Impacts of different growing media on the quality traits and phytochemical compounds of tomato throughout cold storage

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Abstract

Purpose and Methods;

The main aim of the study was to assess the effects of different growing media [tomato stalk waste (TSW) and pre-treated tomato stalk waste (PTSW)] prepared from tomato waste developed as an alternative to commercial growing media (cocopeat and peat + perlite) used in soilless culture on quality traits and phytochemical compounds of tomato fruit (*Solanum lycopersicum* L. cv. 'Bandita F1') during cold storage. The fruit was stored at 8 ± 0.5°C and 90 ± 5% relative humidity (R.H.) for 14 d.

Results;

During cold storage, the lowest weight loss was detected in TSW, the lowest respiration rate in peat + perlite treatment. The firmness of tomato fruit grown in cocopeat and PTSW media was higher than that of peat + perlite and TSW. At harvest and day 7, a* value (redness) of peat + perlite and PTSW treatments were higher than the TSW treatment. In all measurement periods, TSW treatment had higher soluble solids, titratable acidity and vitamin C content than peat + perlite treatment. Total phenolics, flavonoids and antioxidant activity were higher in TSW, PTSW and peat + perlite treatments than in cocopeat.

Conclusions;

As a result, it can be stated that TSW and PTSW media can be used as a growing medium to delay weight loss and maintain the quality of tomato fruit during cold storage.

1. Introduction

Due to the substances they contain, almost all vegetables have protective and therapeutic effects on human health. Tomato is one of these vegetables. Tomato fruit is a rich source of lycopene, beta carotene, flavonoids, vitamins, organic acids, essential amino acids and dietary fiber. It is also the source of vitamin A, vitamin C and potassium minerals and contains iron and phosphorus. Tomatoes are low in calories and fat and are a good source of cholesterol-free dietary fiber (Kabelka and Yang, 2004; Minoia et al., 2010). It has gained tremendous popularity, primarily due to the antioxidant activities and anticancer functions of the phenolic compounds it contains (Raiola, 2014; Seçgin, 2018).

Many factors affect the nutritional value and quality of tomatoes. These factors include genetics, environment (light, temperature, humidity), irrigation, fertilization, growing environment and production systems. Soilless culture greenhouse enterprises, where the climatic factors and plant nutrients required for cultivation can be instantly controlled and directed within the production systems, have become very common in commercial cultivation in Türkiye due to their superior product quality and high yield values (Yörük, 2021). Today, the soilless culture area in Türkiye has reached 13.134 decares (ÖKS, 2019). Organic, inorganic and synthetic growing media are used in soilless cultivation (Leonardi, 2004). Reasons such as the consumption of peat resources in the world and Türkiye, the decrease in perlite reserves, and the waste problem of rock wool have increased the interest in materials that can be found quickly and cheaply, suitable for soilless agriculture from local sources (Frolking, 2001).

In the world, the amount of vegetable harvest and agricultural industry waste increases yearly. Wastes of plant origin; In addition to being a serious source of organic matter, they also have significant potential in terms of plant nutrients they contain. Today, suitable mixtures can be obtained from these wastes and used as a plant-growing medium (Çıtak, 2007). It is reported that the waste materials (plant pruning wastes and all plant organs) formed at the end of plant production in tomatoes are 175 tons/ha annually (Demirtaş et al., 2013). Recycling these wastes is of great importance. Tomato waste is suitable for use as a growing medium in soilless agriculture in terms of its structure and nutrients.

Sustainable agriculture is possible with the efficient use and protection of natural resources. Composting is one of the most successful methods for reintroducing organic waste into the natural cycle. Vegetable wastes have a good organic matter content, but they also have a significant potential in plant nutrients (Çerçioğlu, 2019).

Many factors, including variety, irrigation, pruning, maturity stage, fertilization and growing media, affect the quality of tomato fruit (Hanna, 2009; Arah et al., 2015). Hanna (2009) reported that tomato fruit grown in pine bark medium have higher quality than those grown in perlite medium. However, the number of studies comparing the postharvest fruit quality changes of tomato fruit grown in soilless culture in different growing media is minimal.

The main objective of the study was to assess the effects of different growing media [tomato stem waste (TSW) and pre-treated tomato stem waste (PTSW)] on the quality properties and bioactive compounds of tomato fruit during cold storage.

2. Materials and methods

2.1 Experimental site and plant material

This study was carried out at Ondokuz Mayıs University, Faculty of Agriculture, Department of Horticulture, in 2019. The breeding was conducted in the greenhouse site (glass greenhouse; 4 x 8.8 m). 'Bandita' tomato cultivar (*Solanum lycopersicum* L.), suitable for soilless cultivation, was selected as plant material in the study.

2.2. Design of greenhouse study

In the study, four different growing media were used. Two different growing media (TSW, tomato stalk waste and PTSW; pre-treated tomato stalk waste) were obtained from tomato wastes. In addition, growing bags consisting of cocopeat and peat + perlite (65%+ 35%) were used as commercial growing media for the control treatment.

Tomato wastes used in cultivation are prepared from the end-harvest fresh tomato wastes grown in greenhouses. First, the grinding process was carried out to prepare tomato waste and pre-treated tomato waste media. Grinding fines of tomato waste to be used in the study were performed as described by Bilgin et al. (2016). For this purpose, an 8 mm sieve diameter was used to grind tomato wastes. A hammer-type mill with 8 blades with fixed blades, 3 kW and 2850 d/d rotating speed was used to carry out the grinding process. Physical analyses (organic matter, volume weight, and water holding capacity) and chemical analyses (E.C. and pH) of growing media were detected as stated by researchers (Gülser and Pekşen 2003; Kacar and Inal 2008), and results were shown in Table 1.

Table 1
Physical properties of growing media

Growing media	**pH**	**E.C. (ms cm^{-1})**	**Organic matter (%)**	**Water hold capacity (kg)**	**C/N (%)**	**Volume weight (g/cm^3)**
TSW	6.6	0.9 a*	71.3 b	6.3 c	27.49 a	0.12 b
PTSW	5.7	0.6 b	63.6 b	4.6 c	16.95 b	0.27 a
Peat + Perlite	5.8	0.5 b	46.9 c	13.2 b	22.37 b	0.34 a
Cocopeat	6.2	0.5 b	99.0 a*	43 a*	32.19 a*	0.08 b

*: $p < 0.05$. TSW: Tomato stalk waste, PTSW: pre-treated tomato stalk waste

To be used directly, tomato stalk waste (TSW) has been disinfected with formaldehyde. The disinfection was done by spraying the solution with a mixture of formaldehyde (540 mL) and water (20 L) on the waste with a sprayer. This process was repeated four days later. Tomato waste (TSW, 21 L/bag) was bagged three days after spraying. The dry weight of tomato wastes was 91.3 g m^{-1} (leaf and stem), and the dry weight of a growing bag was determined as 25.2 kg.

Pre-treated tomato stalk waste; tomato waste was determined by considering the C:N ratio (Table 1). Accordingly, 210 L of tomato waste was wetted with a solution (100 L) obtained from a mixture of urea (1 kg), farmyard manure (3 kg), granulated sugar (1 kg) and forest soil (5 kg). A pile was then formed and covered with transparent nylon. The pile was regularly temperature controlled to complete the semi-composting process. The temperature, which was 12.1 ^{o}C when the heap formed, reached its highest level in two months, reaching 62.6 ^{o}C. Then the compost entered the cooling stage, the temperature dropped to 11.1°C and the process was completed. Then, pre-treated tomato waste (PTSW) was bagged into growing bags (21 L/bag).

The TSW, PTSW, peat + perlite and cocopeat were prepared by opening drainage and ventilation holes in the growing bags. The prepared growing media bags were placed in the greenhouse in 5.5 m long, 25 cm wide, and 1.5% inclined channels. Macro and micronutrients used in fertilization were prepared as stock solutions in 2 tanks containing 300 liters (Table 2). Fertilization was performed five times a day at 20 min intervals throughout development.

Table 2
Macro and micronutrient solutions and ratios to be applied in soilless culture (Hoagland ve Arnon, 1938; Day, 1991)

	Elements	**mg/l**	**Chemicals used**	
Stock (A)	N	210 (240)*	Ammonium nitrate	NH_4NO_3 (%33)
	K	250 (300)*	Potassium nitrate	KNO_3 (%13 N, %46 K)
	Ca	150**	Calcium nitrate	$5Ca(NO_3)_2.NH_4NO_3.10H_2O$ (%15.5 N, %19 Ca)
	Fe	2	Iron chelate	Na_2.Fe-EDTA (%12.5 Fe)
Stock (B)	P	40	Phosphoric acid	H_3PO_4 (%85)
	Mg	50	Magnesium sulfate	$MgSO_4.7H_2O$ (%10Mg)
	Zn	0.50	Zinc sulfate	$ZnSO_4.7H_2O$
	Mn	0.75	Manganese sulfate	$MnSO_4.H_2O$
	B	0.4	Boric acid	H_3BO_3
	Cu	0.10	Copper sulfate	$CuSO_4.5H_2O$
	Mo	0.05	Ammonium molybdate	$(NH_4)6Mo_7O_{24}.4H_2O$

*Doses in parentheses will be applied after the 3. batch. **Considering the amount of irrigation water, these rates can be revised again.

The Bandita tomato variety seedlings were planted (60 x 30 cm in a row) in growing bags. After planting, drip irrigation pipes were fixed on the surface of the bags, and then the plants were given 200 ml of life water per plant. On the planting day, only life water was given to the plants and nutrient solution was started to be given from the next day of planting. Pruning was carried out to remove the yellowed and diseased leaves with the shoots emerging from the leaf axils, widely used in tomato cultivation. It has been applied in other maintenance, spraying and cultural processes necessary during the growing period.

2.3. Design of the postharvest study

The tomato fruit was hand-harvested at the pink stage of maturity (30–60% of the surface is pink or red-colored fruit) according to USDA (1991) standards. Enough fruit was collected for each treatment (cocopeat, peat + perlite, TSW and PTSW) and placed in plastic boxes. The fruit was transported to the laboratory with a refrigerated vehicle at 15 ± 2°C and 80 ± 5% relative humidity (R.H.).

Then, healthy, wound-free and disease-free fruit were selected. For each treatment, 6 plastic boxes containing approximately 2.5 kg of fruit (20–25) were created.

The fruit was stored in modified atmosphere packages [MAP, (StePac, Xtend, Israel)]. The MAP's water vapor and carbon dioxide (CO2) permeabilities were 150.0 g/m^2 day atm and 2203 cc/m^2 day atm, respectively. The fruit was pre-cooled with cold air until the flesh temperature dropped to 10°C. The fruit was kept at 8 ± 0.5°C and 90 ± 5% R.H. for 14 d. All fruits' quality analyses and measurements were performed on 7 d and 14 d. In each measurement period, 3 boxes in each treatment were used. Each box was assumed as a replication.

2.3.1. Weight loss

Fruit weight was measured with a digital scale (Radwag, Poland) at the beginning and end of different storage periods. Weight loss (%) was calculated as the difference between the initial and final weight at the end of the storage periods.

2.3.2. Respiration rate and firmness

The respiration rate was detected with a gas analyzer (Vernier, USA) as the quantity of CO_2 produced by the fruit. The results were stated as nanomoles (nmol) of CO_2 kg^{-1} s^{-1}. A digital portable durometer (Agrosta® 100 Field, France) with a 10 mm plunger tip was used for firmness. Ten fruit were used for firmness. Results were stated in Durofel units (%), in which 0 indicates that the fruit is too soft and 100 indicates that the fruit is too firm.

2.3.3. Color Characteristics

Fruit skin color was determined regarding CIE L*, a* and b*. The values of the color characteristics of the fruit were obtained by measuring both sides of the equatorial part of 10 fruit obtained from each application in each analysis period of cold storage using a colorimeter (Minolta, model CR-400, Tokyo, Japan).

2.3.4. Soluble solids content, titratable acidity, and vitamin C

Initially, fruit juice was extracted from 10 fruit (a slice of each fruit) for soluble solids content (SSC), titratable acidity, and vitamin C analyses. SSC was detected with a digital refractometer (Atago PAL-1, Japan) and stated as %. Titratable acidity was measured by titrating with 0.1 N sodium hydroxide to increase the solution pH (10 ml of extract diluted with 10 ml distilled water) to 8.2. Results were stated as g citric acid kg^{-1}. Vitamin C was detected according to the method described in the study of Ozer et al. (2022) and stated as mg kg^{-1}.

2.3.5. Total phenolics and total flavonoids, antioxidant activity

Fruit pulp was homogenized with a blender (Philips, Türkiye) and homogenizer (Scientific Inc., USA). Homogenized tomato samples were placed in 50 ml falcon tubes and stored at -20°C until bioactive analysis [total phenolic compounds, flavonoids and antioxidant activities (DPPH and FRAP)]. Then, frozen samples were dissolved at 21°C and 1.0 g of sample was taken, after that 10 ml methanol was added to each sample. Bioactive compounds such as total flavonoids, total phenolics and antioxidant activity were detected according to the methods described in the study of Ozturk et al. (2019) and read by UV-Vis spectrophotometer (Shimadzu, Japan). Total phenolics were stated in g gallic acid equivalent (GAE) kg^{-1} fresh weight (F.W.). Total flavonoids were stated in g quercetin equivalent (QE) kg^{-1} fw. The antioxidant activity of tomato fruit was detected in two different procedures of DPPH (2,2-diphenyl-1-picryl-hydrazyl-hydrate) and FRAP (Ferric Ions ($Fe + 3$) Reducing Antioxidant Power), the results were stated as mmol trolox equivalent (T.E.) kg^{-1} fw.

2.4. Statistical analysis of data

Standard distribution control of the data obtained in the study was made with the Kolmogorov-Smirnov test, and homogeneity control of variance was performed with the Levene test. After the variance analysis of the obtained data, the Tukey multiple comparison tests determined the significance level (5%) between the treatments. Statistical analyzes were performed in the SAS package program (SAS 9.1 version, USA).

3. Results

The weight loss of the treatments on days 7 and 14 differed significantly ($p < 0.05$). On 7 and 14 d, the lowest weight loss was detected in TSW. Conversely, the highest weight loss was measured in the cocopeat. Similar weight loss was obtained in peat + perlite and PTSW growing media. However, obtained values were lower than cocopeat but higher than TSW (Fig. 1).

At harvest and on day 7, higher respiration was measured from tomato fruit grown in a cocopeat growing medium than in other mediums. On day 14, significantly higher respiration in cocopeat, TSW and PTSW was measured than peat + perlite growing media. In all measurement periods, tomatoes grown on cocopeat and PTSW growing media were firmer than those grown on peat + perlite and TSW. However, the fruit firmness of all treatments at the end of storage was different from each other. The highest firmness (43.6%) was found in cocopeat, and the lowest (29.1%) in peat + perlite (Fig. 2).

The highest L* value was obtained in the cocopeat growing media at harvest. The a* and b* values of tomatoes grown in peat + perlite medium were significantly ($P < 0.05$) higher than those of TSW. On day 7, the L*, a* and b* values of TSW were lower than the other treatments. At the end of storage, tomatoes grown on cocopeat and peat + perlite media had a higher L* value and, on the contrary, lower a* value than TSW and PTSW growing media. While the highest b* value was obtained in peat + perlite, the lowest value was detected in TSW (Fig. 3).

In all measurement periods, higher SSC was obtained in tomato fruit grown in cocopeat, TSW and PTSW compared to peat + perlite. Similarly, at day 7, higher SSC was measured in TSW and PTSW compared to cocopeat. At the end of storage, higher SSC was detected in cocopeat and PTSW compared to other media. Regarding acidity, it was observed that cocopeat and PTSW had higher values than peat + perlite and TSW in all measurement periods. However, the vitamin C content of TSW was higher in all measurement periods compared to other applications (Fig. 4).

In all measurement periods, total phenolics and flavonoids of tomato fruit grown in peat + perlite, TSW and PTSW media were higher than those grown in cocopeat media. However, on the seventh day, the total phenolics of TSW were higher than the content of peat + perlite and PTSW (Fig. 5).

According to the DPPH, the highest antioxidant activity was measured in the PTSW and the lowest cocopeat in all measurement periods. Similar levels of antioxidant activity were measured in TSW and peat + perlite. These measured values were higher than for cocopeat but lower for PTSW. In FRAP, peat + perlite, TSW and PTSW's antioxidant activity was higher than cocopeat in all measurement periods. At the end of storage, the antioxidant activity of all treatments was different from each other. The highest value (35.8 mmol TE 100 g^{-1}) was measured in TSW, and the lowest value was measured in cocopeat (24.8 mmol TE 100 g^{-1}) (Fig. 6).

4. Discussion

Weight and other quality losses in tomato fruit cause producers to suffer economically and consumers to consume lower-quality fruit. Many factors (production system, agricultural techniques, fertilization, irrigation, etc.) before harvest, including the growing media, affect weight loss (Arah et al., 2015; Tilahun et al., 2018). Weight losses were detected in all growing media during storage. The 10% physiological loss (Getinet et al., 2008) required to cease the cold storage in growing media was not reached after 14 days of storage. In our study, shallow weight losses may have been detected because the tomato fruit was stored in modified atmosphere packaging (Sandhya, 2010; Ozer et al., 2022). However, significant differences were determined between the weight losses of the growing media. Significantly, weight losses were lower in TSW than in other settings. Tilahun et al. (2018) reported that the weight losses of tomatoes grown in soil and cocopeat differed. In parallel with our findings, Langenhoven (2004) observed that tomatoes grown in cocopeat media had higher weight losses than tomatoes grown in a pine sawdust medium.

Tomato fruit with soft firmness has a shorter shelf life. Therefore, consumers do not prefer fruits with low firmness in the market (Batu and Thompson, 1998). Our study determined the effect of growing media on fruit firmness. During the cold storage, higher firmness was recorded in tomatoes grown in cocopeat and

PTSW media compared to other media. Similarly, Tilahun et al. (2018) stated that tomatoes grown in cocopeat have higher firmness than those grown in soil. In our study, firmness losses occurred during 14 days of storage. However, the firmness of the fruit in all media, except peat + perlite, was at a marketable level. In the study, all treatments were treated with MAP during cold storage. Therefore, the respiration rate in fruit was suppressed. In all treatments, the respiration rate peaked on day 14. However, Lee et al. (2007) observed a reverse trend and found the highest respiration rate for Roma-type tomatoes at harvest. Our study measured higher respiration rates in tomatoes grown in cocopeat at harvest and day 7 compared to other applications. Similarly, Tilahun et al. (2018) reported that tomatoes grown in cocopeat had a higher respiration rate than those grown in soil.

Homogeneous coloration, assessed by flesh pigmentation and peel, is an important quality criterion for tomato fruit. Fruit with homogeneous skin colors influence consumer buying decisions (Brandt et al., 2006). In our study, growing media affected color values. The + a* value indicates red color development. It was observed that tomatoes grown in cocopeat media had a higher a* value. However, a* value of tomatoes grown in TSW media was lower than those grown in other media. In parallel with our findings, it has been reported in studies (Riaz et al., 2008; Tilahun et al., 2018; Mitsanis et al., 2021) that the growing media affects color development. In addition, the coloration of tomato fruit varies depending on many factors, such as cultivar, ecological and cultural factors, postharvest processes and storage conditions (Altun et al., 2012; Ozer et al., 2022).

Since soluble solids content (SSC) and acidity contributes significantly to the taste and flavor of tomato fruit and fruit with high SSC content are preferred by consumers (Osorio et al. 2014). The study observed that tomato fruit grown in TSW growing media had higher SSC content, titratable acidity and vitamin C than fruit grown in peat + perlite during cold storage. Similarly, researchers (Traka-Mavrona et al., 2001; Tilahun et al., 2018; Mitsanis et al., 2021) stated that SSC, vitamin C and acidity contents of tomato fruit differ depending on the growing media. On the contrary, Inden and Torres (2004) and Ghehsareh et al. (2011) found that the growing medium had no effect on tomatoes' SSC and vitamin C content. Also, many factors, including the cultivation method, harvest time, maturity stage, cultivars, and cultural practices, can affect the fruit quality of tomato fruit (Şen et al. 2004; Mitsanis et al., 2021; Tilahun et al., 2018; Ozer et al. 2022).

In recent years, consumers have preferred the fruit to be rich in bioactive compounds, visual quality, flavor and taste (Pobiega et al., 2020). Therefore, producers need to determine the effect of the growing media in which tomato fruit was grown on bioactive compounds. In the study, the effect of growing media on bioactive compounds was significant ($P < 0.05$). It was observed that tomato fruit grown in TSW media had higher content regarding total phenolics and total flavonoids during cold storage. Also, regarding antioxidant activity, the content of tomato fruit grown in PTSW media was higher. The bioactive content of tomato fruit grown in cocopeat media was revealed to have the lowest content. Mitsanis et al. (2021) showed the effect of growing media on total phenolics and antioxidant activity of tomato fruit, on the contrary, Tilahun et al. (2018) reported that they had no effect. In our study, the content of bioactive compounds may have been high because the media obtained from tomato wastes provided higher nutrient availability in the plant's root zone. This way, Massa et al. (2019) reported that high nutrient content in the root zone promoted the formation of higher bioactive content in tomato fruit.

Conclusions

In soilless agriculture, it is the right approach to choose a growing medium that provides the most suitable environment for plant growth and development and has the most negligible negative impact on the environment after use. Tomato wastes are industrial wastes that can be easily mixed into the soil after use. Also, tomato fruit grown in tomato waste has rich phytochemical content, which is the reason for the preference for consumers. As a result, it was revealed that growing media consisting of tomato wastes has great potential use in soilless agriculture.

Conclusions

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Declarations

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Authors contributions

Esin Yörük Planning, design of experiment in field

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Harun Ozer. Planning, design of experiment in field and writing of the manuscript.

Burhan Ozturk. Planning, design and data analysis of postharvest experiments, and writing of the manuscript.

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Figures

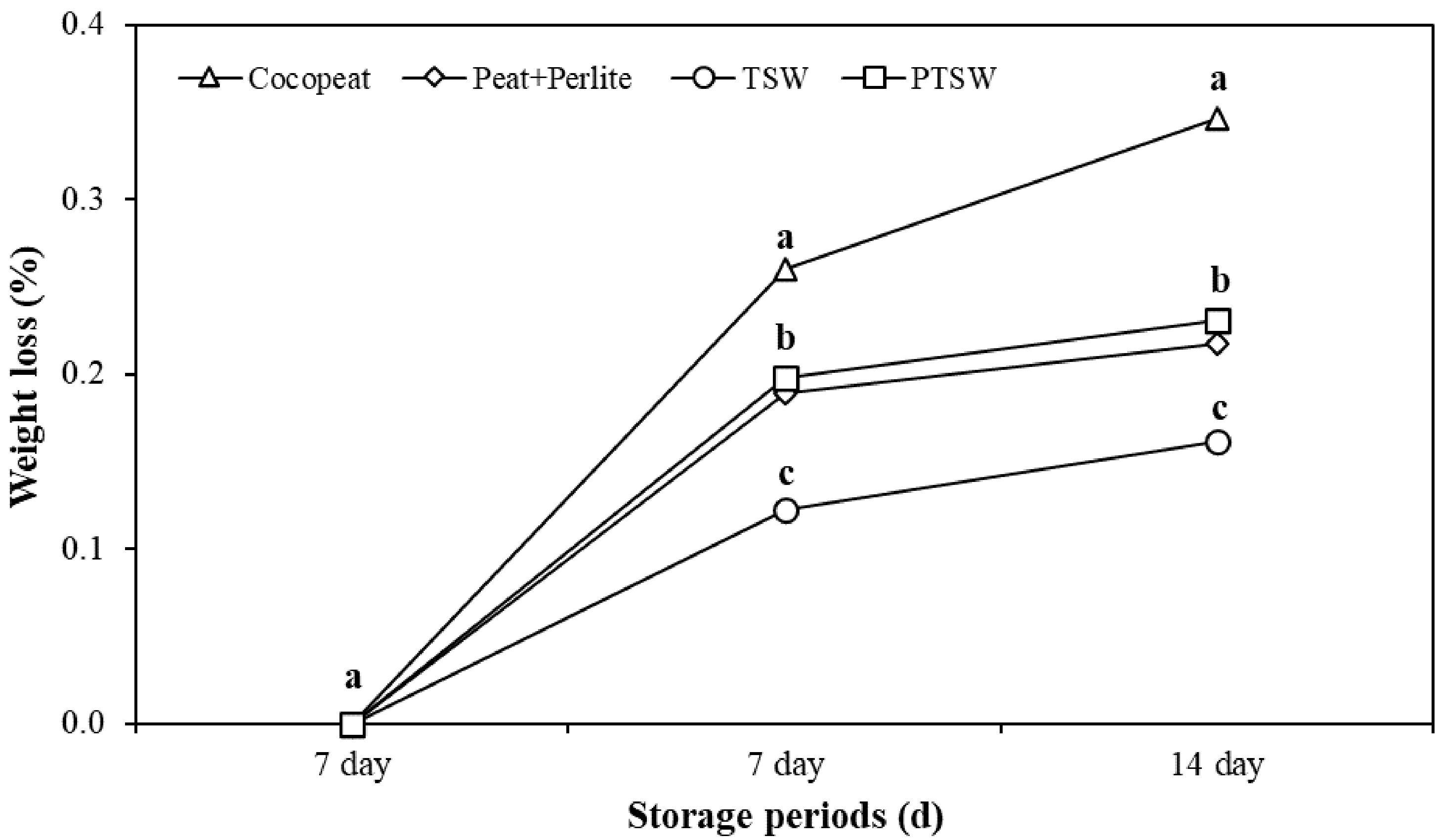


Figure 1

Effects of different growing conditions on weight loss of tomato fruit throughout cold storage. The mean shown with the same letter vertically did not differ according to Tukey's test at $p < 0.05$. $n = 9$ for weight loss (three replicates × three different measurements for each replicate).

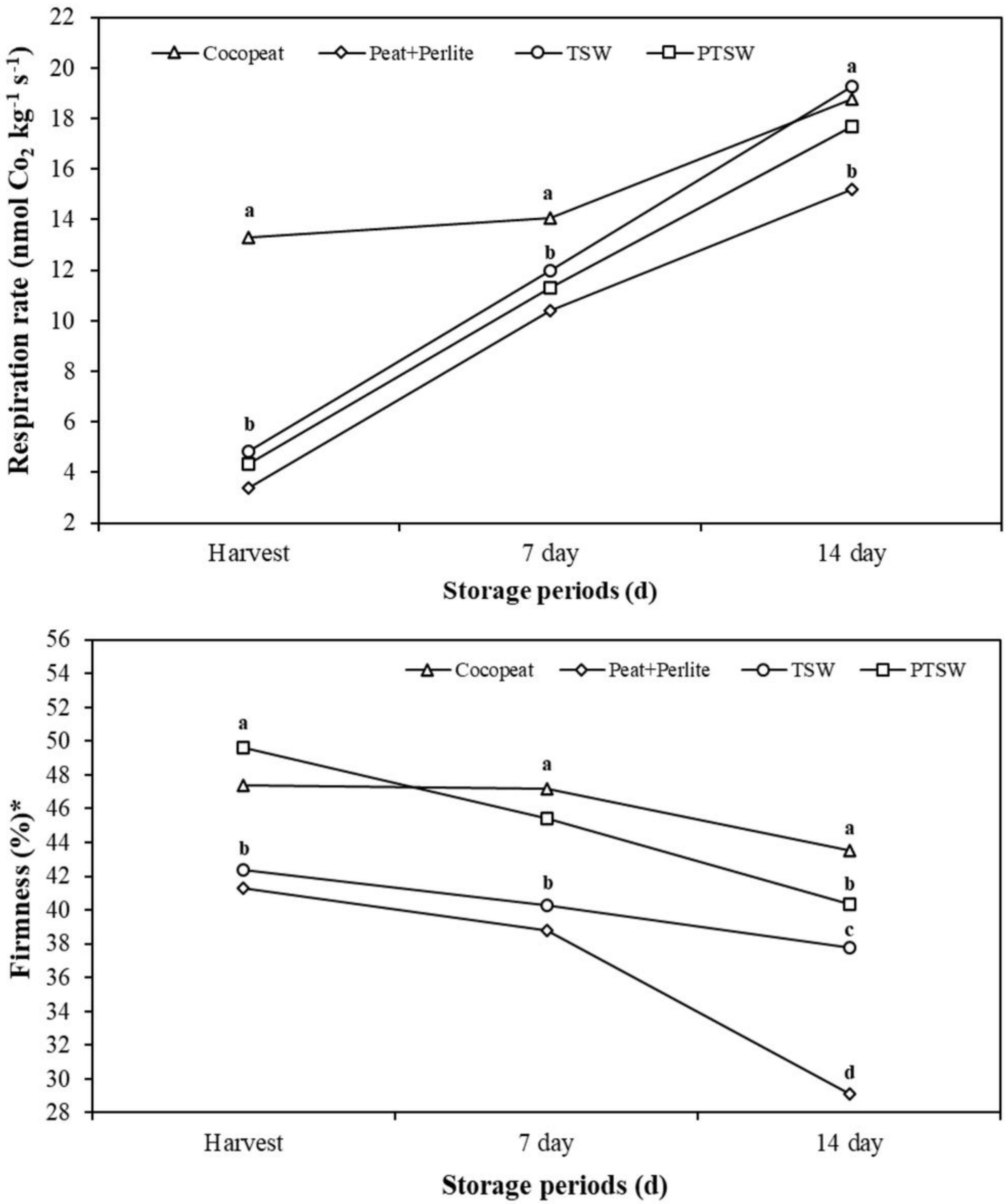


Figure 2

Effects of different growing conditions on respiration rate and firmness of tomato fruit throughout cold storage. The mean shown with the same letter vertically did not differ according to Tukey's test at $p < 0.05$. $n = 9$ for respiration rate (three replicates × three different measurements for each replicate). $n = 60$ for firmness (three replicates × ten fruit × two different measurements for each fruit). * 0 indicates that the fruit is too soft and 100 indicates that the fruit is too firm.

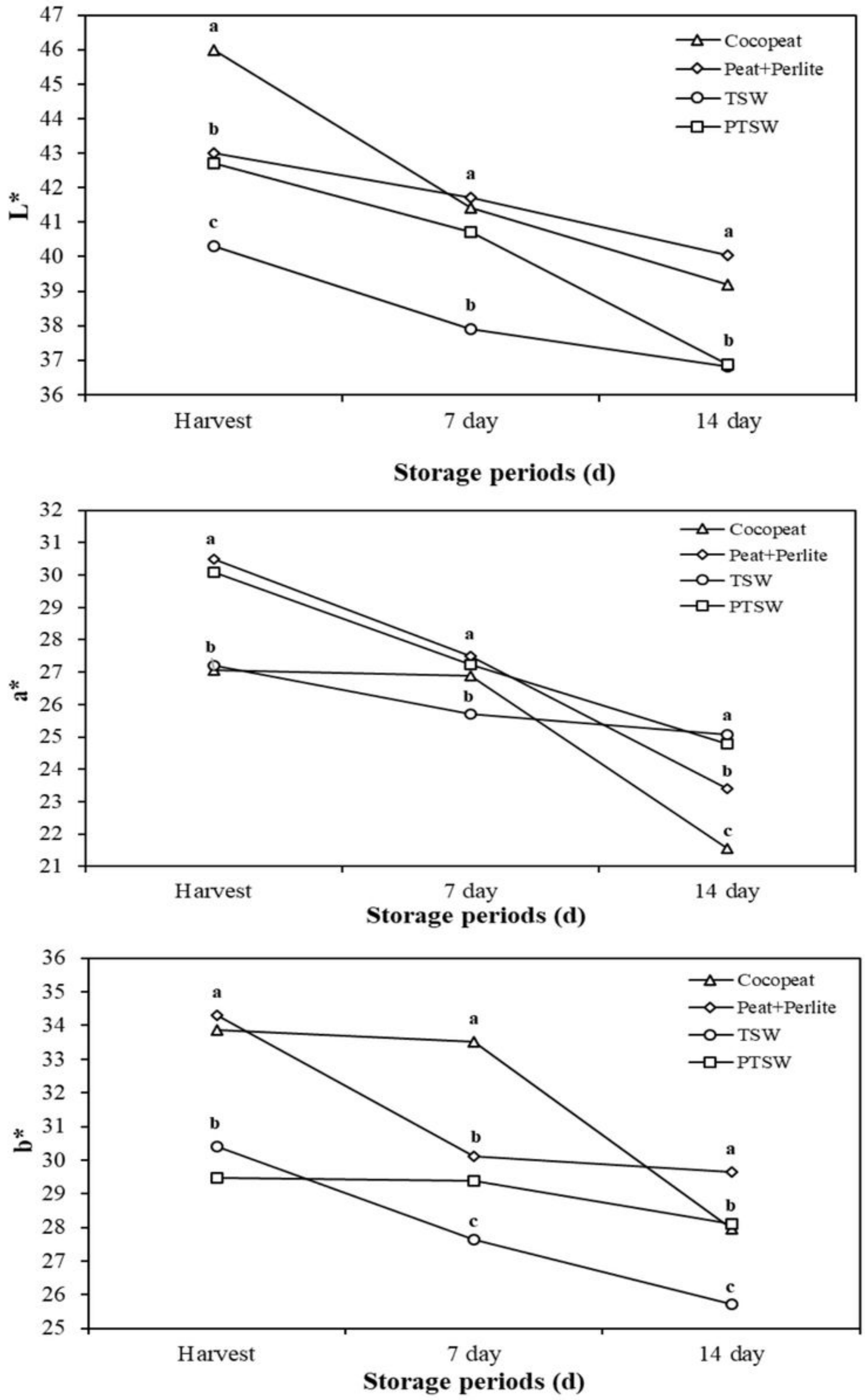


Figure 3

Effects of different growing conditions on color characteristics (L*, a* and b*) of tomato fruit throughout cold storage. The mean shown with the same letter vertically did not differ according to Tukey's test at $p < 0.05$. n = 60 for color characteristics (three replicates × ten fruit × two different measurements for each fruit).

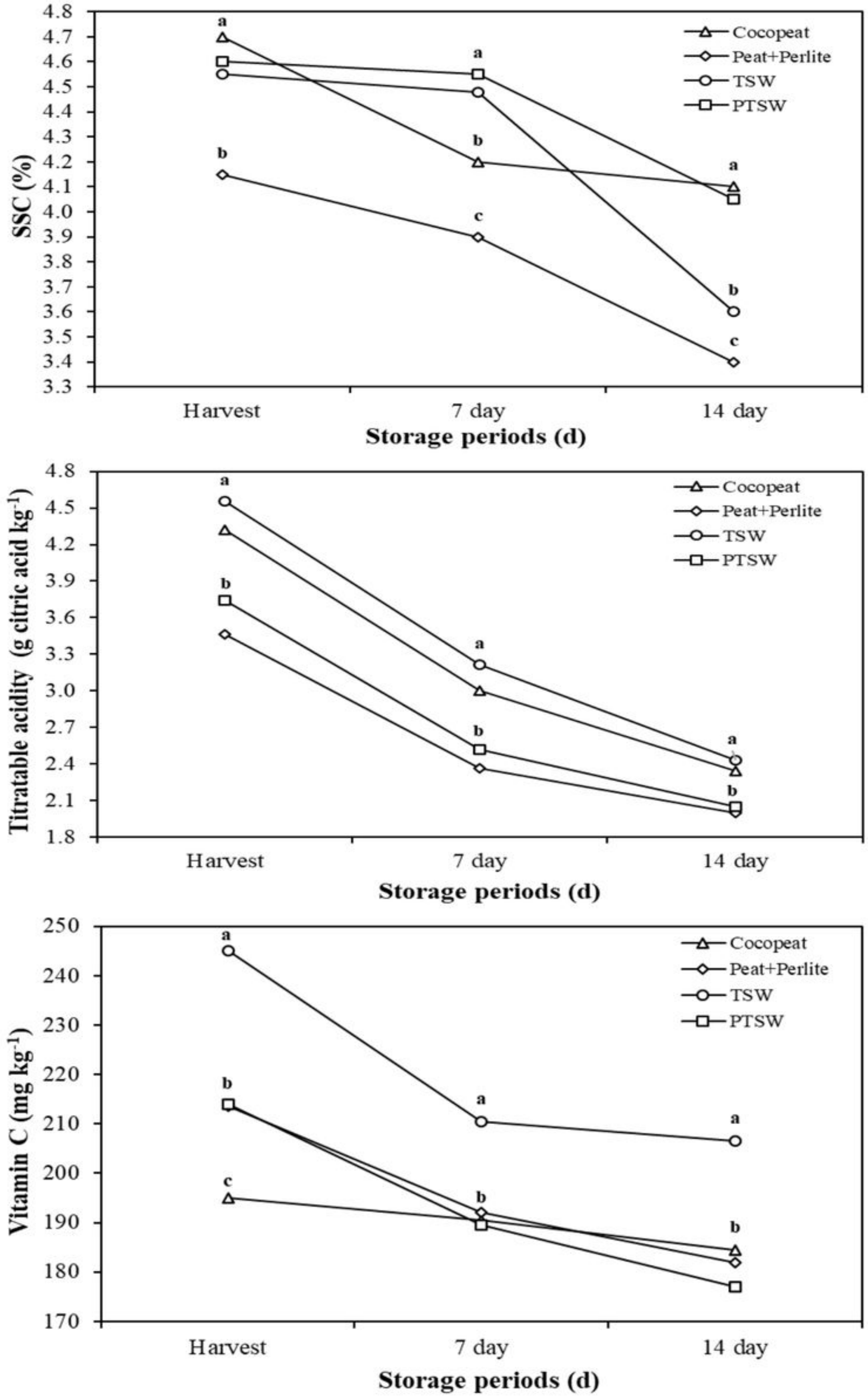
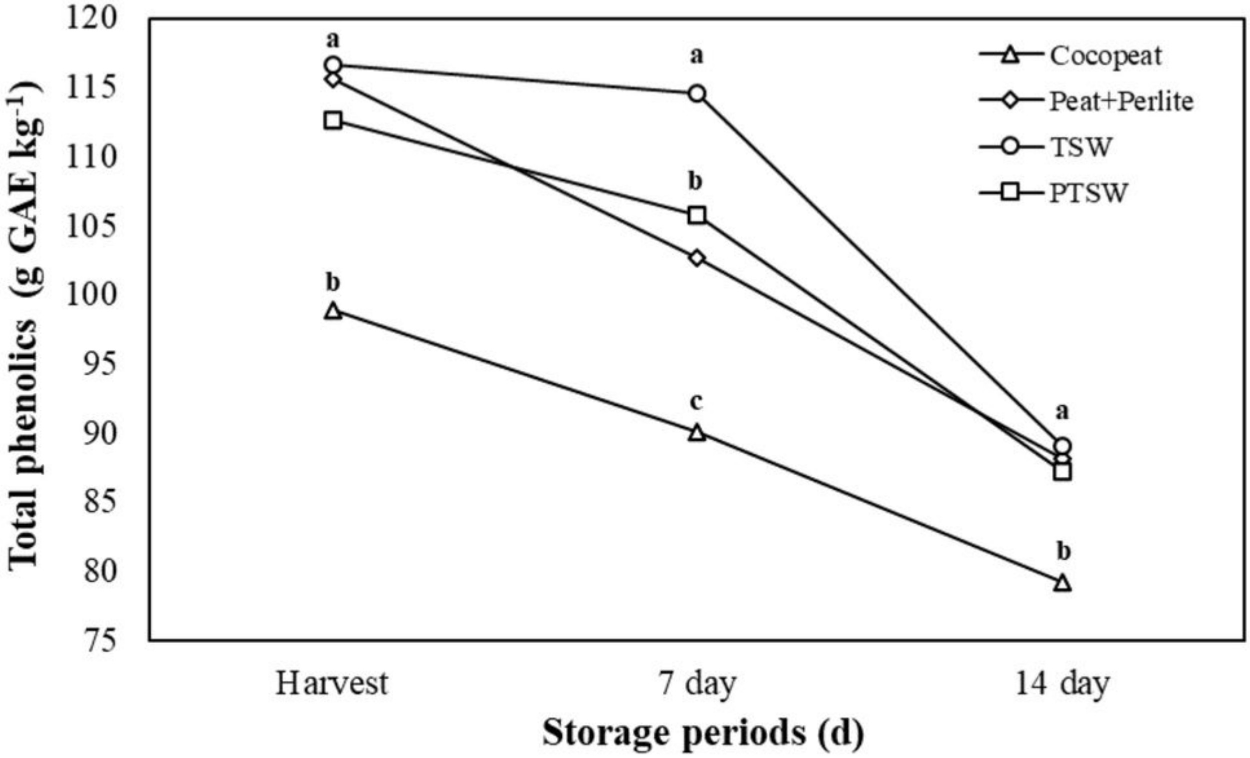


Figure 4

Effects of different growing conditions on SSC, titratable acidity and vitamin C of tomato fruit throughout cold storage. The mean shown with the same letter vertically did not differ according to Tukey's test at $p < 0.05$. n = 9 for SSC, acidity and vitamin C (three replicates × three different measurements for each replicate).



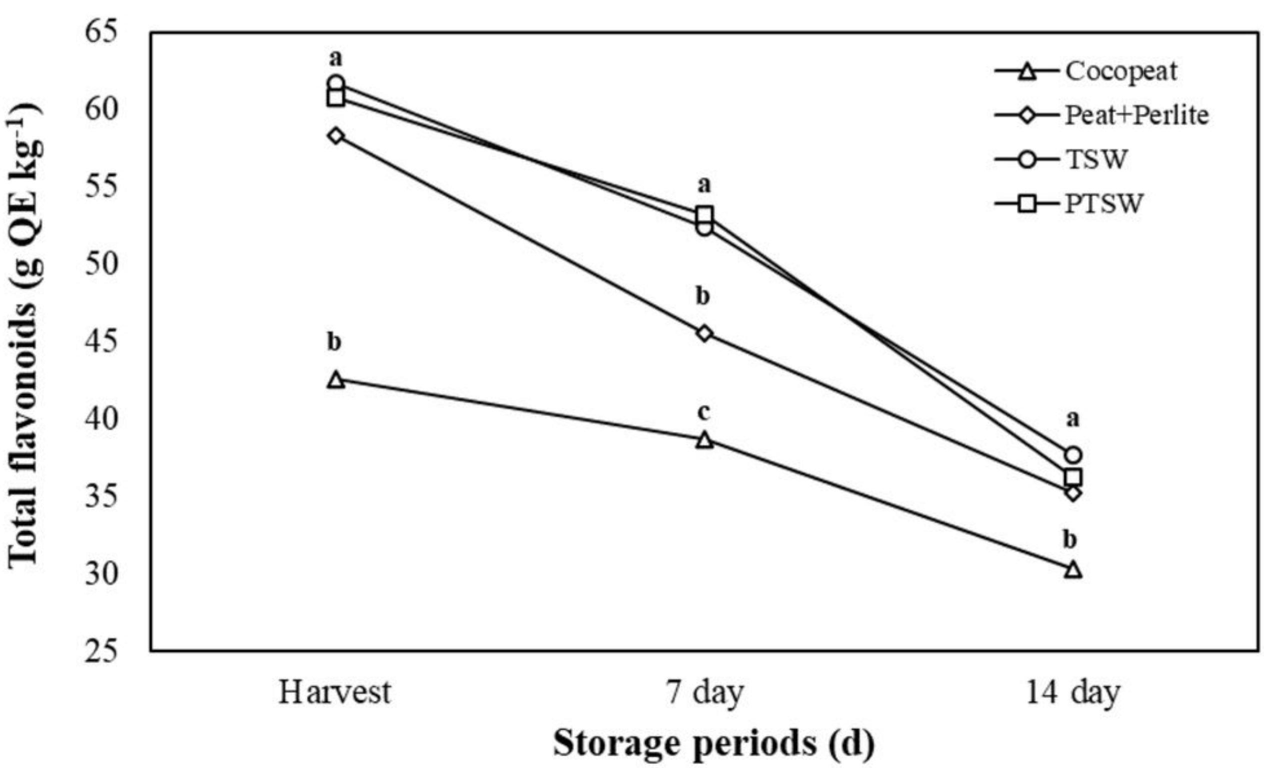


Figure 5

Effects of different growing conditions on total phenolics and total flavonoids of tomato fruit throughout cold storage. The mean shown with the same letter vertically did not differ according to Tukey's test at $p < 0.05$. n = 9 for total phenolics and flavonoids (three replicate × three different measurements for each replicate).

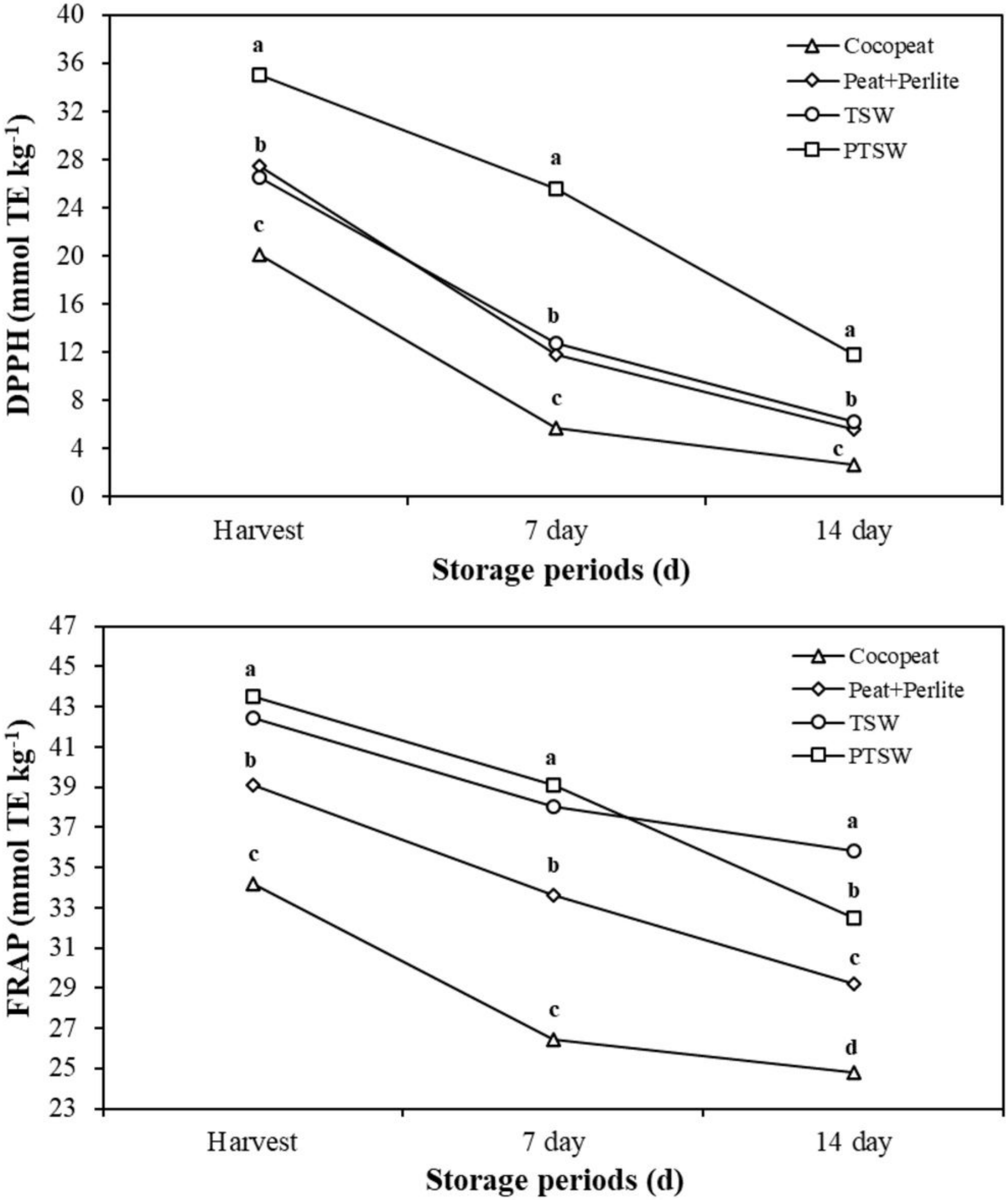


Figure 6

Effects of different growing conditions on tomato fruit's antioxidant activity (DPPH and FRAP assays) throughout cold storage. The mean shown with the same letter vertically did not differ according to Tukey's test at $p < 0.05$. $n = 9$ for antioxidant activity (three replicate × three different measurements for each replicate).

Supplementary Files

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