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Comparison of Storability and Quality of Sweet Pepper (Capsicum annum L.) Grown in Two Different Hydroponics Media

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Abstract This study compared the effects of cocopeat and perlite growth media on the storability and quality of sweet pepper fruit stored using modified atmosphere packages (MAP) and carton boxes. The fruits were stored at 8°C for 35 and 30 days, respectively. Perlite-grown fruits had a significantly lower size at harvest due to the medium's inability to hold plenty of water during the growing stage. Contrary to what is expected for small fruits, the result shows box-stored perlite-grown fruits to have lower weight loss and a longer shelf life than cocopeat-grown fruits, while MAP fruits have indifference. Perlite fruits also had a higher quality in terms of dry matter, soluble solids, and vitamin C, while box-stored fruits had a better visual quality. As expected, respiration and ethylene production rates were high, and fruits had similar after-storage firmness values. Based on the findings, perlite-grown sweet pepper fruits may have a better quality and give preference in a box storage condition.

Keywords Cocopeat, Carton boxes, Modified atmosphere packages, Perlite, Sweet pepper

Introduction

Sweet pepper is one of the world's most important and widely grown horticultural products. It is cultivated due to its nutritional benefits and its ready-to-eat ability in meals[1]. It has also been found to contain dietary compounds that have the potential to prevent diseases and promote overall health and well-being[2]. These and other benefits have led to a significant surge in demand for it. Currently, it is the second-most consumed vegetable in the world[3]. However, due to the rising demand, irrigation has become an extremely important substitute for insufficient rainfall, and the unavailability of fresh water is resulting in the intensive use of poor-quality water, which would increase salinity[4]. Pepper is a moderately sensitive plant, and in situations of excess salinity, plant water uptake is reduced[5], which in turn affects the plant because energy for growth and yield is diverted to expend water from the root zone[6]. In a study by Hoffman et al.[7], a 14% yield decrease slope was reported due to water stress at a threshold of 1.5 dSm^{-1}, while Rhoades et al.[6], reported a 12% yield decrease slope at a threshold of 1.7 dSm^{-1} in a similar study. Apart from salinity, drought is the second primary cause of water stress[8]. Afzaal et al[9]., describe both stresses as affecting plants in similar ways. A study on irrigation intervals on pepper confirms this; a negative effect appeared as intervals increased[10]. However, peppers and other fruits from water-stressed plants have always shown superior quality in terms of total soluble solids due to electrolyte concentration[5]. A study found that mild water stress conditions improved kiwifruit quality[11], while Pena et al.[12] discovered that a water deficit situation reduced the chilling injury symptoms in pomegranates. Some of these considerable advantages are gradually making water stress a consideration in fruit production. In Korea and Japan, salinity treatment has been found to be the current trend to enhance soluble solids for tomatoes[13].

Studies have shown water stress and fruit size relationships to be reversed. This was seen in pepper. Navarro et al.[14] discovered that increasing salinity reduced the pepper's fruit size. A similar case was reported by Sayyari and Ghanbari[10] for increased irrigation intervals. Fruit size has, however, been shown to considerably affect storage, as large-sized tomatoes were seen to have a longer shelf life than smaller ones[15]. This exact observation was reported for tangerines, where small tangerines were observed to have greater proportional weight loss and a shorter shelf life[16]. It implies that although higher fruit quality was achieved through water stress, fruits may have a shorter shelf life. No research we know of has focused on the effect of water stress conditions on the storability of pepper. Hence, this work is aimed at checking the storability

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and after-storage quality of water-stressed grown sweet pepper fruits compared to fruits from other media.

Maintaining the quality and shelf life of pepper requires appropriate techniques[17], and as a way of maintaining the optimum condition, modified atmosphere packaging (MAP) has proven to retain quality and extend the shelf life of fruits[18]. Moreover, when used for green peppers, it was seen to enhance their shelf life[19]. As a result, fruits were stored in MAP using 20,000 $cc \cdot m^{-2} \cdot day^{-1} \cdot atm^{-1}$ OTR film, which was shown to work best for sweet peppers stored at 7 ± 1°C before temperature change[20], which is close to the 8°C optimum temperature[21].

Materials and Methods

1. Plant Materials and Growth Conditions

The sweet pepper (NAGANO RZ F1 (35-152)) used for this experiment was supplied by Gangwando Agricultural Research and Extension Service, and the experiment took place in a plastic greenhouse at Kangwon National University. The plants were transplanted into different hydroponics media; cocopeat and perlite, which were bought from Bio Grow Lanka (PVT) LTD and Green Fire Chemicals, respectively, and Dutch PBG nutrient solutions, which contained N 12.25, P 3.75, K 6.0, Ca 7.5, Mg 2.5, and S 2.5 $me \cdot L^{-1}$, were supplied to plants by an automated drip irrigation system at intervals of either 1 hr, 1 hr 30 min, or 2 hr based on the daily transpiration expectation. The nutrient solutions were kept at a pH of 5.8 ~ 6.0 and an electrical conductivity of 2.3~2.6 dSm^{-1}, and the greenhouse cooling fan system helped to maintain the optimum temperature.

The available water to plants in the different media was measured with time domain reflectometry (TDR). It was checked after 2 hours of full irrigation supply between 12-2 pm, by horizontally pushing the TDR probe into the media surface at a 10 cm depth. The TDR trace result was then recorded.

2. Storage conditions

At 70% maturity stage, fruits were harvested and transported to the laboratory because, when fully matured fruits are harvested, postharvest decay is usually high due to the skin permeability and higher respiration rate of fruits[22]. However, this tends to affect postharvest water loss[23] and quality[24, 25]. Immediately on getting to the laboratory, fruits were sorted for any form of injury, and then stored in the refrigerator before packing. Some fruits were kept back to determine the initial respiration and ethylene production rates, firmness, and soluble solids. After that, fruits were packed in MAP with 20,000 $cc \cdot m^{-2} \cdot day^{-1} \cdot atm^{-1}$ OTR film that was reported to be the best film for sweet pepper[20] and stored at 8 ± 0.5°C with 85% relative humidity for 35 days, while control fruits were stored in carton boxes for 30 days due to the fruit's conditions. The weight loss, visual quality, ethylene, oxygen, and carbon dioxide concentration were checked at 5-day intervals.

3. Gas Condition and Measurement

The ethylene content was measured by collecting 1.0 mL gas samples from the headspace with a syringe and then passing them into the GC machine through the septum. GC-2010, Shimadzu, Japan was used. The gas was equipped with a BP BP 20 Wax column (30 m × 0.25 mm × 0.25 μm, SGE analytical science, Australia), and a flame ionization detector (FID). The gas detector and injector ran at 200°C, while the oven was set at 50°C, and the carrier gas flow rate was 1.76 $mL^{-1} \cdot min$. Similarly, the CO_2 and O_2 content in the packages were measured with an infrared CO_2/O_2 analyzer (Model check mate 9900, PBI-Dansensor, Ringested Denmark). With the stated GC-2010 machine conditions and an infrared CO_2/O_2 analyzer, respectively, the fruit ethylene production and respiration rates were measured after retaining the fruits in an airtight container (1140 mL) and leaving them at ambient conditions for 3 hr. The corresponding ethylene production and respiration rates were then calculated.

4. Weight Loss

The weight loss rate of each treatment was checked in reference to Fahamy and Nakano[26]. Fruits were weighed and recorded for the carton box while it was immediately after packing for the MAP (harvest weight, HW), and then reweighed at subsequent times after removal from refrigerated storage (storage weight, SW). The weight loss rate was determined using this formula:

$$WL(\%) = \left(1 - \frac{SW}{HW}\right) \times 100 \quad (1)$$

5. Visual Quality and Shelf life

After a thorough visual examination by a five-member panel, visual quality score was then assigned to samples. Score points were given in reference to Wang et al.[17]. The scoring points were as follows: 5 points for the best pre-storage condition, 3 points for maintaining marketability, and 1 point for a condition that must be eliminated.

The number of shelf life days was calculated as follows: using marketability as a criterion, a grid line was drawn at the 3 point score on the excel sheet, and the corresponding day gives the shelf life.

6. Biochemical and Physiochemical Traits

The dry matter was determined through this method. Before oven drying at 80°C for 3 days, samples were weighed, and then reweighed after drying and expressed as a percentage using this formula:

$$\text{Dry matter (\%)} = \frac{\text{Dry weight}}{\textit{Fresh weight}} \times 100 \quad (2)$$

The soluble solids content (SSC) was determined using a pocket refractometer (PAL-1, Atago, Tokyo, Japan). The SSC was determined in this manner; the fruits were chopped into small pieces and then wrapped with gauze to extrude juice. The juice was made to drop on the sensor part of the refractometer and the result was shown as brix[27].

The Vitamin C content of extracted sweet pepper juice was determined using the RQ flex reflectometer (Merck, Germany) method according to Arvanitoyannis et al.[28] with some modifications. 2g of the chopped fruit sample was mixed with 18 mL of distilled water, then homogenized and centrifuged. A Merck stick was inserted into the mixture for about 2 seconds while the reflectometer was turned on, and then it was inserted into the device after 10 seconds. The value on the screen represented the vitamin content of the entire fruit.

The following procedure was then used to determine the vitamin C content in 100 g of fruit; prior to taking readings, the instrument was calibrated with three different test strips. According to Arvanitoyannis et al.[28], the line equation $y = 3.9122x - 27.978$ was used. The instrumental reading is substituted as y in the line equation, and the corresponding x is found, which represents the vitamin C content in 100 g of fruit.

Firmness was measured with a Rheometer (Compac-100, Sun Scientific Co. Led., Tokyo, Japan) equipped with a probe (Ø 8.0 mm) at a speed of 1.0 mm/sec. The penetration procedure was that the stainless steel borer was set to move a distance of 15 mm, and the result conformed to the force exerted on a sample under tension.

7. Statistical Analysis

Each treatment had five replicates, and Microsoft Excel 2016 and Graphpad Prism 8.0 (GraphPad Software, San Diego, USA) were used to analyze the data. Two-way ANOVA and Turkey's unpaired t test were used to analyze parametric data, and the means were compared using the least significant difference at $p < 0.05$.

Results and Discussion

1. Harvest Data Information

The media's water content, fresh weight, and dry matter information are listed in Table 1. Water is considered the most important factor influencing the growth and yield of pepper[29]. Water shortages, according to Wiertz and Lenz[30], are more detrimental than nutrient deficiency. When checked, we found the available water in the media to be 17.05% and 28.17% for perlite and cocopeat, respectively, which is very similar to the 17.6% reported for perlite and 27.3% for cocopeat[31]. According to Dalla Costa and Gaianquinto[32], less than 20% available water to plants poses a severe threat in porous media such as sandy soil, and the proper available water should be between 40~60%. As a result of the water retention ability and gradual release to the plants' roots, cocopeat-grown fruits showed a significantly higher fresh weight than perlite-grown fruits, while the perlite-grown fruits correspondingly showed a high dry matter due to their inability to absorb plenty of water. This result agrees with a report on kiwifruit grown in a mild water stress condition[11]. McGlone and Kawano[33] describe dry matter as a great taste indicator because it indicates the fruit's potential or actual sugar level due to the high dominance of carbohydrates. This suggests a better taste for perlite-grown fruit.

2. Weight Loss

The result for the fresh weight loss rate is shown in Figure 1. Fruits stored in the MAP had a non-significant weight loss due to the MAP's ability to retain moisture, while box-stored cocopeat and perlite-grown fruits had weight losses of 9.5% and 8.6%, respectively. The lower weight loss observed in

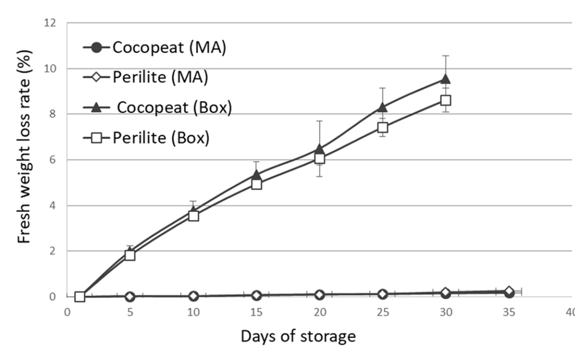

Fig. 1. Fresh weight loss rate of cocopeat-grown and perlite-grown sweet pepper fruits stored at 8°C in modified atmosphere (MA) packaging for 35 days and in carton boxes for 30 days. The vertical bars represent the ± SD of the mean (n = 5).

Table 1. Summary of the media's water content, fresh weight, and dry matter of sweet pepper fruits grown with cocopeat and perlite

Growing Media	Fresh weight (g)	Medium water content (%)	Dry matter (%)
Cocopeat	146.9 ± 9.5[z]	29.3 ± 3.4	8.7 ± 0.1
Perlite	123.9 ± 15.1	13.5 ± 3.3	9.0 ± 0.1
p-value	**	**	*

[z]Mean separation within columns by Turkey's multiple comparison test. NS, *, **: not significant, or significant at $p \leq 0.05$ and 0.01, respectively.

perlite-grown fruits is due to the thicker cuticle that water-stressed fruits develop, as seen in pomegranates and tomatoes[12, 34], while the high moisture content of cocopeat-grown fruits may have also contributed to the higher moisture loss observed. However, box-stored fruit exceeded the 8% permissible weight loss range for pepper[24] but it was within the general 3~10% weight loss for fresh fruits[35].

3. Gas Contents

The O_2 content was observed to decrease as the CO_2 increased for all packages (Figure 2A). Wang et al.[17], describe MAP as modifying the gas conditions by means of allowing oxygen to pass through the film. Before the experiment ended, the CO_2 content in packages of both treatments exceeded the 2~5% permissible tolerance level for sweet peppers[21]. This is thought to be what caused the fruit to deteriorate. As discussed by Tudela et al. [36], the atmosphere environment of the fruit in MAP has a serious effect on the fruit's respiration rates. Despite this, perlite-grown fruit showed a slightly lower CO_2 content throughout the storage.

According to Kays and Paull[37], small fruits produce more ethylene due to their larger surface area. Initially, this wasn't the case; the cocopeat-grown fruits showed high ethylene till the 10th day, before having an almost equilibrium level on the 15th and 20th day (Figure 2B). Afterwards, the perlite-gown fruits showed an increased ethylene content, with a significant difference on the final day. High ethylene levels have been linked to the rate at which fruits ripen and decompose[15]. This suggests a better performance for cocopeat-grown fruits.

4. Respiration and Ethylene Production Rate

Perlite-grown fruits had higher initial and final respiration rates, as well as ethylene production rates (Table 2). According to Abeles et al.[38], the initial high ethylene production rate must have resulted from stress response, whereas the high respiration rate would have been due to osmotic adjustment or the fruit size. Similar observations were reported for sweet peppers grown in similar conditions, and the claim was that an attempt to conserve water and retain partial turgor by the plants resulted in high respiration for the fruit[39]. Also, following Kays and Paull's discussion, it could probably be due to the fruit's size. Small-sized fruits were shown to have a larger surface area, which causes a higher respiration rate to occur[37]. However, after storage, perlite-grown fruits were found to retain high ethylene and respiration rates. This is most likely due to the size now, as the same observations were reported for the ethylene and respiration rates of small-sized tomatoes[15] and guava[40].

5. Visual Quality

Visual quality has been shown to be one of the most vital of all the storage quality indexes, and according to the 3 point

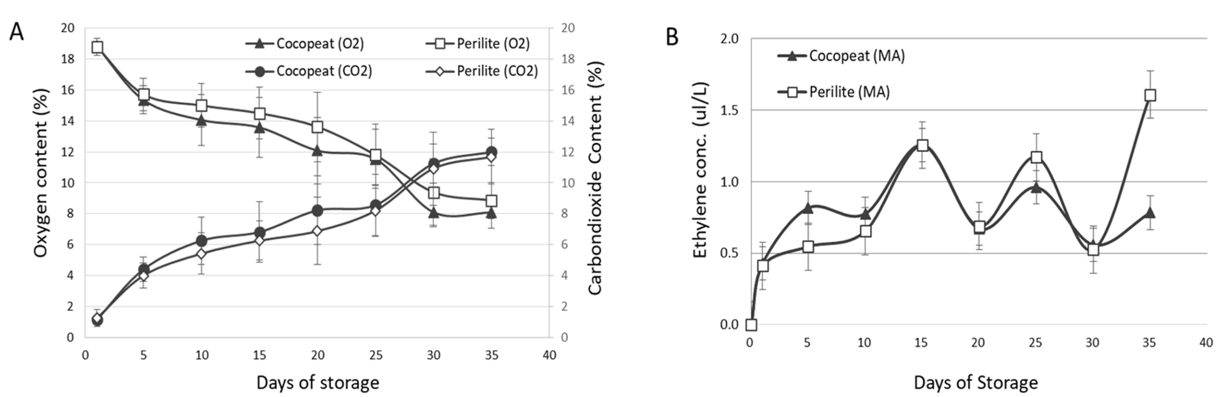

Fig. 2. Changes in oxygen and carbon dioxide (A), and ethylene (B) contents in modified atmosphere (MA) packages stored at 8°C. The vertical bars represent the ±SD values of the mean (n = 5).

Table 2. Respiration and ethylene production rates of sweet pepper fruits before and after 30 days of carton box storage at 8°C.

Measuring time	Growing Media	Respiration rate (CO_2mg/kg/hr)	Ethylene production rate(μg/kg/hr)
Initial	Cocopeat	2.775 ± 0.2b	0.1150 ± 0.01c
	Perlite	5.610 ± 0.3a	0.1750 ± 0.01b
Final	Cocopeat	1.51 ± 0.1c	0.17 ± 0.02b
	Perlite	3.62 ± 0.1b	0.23 ± 0.04a
p-value at Measuring time × growing media		**	**
p-value at Medium		**	*

Mean separation within columns by Turkey's multiple comparison test. NS, *, **: not significant, or significant at $p \leq 0.05$ and 0.001, respectively.

score of Wang et al.[17], all fruits were seen to have lost their marketability after storage (Figure 3A). Probably due to the high ethylene content of perlite-grown fruit, a non-significant difference showed for fruit stored in the MAP, while a lower moisture loss made a significant difference for box-stored fruits. Díaz-Pérez et al.[23] reported moisture loss as the main factor affecting the quality and storability of sweet peppers. In contrast to 42 days and a marketability value of 88% for green peppers stored in MAP, as reported by Singh et al.[19], a shelf life of 28 days was seen for MAP in this experiment (Figure 3B), which was as a result of the high CO_2 content (Figure 2A), which is supposed to be between 2–5%[21], and a shelf life of 19 and 22 days was seen for box-stored cocopeat and perlite-grown fruits, respectively, which is similar to the 20 days reported for green sweet peppers[41].

6. Biochemical and Physiochemical Traits

Perlite-grown fruit showed a high soluble solid content (SSC) as envisaged before storage, which was similar to other researchers' observations of water stress conditions[10, 42]. Zeng et al.[43] depict SSC as an extremely important fruit quality index, while Kurunc et al. [5] went further by giving an explicit explanation of how water stress conditions tend to favorably influence SSC, stating that it is primarily due to electrolyte concentration that results from the plant's inability to uptake sufficient water. The observation was quite the same after storage; perlite-grown fruit maintained a high SSC in both the MAP and the box. However, it was higher for box-stored fruits due to the ripening process, as shown by Islam et al.[15].

In agreement with Medyouni et al.[44]. observation of water-stressed tomatoes, vitamin C showed to be greatly influenced in this experiment. Perlite-grown fruit had higher vitamin C content because of the ascorbic acid accumulation, which plays a key role in ROS (reactive oxygen species) detoxification in water stress tolerance[45]. Similarly, the after-storage vitamin C content was found to have slightly increased for box-stored fruits, whereas it was seen to be well maintained in the MAP fruits. Due to the atmospheric modification, MAP fruits maintained their vitamin C content, while the increase for box-stored fruit was due to the fruit's maturity. In agreement

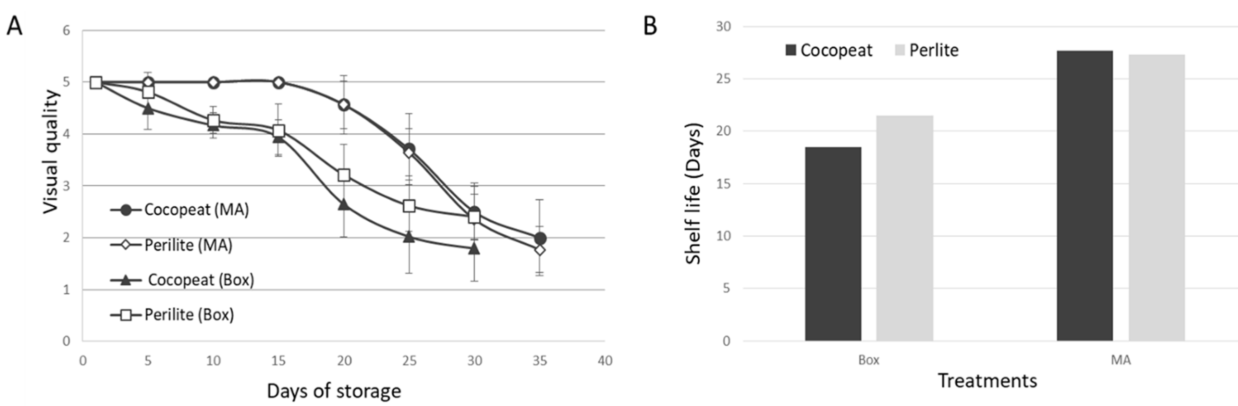

Fig. 3. The visual quality (A) and shelf life (B) of cocopeat-grown and perlite-grown sweet pepper fruits stored at 8°C in modified atmosphere (MA) packaging and carton boxes. The vertical bars are the ± SD values of the mean (n = 5).

Table 3. Soluble solids content (SSC), vitamin C, and firmness of sweet pepper fruits stored at 8 °C in modified atmosphere (MA) packaging and carton boxes on the initial and final day

Storage conditions	Growing Media	Soluble solids (°Brix)	Vitamin C (mg 100 g^{-1} FW)	Firmness (N)
Initial	Cocopeat	6.9 ± 0.1d^z	130.00 ± 10.4b	48.9 ± 2.9a
	Perlite	8.2 ± 0.1b	158.00 ± 20.8b	44.2 ± 1.7b
MA	Cocopeat	6.0 ± 0.1e	123.2 ± 9.1b	45.5 ± 6.6b
	Perlite	7.6 ± 0.1c	156.4 ± 23.8b	44.6 ± 4.2b
Box	Cocopeat	7.4 ± 0.1c	148.0 ± 15.0b	35.8 ± 4.1c
	Perlite	9.5 ± 0.1a	183.2 ± 21.9a	36.7 ± 4.0c
p-value at Storage conditions × Growing media		**	NS	NS
p-value at Storage conditions		**	NS	NS
p-value at Growing media		**	NS	NS

^{z}Mean separation within columns by Turkey's multiple comparison test. NS, *, **: not significant, or significant at $p \le 0.05$ and 0.001. Different letters among treatments represent statistical differences using Turkey's multiple comparison test at $p < 0.05$.

with our result, Gil et al.[46] found that after storage, the vitamin C content of mangoes has increased include. Although a similar observation was seen for strawberries, which was caused by reversed oxidation, the increase was observed for only the box -stored fruit, which confirmed our hypothesis.

Perlite-grown fruit showed a significantly lower firmness value after harvest. This agrees that insufficient water uptake causes a reduction in fruit firmness, which has been supported by Navarro et al. (2001), who report that insufficient water uptake caused by increased salinity reduces pulp thickness and firmness for pepper and a similar situation for melon by Barzegar et al.[42]. However, insignificant firmness values were seen after storage due to low fruit moisture loss (Figure 1), which, according to Mitropoulos and Lambrinos[47], is the cause of firmness changes. This result agrees with a report by Pena et al.[12], where the initial firmness for pomegranates grown in a deficit irrigation condition was lower than the control, and after storage, the control fruit was seen to have lost 38% of its firmness, having similar values to the fruits grown in a deficit condition. As was expected, fruits stored in MAP showed higher firmness due to moisture loss retentivity of the MAP.

Conclusion

The effect of two different hydroponics media (water stressed and non-water stressed) and two different modes of storage at 8°C was examined. The study focused on the quality and storability, and a shelf life of 19 days and 22 days was revealed for box-stored cocopeat-grown and perlite-grown fruits, respectively, while a shelf life of 28 days was observed for both fruits in 20,000 $cc{\cdot}m^{-2}{\cdot}day^{-1}{\cdot}atm^{-1}$OTR film MAP. Mild water stress, which results from the poor water holding capacity of the perlite medium, shows to reduce the fruit size, but doesn't affect the storability and quality as envisaged, but rather thickens the cuticle, which reduces moisture loss and maintains fruit firmness. Perlite-grown fruits also had higher quality in terms of soluble solids and vitamin C.

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