante') and conical ('Raon red', 'Raon orange', and 'Raon yellow') types shipped in a container at 10°C for two weeks, transferred at 10°C for one week, and then stored at 22°C for one week of additional shelf life in the winter and summer seasons, with a tray size of 34.5 cm × 49.5 cm.

regardless of the fruit type or cultivar (Fig. 3). Fruit respiration and ethylene production were not consistent throughout the simulated export period, irrespective of the export season, cultivar type, or fruit pericarp color (Fig. 3). The SSC was higher in the conical type than in the blocky type of paprika cultivar, regardless of the export season or cultivar. While the SSC in the conical cultivars did not differ between export seasons, it was greatly reduced in the summer season instead of in the winter season. The SSC levels were highest in the 'Raon red' conical type and the 'DSP 7054' blocky type of paprika cultivar, irrespective of the export season (Fig. 3). The TA was higher in conical type than in the blocky type of paprika cultivar. It was also much higher in the summer export season than in the winter export season. The 'Raon red' cultivar had the highest TA, while the 'Volante' cultivar had the lowest when compared to the other cultivars, irrespective of the export season (Fig. 3). Notably, the SSC to TA ratio responded inconsistently to the simulated export period and export season (Fig. 3).

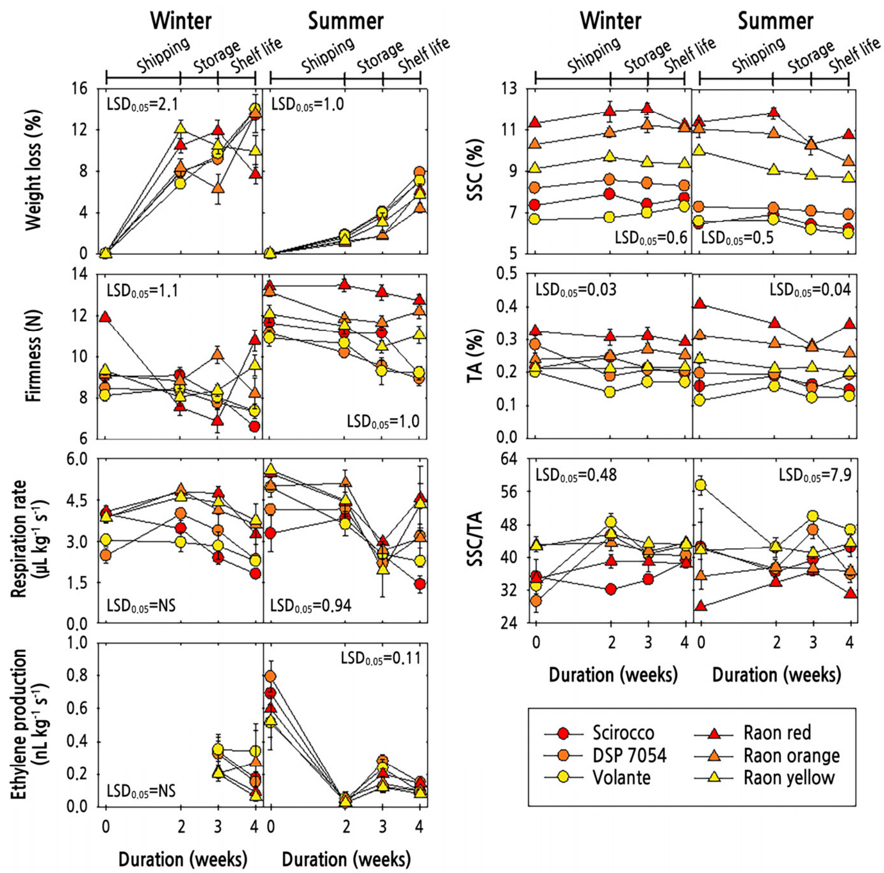

Fig. 3. Physiological responses of the fruit weight loss, pericarp firmness, respiration rate, ethylene production rate, soluble solids content (SSC), titratable acidity (TA), and SSC/TA ratio for paprika cultivars classified as the blocky ('Scirocco', 'DSP 7054', and 'Volante') and conical ('Raon red', 'Raon orange', and 'Raon yellow') types shipped in a container at 10°C for two weeks, transferred at 10°C for one week, and then stored at 22°C for one week of additional shelf life in the winter and summer seasons. Weight loss and pericarp firmness data points are expressed as the mean of 15 paprika fruits as replicates ($n = 15$) ± standard error. However, ethylene production and respiration rate data points indicate the mean of six paprika fruits as replicates ($n = 6$) ± standard error. SSC and TA data points indicate the mean of three replicates ($n = 3$) ± standard error. Different letters indicate significant differences among regions based on the least significant difference (LSD) test ($p < 0.05$).

Responses of Color Variables in the Fruit Pericarp

The lightness of the pericarp (L^*) remained consistent in the winter export season, regardless of the cultivar type. However, it gradually increased in the summer export season. Among the cultivars, the 'Volante' and 'Raon yellow' types had the highest pericarp L^* value during the simulated export period, irrespective of the export season. However, pericarp L^* was lowest in the 'Scirocco' and 'Raon red' cultivars, compared to those of the other cultivars. Pericarp L^* was typically higher in the conical type than in the blocky type of paprika cultivar (Fig. 4). Pericarp chroma (C^*) also similarly responded during the simulated export period. That is, C^* value tended to decrease slightly during the winter simulated export period, but it gradually increased during the simulated export period in summer, irrespective of the cultivars. Pericarp C^* was typically higher in the conical type than in the blocky type, regardless of the simulated export period (Fig. 4). The pericarp hue angle (h^o) was highest in the yellow pericarp paprika cultivars and lowest in the red pericarp cultivars, compared to those of other cultivars, irrespective of the simulated export season or cultivar fruit type (Fig. 4). Pericarp

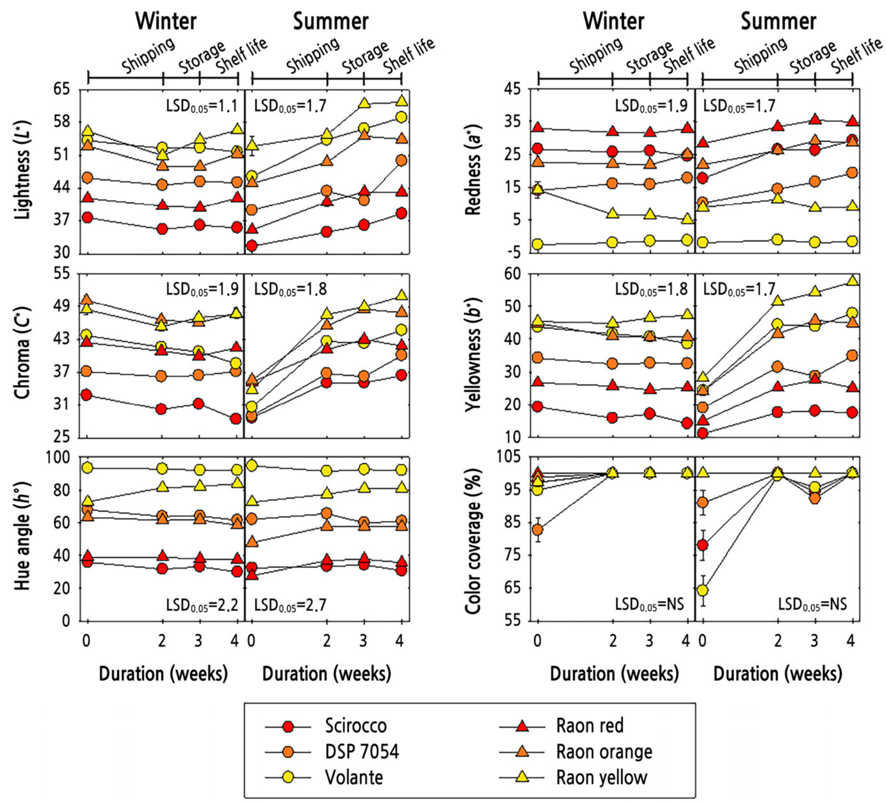

Fig. 4. Color responses of the lightness (L^*), chroma (C^*), hue angle (h°), greenness to redness (a^*), blueness to yellowness (b^*), and color coverage (%) ratio in paprika fruit classified as blocky ('Scirocco', 'DSP 7054', and 'Volante') and conical ('Raon red', 'Raon orange', and 'Raon yellow') types shipped in a container at 10°C for two weeks, transferred at 10°C for one week, and then stored at 22°C for one week of additional shelf life in the winter and summer seasons. Each of the data points indicates the mean of 15 paprika fruits as replicates (n = 15) ± standard error. Different letters indicate significant differences among regions based on the least significant difference (LSD) test ($p < 0.05$).

redness in terms of the a^* value was highest in the red paprika cultivars ('Scirocco' and 'Raon red') but lowest in the yellow paprika cultivars ('Volante' and 'Raon yellow'). However, pericarp yellowness in terms of the b^* value was highest in the yellow pericarp paprika cultivars and lowest in the red paprika cultivars (Fig. 4). Pericarp color coverage varied widely at harvest, although the corresponding pericarp of each cultivar was fully covered with color during the simulated export period, irrespective of the export season (Fig. 4).

Incidence and Severity of Physiological Disorders

The shriveling of the fruit pericarp increased immediately after the completion of the shipping period in the winter season, irrespective of the cultivar type. After the shipping period, the incidence of shriveling of the fruit pericarp remained high. The severity of fruit pericarp shriveling increased gradually in the blocky type of paprika cultivar, regardless of the cultivar type; however, it became inconsistent after the shipping period in the conical type of paprika cultivar in the winter season. However, in the summer season, the incidence and severity of pericarp shriveling were sharply enhanced after two-weeks of cold storage, regardless of the pericarp color or fruit type. During the shelf life period, the incidence and severity of fruit shriveling were much higher in the blocky type than in the conical type of paprika cultivar, irrespective of the pericarp color (Fig. 5).

The incidence and severity of fruit softening increased sharply during the shipping period regardless of the pericarp color or fruit type. However, during cold storage, the handling period for wholesale distribution, and the shelf life period for retail marketing, the incidence and severity of fruit softening remained inconsistent in the winter season. In the summer season, while no fruit softening was detected during shipping, it rapidly increased during the cold storage and shelf life periods. Furthermore, the incidence and severity of fruit softening were much higher in the blocky type than in the conical type of paprika cultivar, irrespective of the pericarp color (Fig. 5).

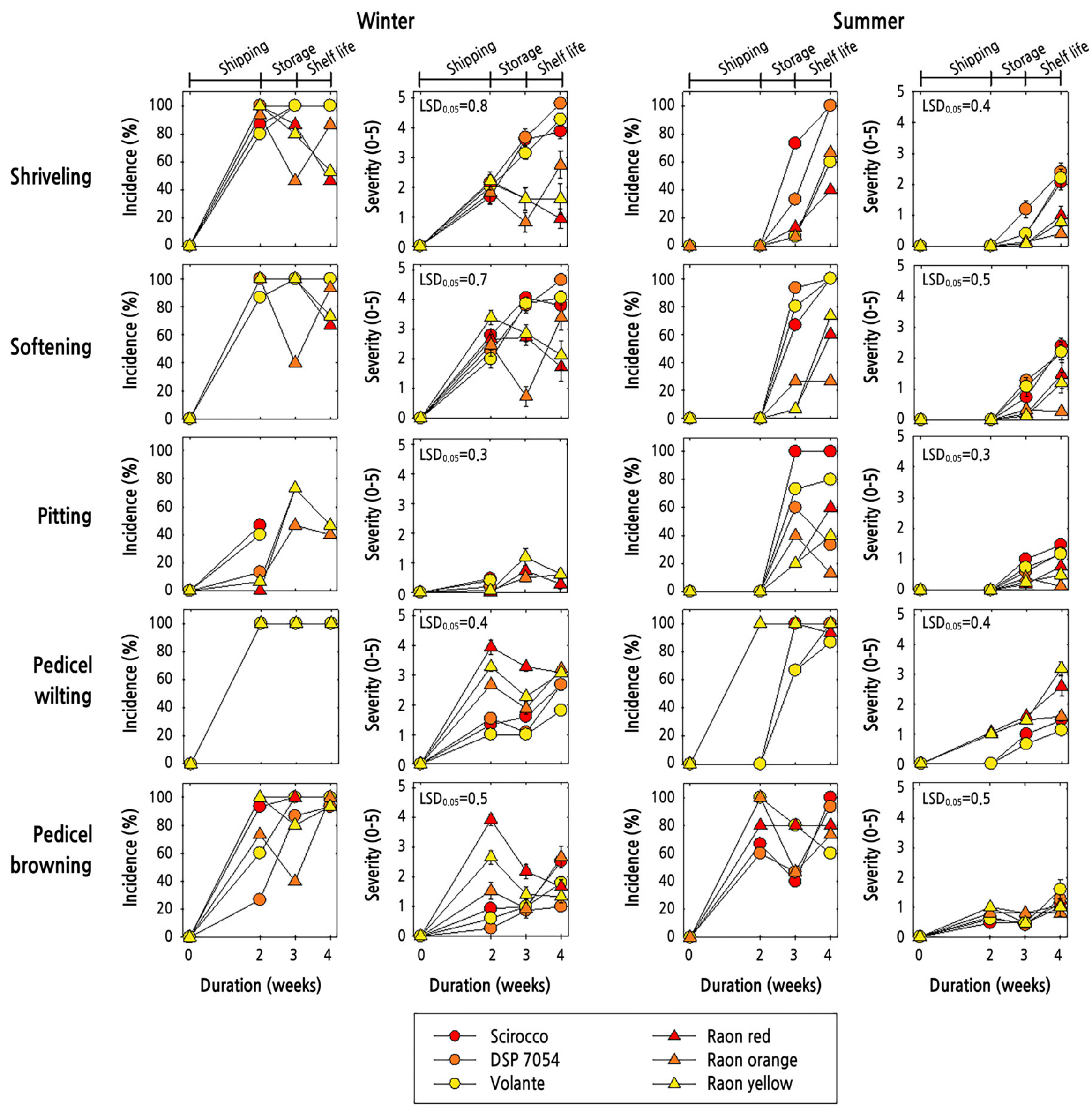

Fig. 5. Incidence and severity of pericarp shriveling, softening, pericarp pitting, pedicel wilting, and pedicel browning in the fruit of paprika cultivars classified by blocky ('Scirocco', 'DSP 7054', and 'Volante') and conical ('Raon red', 'Raon orange', and 'Raon yellow') types of paprika cultivars shipped in a container at 10°C for 2 weeks, transferred at 10°C for 1 week, and then stored at 22°C for 1 week additional shelf life in winter and summer seasons. Each datum point indicates the mean of 15 replicates (n = 15) ± standard error. The severity of physiological disorders is subjectively scored as 0 = 0%, 1 = 1-10%, 2 = 11-25%, 3 = 26-50%, 4 = 51-75%, and 5 = 76-100% area coverage of the paprika fruit. Different letters indicate significant differences among regions based on the least significant difference (LSD) test (p < 0.05).

The incidence and severity of pericarp pitting in the blocky type of paprika cultivar were only detected during the shipping period, not after the cold storage or shelf life periods. However, there was slight pericarp pitting in the conical type of paprika cultivar, irrespective of the pericarp color in the winter season. Pericarp pitting was not detected at all during the shipping period, although the incidence and severity of pericarp pitting greatly increased during the cold storage and shelf life periods, regardless of the paprika type or pericarp color. The incidence and severity of pericarp pitting were found to be higher in the blocky type than in the conical type of paprika cultivar (Fig. 5).

The incidence of pedicel wilting increased sharply during the shipping period or immediately after, irrespective of the cultivar type or pericarp color. The severity of pedicel wilting was much higher in the winter season than in the summer season. Interestingly, the severity of pedicel wilting was higher in the conical type than in the blocky type of paprika cultivar, regardless of the pericarp color or handling season (Fig. 5). The incidence of pedicel browning was high during the shipping and subsequent periods, irrespective of the type or pericarp color. However, the severity of pedicel browning was much higher in the winter season than in the summer season. That is, the severity of pedicel browning varied widely in the winter season, but it remained the same in the summer season, regardless of the cultivar type or pericarp color (Fig. 5).

Correlation Networks of Fruit Quality Parameters

Depending on the fruit handling season, the overall responses of the correlation coefficient networks appeared differently, as shown in Fig. 6. That is, the fresh weight of fruit was positively correlated with pericarp shriveling, fruit softening, pedicel wilting, and pedicel browning in the winter season and with pericarp pitting, pericarp shriveling, fruit softening, and pedicel browning in the summer season. Irrespective of the type or cultivar, pericarp a^* was negatively correlated with the coverage of the pericarp color, pericarp C^*, pericarp h^o, SSC/TA, pericarp b^*, and pericarp L^*, whereas pericarp L^* was strongly and positively correlated with pericarp h^o, pericarp C^*, and pericarp b^* in the winter season. TA, SSC, SSC/TA, the fruit respiration rate (CO_2), pericarp firmness, and pericarp color coverage were weakly positively correlated with pericarp L^* in the winter season. Similarly, in the summer season, pericarp h^o, and b^* were strongly and positively correlated with pericarp L^* but were negatively correlated with pericarp a^*. The fruit respiration rate (CO_2), SSC/TA, pericarp firmness, SSC, pericarp color coverage, and pericarp h^o, L^*, C^*, and b^* values were weakly positively correlated with pericarp L^* in the summer season (Fig. 6). Nevertheless, fruit quality attributes were similarly correlated with themselves irrespective of the export season.

In the blocky type of paprika cultivar, TA was negatively correlated with SSC/TA but positively correlated with SSC. Pericarp shriveling, pedicel wilting, fruit softening, and the fresh weight of the fruits were negatively correlated with pericarp firmness but positively correlated with pedicel browning. Moreover, the fresh weight of the fruits was strongly and positively correlated with pericarp shriveling and fruit softening. Pericarp L^*, h^o, and b^* values were positively correlated with pericarp C^* but negatively correlated with pericarp a^* regardless of the pericarp color. In the conical type of paprika cultivar, the fresh weight of the fruits was strongly and positively correlated with fruit softening and fruit shriveling but weakly correlated with pedicel wilting and pedicel browning. However, pericarp firmness was negatively correlated with fruit softening, the fresh weight of the fruits, pedicel browning, fruit shriveling, and SSC/TA. In addition, TA was negatively correlated with SSC/TA, pericarp L^*, and pericarp h^o, in which was negatively correlated with pericarp a^* irrespective of the pericarp color (Fig. 6).

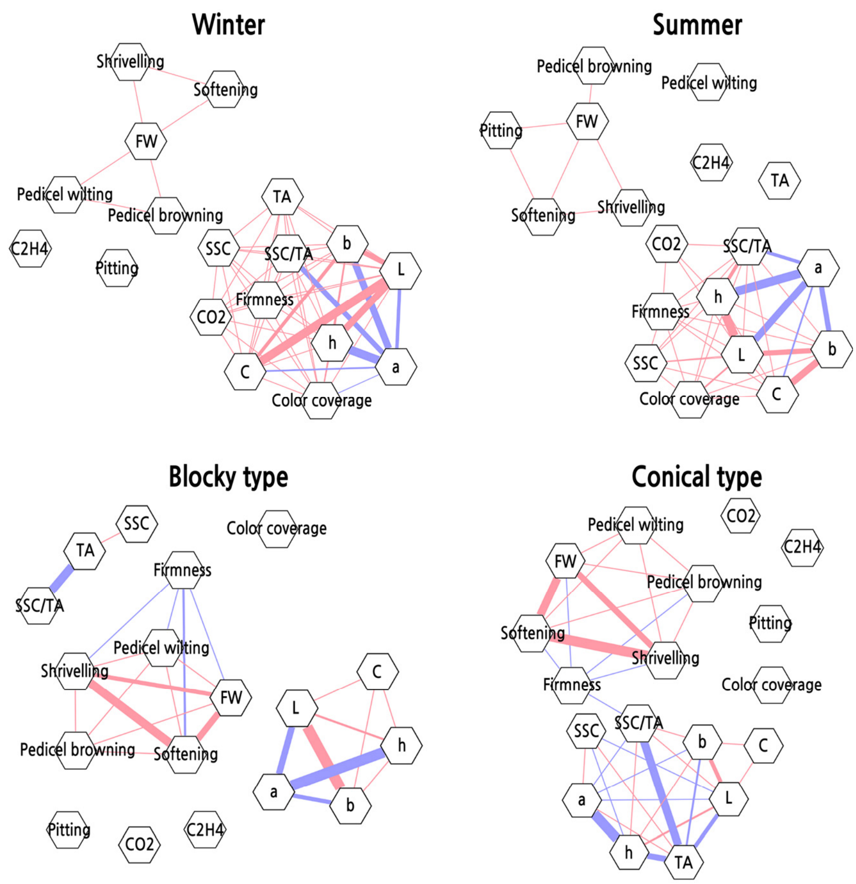

Fig. 6. Pearson's correlation coefficient network ($r \geq |0.60|$) among response variables for paprika cultivars classified as blocky ('Scirocco', 'DSP 7054', and 'Volante') and conical ('Raon red', 'Raon orange', and 'Raon yellow') types shipped in a container at 10°C for 2 weeks, transferred at 10°C for 1 week, and then stored at 22°C for 1 week additional shelf life in winter and summer seasons. Red and blue colors indicate positive and negative correlations among variables, respectively. Thickness of the correlation coefficient network lines indicates the significance of the correlation coefficient (r) among variables.

Discussion

Irrespective of the fruit type and cultivar, the storage temperature and storage humidity greatly fluctuate in the winter season, but not in the summer season. Such differential responses of the storage temperature and relative humidity would result from seasonal differences at these times, as the winter season is typically dry, whereas the summer season is generally humid due to the monsoon (or rainy) season, which generally lasts from the end of June to the middle of July. That is, a climatic alteration in the relative humidity depending on the calendar month clearly appeared during the simulated export period, while the storage temperature remained relatively constant during the entire simulated export period. The daily responses of the relative humidity fluctuated greatly within same pallet of 'Wonhwang' Asian pear fruit during its export period from Korea to Taiwan (Seo et al., 2019). That is, properly managing the relative humidity is critical for maintaining high quality fruit, compared to the quality obtained when the storage temperature is kept constant during the export period. In addition, the responses to changes in the relative humidity varied greatly during the shelf life period, irrespective of the export season or fruit type. Hence, additional care and special attention must be utilized differently to maintain the quality of the fruit depending on the export season. The responses to the relative humidity varied depending on the fruit type. That is, the relative humidity fluctuated more greatly in the blocky type than in the conical type of paprika cultivar, irrespective of the export season. It is possible that these controversial results arose due to the packing materials used, which depends on the fruit type being exported. Therefore, special care and additional attention are required to maintain the proper storage humidity during the winter season. Nevertheless, management of the storage humidity should be considered separately depending on the export season, fruit type, and/or package type or material (Lwin et al., 2022).

Fruit weight loss was higher in the winter season than in the summer season regardless of the fruit type or cultivar. The greater loss of the fruit weight could be strongly associated with the reduced storage humidity in the winter season, compared to that in the summer season. However, the fruit respiration rate did not differ much and depended on the export season, although the fruit respiration rate could differ depending on the fruit type instead of the pericarp color in the winter season. Hence, it can be suggested that fruit weight loss is more clearly linked to the control of the storage humidity rather than to the fruit respiration during the export period. In addition, pericarp firmness was lower in the winter season than in the summer season, irrespective of the fruit type or pericarp color. When the shelf life period was extended, the loss of the fruit weight was negatively correlated with the firmness of the fruit pericarp, regardless of the cultivar (Lwin et al., 2022). Fruit firmness was negatively linked to the fresh weight loss during export from Korea to Taiwan (Seo et al., 2019). The present study showed that fruit firmness was negatively correlated with the fruit weight loss, irrespective of the fruit type (Fig. 6). These results indicated that the fluctuations in storage humidity levels may induce fruit weight loss, thereby reducing the pericarp firmness during the export period.

While the TA was not greatly influenced by the export season, the SSC outcome for the blocky type of paprika cultivar was clearly affected, in contrast to that of the conical types. That is, the SSC levels in the conical type of paprika cultivar did not respond differently to the export season. Regardless of the export season, both the SSC and TA levels were greatly affected depending on the cultivar type at harvest (Lang et al., 2020). During cold storage, the SSC level of all cultivars was not strongly affected (Lim et al., 2008b). However, the contents of individual soluble carbohydrates, specifically fructose, glucose, and sucrose, were higher in the conical type than in the blocky type of paprika cultivar (Kye et al., 2022). In this study, the SSC level was typically higher in the conical type than in the blocky type of paprika cultivar, irrespective of the pericarp color or export season. Nonetheless, the SSC level was highly influenced by the harvest season (Penchaiya et al., 2009). As shown in Fig. 3, the SSC level was clearly lower in the summer season than in the winter season, regardless of the cultivar. That is, the SSC levels in the blocky type of paprika cultivar would be greatly affected by seasonal factors. However, the SSC level was higher in the 'Raon red' cultivar than in the 'Raon yellow' cultivar, both of which are conical types of paprika cultivars, irrespective of the export season. The contents of soluble carbohydrates differed considerably depending on the pericarp color for the conical type of paprika cultivar at harvest (Kye et al., 2022). Therefore, the results suggest that the SSC and TA levels would not be affected by the export period, although they would be highly influenced by the export season and cultivar (or pericarp color).

Among the physiological responses of the pericarp color variables, pericarp L^* did not differ during the simulated export period in the winter season, although there were major variations among the cultivars and fruit types. However, in the summer season, pericarp L^* increased gradually, irrespective of the cultivar or fruit type. Pericarp C^* also responded similarly to the export season. During cold storage, the pericarp color variables of green paprika fruit fluctuate (Cuadra-Crespo and del Amor, 2010), although they gradually decrease in the case of cold-stored paprika (Singh et al., 2014; Taheri et al., 2020). Even during the shelf life period, the pericarp L^* and h^o values of yellow paprika cultivars do not differ much (Frans et al., 2021). The phenotypic responses of pericarp color variables are greatly affected by the storage humidity in cold-stored green paprika (Nunes et al., 2012). Here, the storage humidity results during simulated export showed that the pericarp color responses could be influenced by the export season. Nonetheless, the results of the correlation coefficient network and the phenotypic responses of the pericarp color variables did not vary much between different export seasons, although the pericarp color variables were greatly affected by the fruit type. When the relative humidity was low, the surface area of the pericarp should also be lower in the conical type than in the blocky type of paprika cultivar. Thus, the pericarp color variables were lower in the blocky type than in the conical type during the simulated export period. The results of the correlation coefficient network were clearly different depending on the fruit type. Hence, the findings suggest that the pericarp color is affected by the storage humidity, although it reacts differently depending on the fruit type of paprika cultivar during the simulated export period.

The incidence and severity of fruit shriveling were higher in the winter season than in the summer season. These results could be strongly associated with the lower relative humidity during the simulated export period in the winter season. In fact, it is the rainy (or monsoon) season at the end of June in Korea. Consequently, the storage humidity level remained relatively high in the summer season compared to the winter season, irrespective of the fruit type or cultivar. Thus, it is assumed that the climatic difference would affect the incidence and severity of physiological disorders, specifically fruit shriveling. At the same time, the incidence and severity of fruit softening were also higher in the winter season than in the summer season, irrespective of the fruit type or cultivar. Nevertheless, the results of the correlation coefficient network on the relationship between the fruit weight loss and physiological disorders did not differ between the export seasons or between the fruit types. Thus, the incidence and severity of fruit shriveling and softening could be strongly associated with fruit weight loss, regardless of the export season or fruit type. The incidence rate of fruit shriveling in the red paprika fruit is highest during the retail display period, compared to that observed throughout the simulated postharvest chain system (Fernández-Trujillo et al., 2009). Even when the shelf life period is extended, the severity of fruit shriveling in both red and yellow paprika cultivars increases sharply immediately after a shelf life period of one week (Lwin et al., 2022). The severity of fruit shriveling and softening in the red paprika fruit increase gradually during cold storage (Rodoni et al., 2012) and is further aggravated during supply chain and home storage periods (Owoyemi et al., 2021). Thus, lower storage humidity caused a deficit in the vapor pressure, inducing fruit weight loss and reducing the pericarp firmness. This can aggravate the incidence and severity of physiological disorders, including fruit shriveling, fruit softening, and pericarp pitting (Dijkink et al., 2004). Therefore, it is important to control the relative humidity to maintain the quality of the fruit during the entire export period, irrespective of the fruit type and/or cultivar.

Along with the incidence and severity of physiological disorders in pericarp tissues, the pedicel could be highly susceptible to wilting, browning, and rotting (or decay). Although we did not evaluate pedicel rot, pedicel wilting and browning were detected, and they tended to worsen when extending the export period, irrespective of the fruit type or cultivar. Similar to the severity of fruit shriveling and softening, the severity of pedicel wilting and browning was much higher in the winter season than in the summer season. The incidence and severity of pedicel browning tend to worsen during the shelf life after cold storage periods (Kong et al., 2020). As indicated in Fig. 6, the severity of pedicel browning and wilting in both types of paprika cultivar in the winter season was also positively correlated with the fruit weight loss. Thus, proper management of the storage humidity is a key step toward ideal maintenance of the fruit quality, as this strategy reduces the incidence of physiological disorders during the export period. Therefore, along with controlling various fruit quality attributes, the incidence and severity of pedicel browning and wilting should be controlled by maintaining the storage humidity at high levels.

Hence, managing the relative humidity is critical for maintaining fruit quality levels during export; thus, fruit weight losses are greater in the winter season than in the summer season due to the lower relative humidity. Pericarp firmness is also lower in the winter season than in the summer season, while SSC and TA are greatly affected by the harvest season and cultivar rather than by the export period. In conclusion, it was confirmed that the degree to which seasonal differences affecting the fruit quality during the simulated export period was determined by the storage humidity. Therefore, it is necessary to consider reductions in the incidence and severity of physiological disorders so as to improve the fruit quality during the export period by appropriately managing storage humidity levels according to the season.

Literature Cited

Baek S, Shin Y (2020) Physicochemical qualities, antioxidant compounds, and activities of six mini paprika cultivars. Kor J Food Sci Technol 52:377-384. doi:10.9721/KJFST.2020.52.4.377

Basu S, Duren W, Evans CR, Burant CF, Michailidis G, Karnovsky A (2017) Sparse network modeling and metscape-based visualization methods for the analysis of large-scale metabolomics data. Bioinformatics 33:1545-1553. doi:10.1093/bioinformatics/btx012

Byeon SE, Lee J (2020) Differential responses of fruit quality and major targeted metabolites in three different cultivars of cold-stored figs (*Ficus carica* L.). Sci Hortic 260:108877. doi:10.1016/j.scienta.2019.108877

Byeon SE, Park GH, Lee J, Lwin HP, Su'udi M, Kim J, Lee J (2022) Alteration of fruit quality attributes and cell wall-degrading enzymatic activities in cluster tomatoes after combination treatment with 1-methylcyclopropene and modified atmosphere packaging during cold storage. Hortic Sci Technol 40:307-323. doi:10.7235/HORT.20220029

Choi IL, Yoo TJ, Kang HM (2015) UV-C treatments enhance antioxidant activity, retain quality and microbial safety of fresh-cut paprika in MA storage. Hortic Environ Biotechnol 56:324-329. doi:10.1007/s13580-015-0141-y

Cuadra-Crespo P, del Amor FM (2010) Effects of postharvest treatments on fruit quality of sweet pepper at low temperature. J Sci Food Agric 90:2716-2722. doi:10.1002/jsfa.4147

Díaz-Pérez JC, Muy-Rangel MD, Mascorro AG (2007) Fruit size and stage of ripeness affect postharvest water loss in bell pepper fruit (*Capsicum annuum* L.). J Sci Food Agric 87:68-73. doi:10.1002/jsfa.2672

Dijkink BH, Tomassen MM, Willemsen JHA, van Doorn WG (2004) Humidity control during bell pepper storage, using a hollow fiber membrane contactor system. Postharvest Biol Technol 32:311-320. doi:10.1016/j.postharvbio.2003.12.002

Fernández-Trujillo JP, Serrano JM, Martínez JA (2009) Quality of red sweet pepper fruit treated with 1-MCP during a simulated post-harvest handling chain. Food Sci Technol Int 15:23-30. doi:10.1177/1082013208100464

Fox AJ, Pozo-Insfran DD, Lee JH, Sargent SA, Talcott ST (2005) Ripening-induced chemical and antioxidant changes in bell peppers as affected by harvest maturity and postharvest ethylene exposure. HortScience 40:732-736. doi:10.21273/HORTSCI.40.3.732

Frank CA, Nelson RG, Simonne EH, Behe BK, Simonne AH (2001) Consumer preferences for color, price, and vitamin C content of bell peppers. HortScience 36:795-800. doi:10.21273/HORTSCI.36.4.795

Frans M, Aerts R, Ceusters N, Luca S, Ceusters J (2021) Possibilities of modified atmosphere packaging to prevent the occurrence of internal fruit rot in bell pepper fruit (*Capsicum annuum*) caused by *Fusarium* spp. Postharvest Biol Technol 178:111545. doi:10.1016/j.postharvbio.2021.111545

Kasampalis DS, Tsouvaltzis P, Ntouros K, Gertsis A, Gitas I, Moshou D, Siomos AS (2022) Nutritional composition changes in bell pepper as affected by the ripening stage of fruits at harvest or postharvest storage and assessed non-destructively. J Sci Food Agric 102:445-454. doi:10.1002/jsfa.11375

Kim JS, An CG, Park JS, Lim YP, Kim S (2016) Carotenoid profiling from 27 types of paprika (*Capsicum annuum* L.) with different colors, shapes, and cultivation methods. Food Chem 201:64-71. doi:10.1016/j.foodchem.2016.01.041

Kong XM, Ge WY, Wei BD, Zhou Q, Zhou X, Zhao YB, Ji SJ (2020) Melatonin ameliorates chilling injury in green bell peppers during storage by regulating membrane lipid metabolism and antioxidant capacity. Postharvest Biol Technol 170:111315. doi:10.1016/j.postharvbio.2020.111315

Kye Y, Kim J, Hwang KT, Kim S (2022) Comparative phytochemical profiling of paprika (*Capsicum annuum* L.) with different fruit shapes and colors. Hortic Environ Biotechnol 63:571-580. doi:10.1007/s13580-022-00420-y

Lang KM, Nair A, Moore KJ (2020) Cultivar selection and placement of shadecloth on midwest high tunnels affects colored bell pepper yield, fruit quality, and plant growth. HortScience 55:550-559. doi:10.21273/HORTSCI14714-19

Latt TT, Lwin HP, Seo HJ, Lee J (2023) 1-Methylcyclopropene delays degradation of peel greenness but induces internal physiological disorders in cold-stored fruit of interspecific pears. Sci Hortic 312:111852. doi:10.1016/j.scienta.2023.111852

Lee C, Lee J, Lee J (2022a) Relationship of fruit color and anthocyanin content with related gene expression differ in strawberry cultivars during shelf life. Sci Hortic 301:111109. doi:10.1016/j.scienta.2022.111109

Lee J, Mattheis JP, Rudell DR (2013) Fruit size affects physiological attributes and storage disorders in cold-stored 'Royal Gala' apples. HortScience 48:1518-1524. doi:10.21273/HORTSCI.48.12.1518

Lee J, Mattheis JP, Rudell DR (2019) High storage humidity affects fruit quality attributes and incidence of fruit cracking in cold-stored 'Royal Gala' apples. HortScience 54:149-154. doi:10.21273/HORTSCI13406-18

Lee J, Park GH, Na MH, Cho K, Na H (2022b) Effects of the application times and strength of additional fertilizers on onion bulb quality parameters at harvest and during storage. Hortic Sci Technol 40:134-146. doi:10.7235/HORT.20220013

Lim CS, Kang SM, Cho JL, An CG, Oh JY, Hwang HJ (2008a) Quality of bell pepper (*Capsicum annuum* L.) as affected by cultivar and storage period. Acta Hortic 768:533-537. doi:10.17660/ActaHortic.2008.768.71

Lim CS, Kang SM, Cho JL, Gross KC, Woolf AB (2007) Bell pepper (*Capsicum annuum* L.) fruits are susceptible to chilling injury at the breaker stage of ripeness. HortScience 42:1659-1664. doi:10.21273/HORTSCI.42.7.1659

Lim CS, Lim JM, Kim BS, Kang SM, Cho JL, Hwang HJ (2008b) Changes in fruit quality of paprika and color pimento (*Capsicum annuum* L.) stored at low temperatures. Acta Hortic 768:539-544. doi:10.17660/ActaHortic.2008.768.72

Liu L, Wei Y, Shi F, Liu C, Liu X, Ji S (2015) Intermittent warming improves postharvest quality of bell peppers and reduces chilling injury. Postharvest Biol Technol 101:18-25. doi:10.1016/j.postharvbio.2014.11.006

Luitel BP, Kang WH (2013) Assessment of fruit quality variation in doubled haploids of minipaprika (*Capsicum annuum* L.). Hortic Environ Biotechnol 54:257-265. doi:10.1007/s13580-013-0112-0

Lwin HP, Lee J (2022) Differential effects of postharvest 1-MCP treatment on fruit quality and targeted major metabolites in long-term cold-stored 'Wonhwang' pears. Hortic Environ Biotechnol 63:499-513. doi:10.1007/s13580-021-00412-4

Lwin HP, Lee J, Lee J (2022) Perforated modified atmosphere packaging differentially affects the fruit quality attributes and targeted major metabolites in bell pepper cultivars stored at ambient temperature. Sci Hortic 301:111131. doi:10.1016/j.scienta.2022.111131

Manolopoulou H, Xanthopoulos G, Douros N, Lambrinos G (2010) Modified atmosphere packaging storage of green bell peppers: Quality criteria. Biosyst Eng 106:535-543. doi:10.1016/j.biosystemseng.2010.06.003

McGuire RG (1992) Reporting of objective color measurements. HortScience 27:1254-1255. doi:10.21273/HORTSCI.27.12.1254

Mohi-Alden K, Omid M, Soltani Firouz M, Nasiri A (2022) Design and evaluation of an intelligent sorting system for bell pepper using deep convolutional neural networks. J Food Sci 87:289-301. doi:10.1111/1750-3841.15995

Nunes MCN, Delgado A, Emond JP (2012) Quality curves for green bell pepper (*Capsicum annuum* L.) stored at low and recommended relative humidity levels. Acta Hortic 945:71-78. doi:10.17660/ActaHortic.2012.945.8

Owoyemi A, Rodov V, Porat R (2021) Retaining red bell pepper quality by perforated compostable packaging. Food Sci Nutr 9:3683-3692. doi:10.1002/fsn3.2329

Penchaiya P, Bobelyn E, Verlinden BE, Nicolaï BM, Saeys W (2009) Non-destructive measurement of firmness and soluble solids content in bell pepper using NIR spectroscopy. J Food Eng 94:267-273. doi:10.1016/j.jfoodeng.2009.03.018

Rodoni LM, Concellón A, Chaves AR, Vicente AR (2012) Use of UV-C treatments to maintain quality and extend the shelf life of green fresh-cut bell pepper (*Capsicum annuum* L.). J Food Sci 77:C632-C639. doi:10.1111/j.1750-3841.2012.02746.x

Rural Development Administration (RDA) (2023) Guideline of agricultural technology for paprika. Accessed on April 11, 2023. https://www.nongsaro.go.kr/portal/ps/psb/psbl/workScheduleDtl.ps?menuId=PS00087&cntntsNo=30649&sKidofcomdtySeCode=210001&totalSearchYn=Y

Seo HJ, Wang YS, Lwin HP, Choi JH, Chun JP, Roan SF, Chen IZ, Lee J (2019) Early season 'Wonhwang' pear fruit quality following international transport and storage is negatively impacted by fruitlet stage gibberellic acid$_{4+7}$ (GA_{4+7}) application but improved by postharvest 1-methylcyclopropene (1-MCP). Sci Hortic 256:108549. doi:10.1016/j.scienta.2019.108549

Singh R, Giri SK, Kotwaliwale N (2014) Shelf-life enhancement of green bell pepper (*Capsicum annuum* L.) under active modified atmosphere storage. Food Packag Shelf Life 1:101-112. doi:10.1016/j.fpsl.2014.03.001

Smith DL, Stommel JR, Fung RWM, Wang CY, Whitaker BD (2006) Influence of cultivar and harvest method on postharvest storage quality of pepper (*Capsicum annuum* L.) fruit. Postharvest Biol Technol 42:243-247. doi:10.1016/j.postharvbio.2006.06.013

Taheri A, Behnamian M, Dezhsetan S, Karimirad R (2020) Shelf life extension of bell pepper by application of chitosan nanoparticles containing *Heracleum persicum* fruit essential oil. Postharvest Biol Technol 170:111313. doi:10.1016/j.postharvbio.2020.111313