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The Effect of Modified Atmosphere Packaging on the Shelf-life of Greenhouse-grown Tomato

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ABSTRACT: In the present study, packaging of a greenhouse-grown tomato on the culture medium containing 0, 25, 50, 75 and 100% compost tea under modified atmosphere: MA (88%N_2 + 8%CO_2 + 4%O_2) in polyethylene and nanosilicon-polyethylene bags was studied at 5°C for 30 days. Several quality parameters such as moisture content, pH, total soluble solids (TSS), titratable acidity (TA), Vitamin C content, texture, and respiration rate were evaluated after 0, 10, 20, and 30 days of storage. Data were then analyzed using three-factor (i.e. substrate, packaging film, and storage time) completely randomized design with three replicates by SPSS software. Results showed that in term of substrate, the treatments containing compost tea had a significant effect on the characteristics of tomato in comparison with substrate without compost tea. However, the different levels of compost tea did not show the same results for all experiments. In term of storage time, most of the characteristics had a decreasing trend; however, they were in the defined standard domain for these properties. In term of the type of film, nano film was superior to polyethylene film. These findings confirmed the extension shelf life and maintain the quality of growing tomatoes on the substrate containing compost tea packaged under MA in a nanosilicon-polyethylene film for one month.

Keywords: *Cold storage, Compost tea, Nanopolymer, Packaging, Shelf-life, Tomato.*

Introduction

Nowadays, tomatoes cultivation in the greenhouse is common as well as in farm due to the marketing demand. Hydroponic cultivation is known as one of the plant production methods in controlled environment called greenhouses (Gericke, 1937). However, the use of chemical fertilizers in this cultivation is almost unavoidable, and the remainder of chemical fertilizers in crops creates an environmental pollution, as well as non-safety products. Therefore, many societies in the world are looking for a product that has the least accumulation of chemical toxic elements. Compost is an organic substance added as a fertilizer and additive to soil (Bezanson *et al*., 2014). Compost tea is also usually produced by soaking compost in water, just like tea leaves in hot water, which is a nutritious organic solution (Ingram and

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Millner, 2007). Compost tea is used to produce organic products in greenhouse conditions (Liguori *et al*., 2015), and its consumption in addition to providing the nutritional needs due to the large population of beneficial microorganisms, such as fungi and bacteria causes root growth, increased absorption of nutrients and beneficial root secretions (Joe *et al*., 2017). Several studies have been carried out on the effect of compost, vermicompost and compost tea culture on germination (Atiyeh *et al*., 2002; Dehdashtizade *et al*., 2009; Arancon *et al*., 2012), increasing the growth (Atiyeh *et al*., 2002; Federico *et al*., 2007; Arancon *et al*., 2007 and 2012), productivity improvement (Atiyeh *et al*., 2002; Riahi *et al*., 2009), and improving quality and marketability (Atiyeh *et al*., 2002; Riahi *et al*., 2009) of tomato.

Tomato is an important crop in term of its economic and nutritional value and thus is grown as a popular product both in the field and in the greenhouse (Oms-Oliu *et al*., 2011). It is a climacteric fruit, and too ripping of this crop leads to its softening, gets damaged, and decreases its marketability. Although changes in ripening can be delayed by cooling, keeping tomato at low temperatures is restricted due to injuries from cooling such as cavitation, incomplete or inconsistent ripening, and increased fungal contamination in the fruit (Geeson *et al*., 1994). According to this description, the use of packaging techniques is essential for longer storage of this crop. One of the most important methods for increasing the shelf life of fresh products is Modified Atmosphere Packaging (MAP) (Sandhya, 2010; Tajeddin *et al*., 2017). The MAP method is the packaging of a spoilable product in the atmosphere that has changed and its composition is different from that of air. In this method, the gas composition in the known permeability package is modified to reduce respiration, microbial growth, enzymatic degradation and prolonged shelf life (Caleb *et al*., 2012). Oxygen, nitrogen, and carbon dioxide are gases that are often used in the MAP, and the gases contained in the package are naturally or artificially replaced with one or a combination of these gases (Farber *et al*., 2003; Mangaraj *et al.*, 2009; Tajeddin *et al*., 2017). Some studies that have been carried out on the use of MAP for tomatoes produced in field are including: Pink tomato packed with inactive MAP in polyethylene films with a thickness of 50 and polypropylene with a thickness of 25 microns, preserved their characteristics up to 60 days (Batu and Thompson, 1998); MAP provided good quality tomato slices with a shelf life of 2 weeks or more at 5°C (Hong and Gross, 2001); the best overall tomato slice quality was found at 5°C under higher CO_2 (Gil *et al*., 2002); the storage of tomatoes in polyethylene films by MAP at 9 ± 1°C increased the shelf-life of the product up to 42 days (Ahmadzadeh Ghavidel, 2008); keeping tomatoes in a polypropylene film with a gas mixture of 88%N_2 + 8%CO_2 + 4%O_2, at 4°C and a vacuum pressure level of 0.4 bar, preserves the quality and prolongs the shelf-life (Ebrahimian, 2012). In addition, the use of nano polymers in food packaging- MAP method is a new way for expanding this packaging method (Tajeddin *et al*., 2017). However, the present study was conducted to develop an appropriate package using MAP and two types of polymeric and nano polymeric films, with the aim of optimal keeping of tomatoes obtained from hydroponic culture containing compost tea.

Materials and Methods

- *Materials*

Tomatoes were harvested from the greenhouse of the Agricultural Engineering Research Institute (AERI). Low density polyethylene (LDPE) film with a thickness of 42 and a nano silicon-polyethylene film with a thickness of 31 microns were purchased from the Aytak Nanobaspar Corporation, Iran.

- *Preparation samples*

First, a combination of different levels of compost tea and complete fertilizer solution were added to the perlite, cocopeat and washed sand substrates (20:40:40), which was placed in 10 liter pots. Tomatoes were then cultured on a hydroponic culture medium containing 0, 25, 50, 75 and 100% compost tea. They were harvested after about eight weeks from the cultivation time to study the effect of different levels of compost tea and complete fertilizer solution on the quality of tomato. Thus, quantitative and qualitative tests were performed immediately as zero day indices on the samples. Then, fresh tomatoes were washed with water, dried at laboratory temperature, placed in LDPE and nano silicon-polyethylene films, and packed in a MAP machine (HenkelMan, Boxer 42, Holland) with gas combination of 88%N_2 + 8%CO_2 + 4%O_2. Several replications of packaged samples were transferred to cold storage at a temperature of 5°C ± 1 for investigating physicochemical properties at different storage times.

- *Moisture content*

Moisture measurement was carried out using an oven at 100-150°C and the moisture content was calculated from Equation 1, (AOAC, 2005a):

$$\text{Moisture percentage} = (M_1 - M_2)/ M_0 \times 100 \quad (1)$$

Where M_0 is sample weight, M_1 is the weight of container and sample before drying, and M_2 is the weight of container and sample after drying.

- *Potential hydrogen (pH)*

The pH was measured using a pH meter (Metrohm-691, Switzerland) after calibration of device.

- *Total soluble solids (TSS)*

Measurement of total soluble solids content of tomatoes was performed by distilled water at 25 °C after calibration of a digital manual refractometer (Atago, Japan).

- *Titratable acidity (TA)*

The titratable acidity of tomatoes was measured per gram of citric acid in 100 grams of fruit (acid index for citric acid: 64) using Equation 2, (Tsegay *et al*., 2013):

$$\text{Acidity percentage} = (V \times 0.1 \times (64/1000) \times 100)\ /\text{sample volume} \quad (2)$$

Where V is volume of used sodium hydroxide

- *Ascorbic acid content*

The concentration of ascorbic acid was measured by the chemical method of 2.6 dicloropenol indophenol, an oxidation and reduction indicator, using Equation 3, (AOAC, 2005b).

$$\text{Ascorbic acid percentage} = [(V_0 - V_1) \times M_1] \times 100/ M_0 \quad (3)$$

M_0: Sample mass in grams used in the titration test.

M_1: The mass of ascorbic acid in milligrams, which is equivalent to one milliliter of colored solution.

V_0: Volume of colored solution of substance in milliliters used for sample titration.

V_1: Volume of colored solution of substance in milliliters used in the control test.

- *Texture analysis*

It was measured by penetration test using Instron Universal Testing Machine (Hounsfield, H5KS model, UK) with 500 N load cell. In this test, the probe with a diameter of 3.2 millimeters at a speed of 120 millimeters per minute penetrated into the tissue of tomato, and the amount of force introduced into the tissue was measured (in

Newton Unit) at two points of its surface (Castro *et al*., 2008).

- *Respiration rate*

The respiration rate was measured using a CO_2-sensitive sensor (Micro-5 Testo, Germany). After placing the tomato specimens in a 20 × 20 × 10 cm^3 plastic container, the amount of CO_2 produced by a certain weight of the fruit in a specified time (one hour) is being transferred by the sensor to the memory card of the device. Therefore, the respiration rate (mg CO_2/kg.h) of tomatoes was calculated using the quotient of the CO_2 slope of the curve plotted against to time (Tajeddin and Behmadi, 2019).

- *Statistical analysis*

The collecting data from quantitative and qualitative indices in three replications was analyzed based on a factorial experiment in a completely randomized design using N-way ANOVA by SPSS software version 16. Three factors were including substrate at five levels (0, 25, 50, 75, and 100% compost tea), type of packaging material at two levels (LDPE and nanosilicon-polyethylene films), and storage time at four levels (0, 10, 20, and 30 days). Duncan's test was used to compare the means values.

Results and Discussion

Table 1 shows all measured indices (means ± SD for three replicates) of greenhouse-grown tomatoes on compost tea media, packaged under modified atmosphere, and stored at 5°C for 30 days.

Table 1. Measured indices (means ± SD) of all samples (cultured tomato on compost tea media, MAP, and stored at 5°C for 30 days)

Substrate	Film	Time (day)	Moisture (%)	pH	TSS (%)	TA (%)	Ascorbic acid (mg/100 g)	Texture (N)	Respiration (mgCO_2/kg.h)
0% Compost tea	Silicon nano polymer	0	94.67 ± 0.50	4.18 ± 0.04	4.63 ± 0.27	1.40 ± 0.60	43.03 ± 0.97	4.93 ± 0.68	12.45 ± 0.91
		10	94.37 ± 0.18	4.23 ± 0.16	4.71 ± 0.29	1.31 ± 0.10	39.17 ± 0.76	4.52 ± 0.45	14.23 ± 0.68
		20	93.76 ± 0.40	4.47 ± 0.27	4.83 ± 0.29	1.23 ± 0.15	38.20 ± 1.31	3.90 ± 0.58	12.78 ± 1.44
		30	93.43 ± 0.45	4.50 ± 0.01	5.12 ± 0.22	1.10 ± 0.10	34.83 ± 0.76	3.43 ± 0.62	10.81 ± 0.47
0% Compost tea	LDPE	0	94.67 ± 0.50	4.18 ± 0.04	4.63 ± 0.27	1.40 ± 0.06	43.03 ± 0.97	4.93 ± 0.68	12.45 ± 0.91
		10	94.52 ± 0.53	4.21 ± 0.05	4.70 ± 0.36	1.31 ± 0.09	41.00 ± 1.00	4.66 ± 0.83	13.39 ± 0.58
		20	94.41 ± 0.52	4.24 ± 0.13	4.83 ± 0.15	1.20 ± 0.10	39.67 ± 1.53	4.09 ± 0.81	12.09 ± 1.80
		30	94.34 ± 0.45	4.26 ± 0.01	4.90 ± 0.10	1.15 ± 0.13	38.33 ± 2.08	3.77 ± 0.46	11.80 ± 2.42
25% Compost tea	Silicon nano polymer	0	94.00 ± 0.35	4.18 ± 0.02	5.40 ± 0.39	1.50 ± 0.09	46.03 ± 1.13	7.15 ± 0.38	11.53 ± 0.95
		10	93.79 ± 0.37	4.27 ± 0.08	5.53 ± 0.42	1.40 ± 0.17	43.00 ± 1.00	6.72 ± 0.45	13.26 ± 1.20
		20	93.58 ± 0.41	4.47 ± 0.44	5.57 ± 0.38	1.23 ± 0.11	41.00 ± 1.00	5.24 ± 0.74	11.29 ± 1.22
		30	93.17 ± 0.31	4.60 ± 0.01	5.85 ± 0.15	1.17 ± 0.15	38.90 ± 1.01	4.93 ± 0.54	10.17 ± 1.22
25% Compost tea	LDPE	0	94.00 ± 0.35	4.18 ± 0.03	5.40 ± 0.39	1.50 ± 0.09	46.03 ± 1.13	7.15 ± 0.38	11.53 ± 0.95
		10	93.95 ± 0.16	4.23 ± 0.03	5.42 ± 0.40	1.38 ± 0.07	44.00 ± 1.00	6.23 ± 0.77	12.82 ± 1.13
		20	93.92 ± 0.12	4.25 ± 0.04[j]	5.53 ± 0.31	1.21 ± 0.12	40.03 ± 1.35	5.85 ± 0.48	11.47 ± 0.52
		30	93.91 ± 0.09	4.27 ± 0.01	5.60 ± 0.26	1.14 ± 0.05	39.30 ± 1.54	5.50 ± 0.74	10.77 ± 0.58

Substrate	Film	Time (day)	Moisture (%)	pH	TSS (%)	TA (%)	Ascorbic acid (mg/100 g)	Texture (N)	Respiration ($mgCO_2$/kg.h)
50% Compost tea	Silicon nano polymer	0	93.87 ± 0.23	4.14 ± 0.01	5.00 ± 0.22	1.80 ± 0.01	45.06 ± 1.63	6.86 ± 0.32	12.89 ± 0.99
		10	93.60 ± 0.02	4.20 ± 0.25[c]	5.20 ± 0.46	1.63 ± 0.15	43.13 ± 1.63	6.30 ± 0.52	14.26 ± 0.87
		20	93.38 ± 0.36	4.27 ± 0.04	5.30 ± 0.26	1.33 ± 0.15	42.67 ± 1.53	5.31 ± 0.77	12.69 ± 1.05
		30	92.82 ± 0.40	4.41 ± 0.01	5.55 ± 0.50	1.13 ± 0.11	37.13 ± 1.80	4.85 ± 0.70	10.70 ± 0.79
50% Compost tea	LDPE	0	93.87 ± 0.23	4.14 ± 0.01	5.00 ± 0.22	1.80 ± 0.01	45.06 ± 1.63	6.86 ± 0.32	12.87 ± 0.99
		10	93.81 ± 0.38	4.25 ± 0.06	5.17 ± 0.15	1.73 ± 0.06	42.00 ± 1.00	6.05 ± 0.06	12.97 ± 1.78
		20	93.69 ± 0.26	4.28 ± 0.01	5.20 ± 0.10	1.67 ± 0.06	39.67 ± 1.53	5.38 ± 0.48	12.69 ± 0.52
		30	93.61 ± 0.39	4.32 ± 0.03	5.30 ± 0.20	1.50 ± 0.13	39.10 ± 1.56	4.82 ± 0.68	11.67 ± 0.30
75% Compost tea	Silicon nano polymer	0	93.41 ± 0.53	4.31 ± 0.03	5.45 ± 0.22	1.33 ± 0.05	44.06 ± 1.13	7.20 ± 0.60	12.27 ± 0.63
		10	93.11 ± 0.21	4.48 ± 0.24	5.47 ± 0.21	1.15 ± 0.18	42.33 ± 3.05	6.58 ± 0.64	14.49 ± 1.48
		20	92.89 ± 0.29	4.73 ± 0.06	5.62 ± 0.42	1.07 ± 0.11	41.40 ± 1.51	4.52 ± 0.57	11.61 ± 0.99
		30	92.52 ± 0.32	4.76 ± 0.05	5.78 ± 0.26	1.03 ± 0.06	36.67 ± 2.08	4.29 ± 0.42	10.13 ± 1.10
75% Compost tea	LDPE	0	93.41 ± 0.53	4.31 ± 0.03	5.45 ± 0.22	1.33 ± 0.05	44.06 ± 1.13	7.20 ± 0.60	12.27 ± 0.63
		10	93.34 ± 0.42	4.37 ± 0.16	5.61 ± 0.16	1.27 ± 0.15	43.67 ± 1.53	6.68 ± 0.44	12.82 ± 1.81
		20	93.25 ± 0.22	4.58 ± 0.05	5.62 ± 0.42	1.18 ± 0.16	41.00 ± 1.00	5.24 ± 0.30	11.49 ± 0.59
		30	93.18 ± 0.22	4.64 ± 0.09	5.70 ± 0.26	1.13 ± 0.15	38.83 ± 1.46	4.54 ± 0.60	10.63 ± 0.63
100% Compost tea	Silicon nano polymer	0	94.20 ± 0.34	4.17 ± 0.01	5.00 ± 0.10	1.58 ± 0.02	43.12 ± 0.87	7.21 ± 0.60	10.54 ± 0.55
		10	93.90 ± 0.11	4.37 ± 0.10	5.20 ± 0.56	1.40 ± 0.10	42.67 ± 1.53	6.81 ± 0.47	12.73 ± 1.19
		20	93.53 ± 0.50	4.48 ± 0.07	5.55 ± 0.44	1.27 ± 0.15	40.90 ± 1.35	5.04 ± 0.52	10.78 ± 0.49
		30	93.03 ± 0.08	4.54 ± 0.19	5.68 ± 0.30	1.17 ± 0.15	36.33 ± 2.08	4.63 ± 0.45	10.78 ± 0.49
100% Compost tea	LDPE	0	94.20 ± 0.34	4.17 ± 0.01	5.00 ± 0.10	1.58 ± 0.02	43.12 ± 0.87	7.21 ± 0.60	10.54 ± 0.55
		10	94.19 ± 0.01	4.36 ± 0.03	5.22 ± 0.24	1.43 ± 0.15	40.67 ± 1.53	6.71 ± 0.44	12.34 ± 0.79
		20	93.15 ± 1.00	4.27 ± 0.09	5.30 ± 0.17	1.37 ± 0.15	40.00 ± 1.00	5.54 ± 0.73	11.65 ± 0.62
		30	94.13 ± 0.14	4.51 ± 0.03	5.37 ± 0.25	1.23 ± 0.15	38.67 ± 1.15	5.17 ± 0.55	10.88 ± 0.83

However, the results of variance analysis of the effects of independent variables including substrate, packaging film and storage time on dependent variable of packaged tomatoes are as follows.

- *Moisture content*

The amount of tomato juice has been reported about 92.5-95% (Mazaheri Tehrani *et al*., 2007) and more than 94% (Sahin *et al*., 2010). The results of this study also confirm this. Despite the decrease in moisture content of tomatoes in all samples during storage time, its value for all samples was higher than 92.5%. The results of the variance analysis of the effect of different factors on the moisture

Table 2. Variance analysis of various factors effect on tomato moisture

Source of Variation	Sum of squares	Freedom degree	Mean Squares	F	Sig
Substrate	16.6	4	4.02	28.22	0.000***
Film	3.19	1	3.19	22.39	0.000***
Time	7.01	3	2.34	16.42	0.000***
Substrate*film	0.095	4	0.024	0.166	0.955 ns
Substrate*time	1.14	12	0.095	0.668	0.776 ns
Film*time	2.91	3	0.970	6.82	0.000***
Substrate*film*time	0.968	12	0.08	0.567	0.862 ns
Error	11.38	80	0.142		
Total	1053922.28	120			

*** The effect of the factor on moisture content of tomatoes (P<0.001)
ns: The effect of the factor on moisture content of tomatoes is not significant.

content of the samples (Table 2) show that all factors and the interaction between film type and storage time had significant effects on the moisture content of tomatoes (P<0.001).

Means comparison of the substrate effect on tomato moisture content by Duncan's test also showed that three substrates containing 25, 50 and 100% compost tea are in the same category, but substrates without compost tea (control) and containing 75% compost tea are in separate category. Thus, the highest amount of moisture is for the substrate containing 75% compost tea, and the lowest amount is for the control substrate. In addition, the moisture content of tomatoes from 94.03% in the 0-day was reduced to 93.41% on 30-day, but still moisture content of all samples was above 93%. According to Table 2, it appears that the effect of LDPE and nanosilicon-polyethylene films is significant at 99% confidence level on tomato moisture content. Regarding the mean moisture content of five substrate treatments in 0-day (94.03%), and reaching this mean to 92.99% and 93.83% respectively for LDPE and nanosilicon-polyethylene films at the end of the maintenance period, it is possible to conclude that nano film played a better role in maintaining the moisture content of tomatoes than polyethylene films.

- *pH*

Due to the partial increase in the pH in all tomato samples during storage time, Table 3 shows that the all factors had significant effects on the tomato pH (P<0.001), but the interactions of the factors, other than the film type × storage time, have no significant effect on the pH of the tomato.

Means comparison showed that the effect of 0, 25, and 50% levels of the substrate factor on the pH of the tomato is the same and their pHs are placed in the same category. The effect of 75 and 100% levels of substrate are also categorized together in the separate classes. The least amount of pH (4.25) was for grown tomatoes on the substrate containing 50% compost tea and the highest pH (4.52) was for grown tomatoes on substrate with 75% compost tea. Considering the significance effect of storage time on the pH index of tomatoes (Table 3), the comparison of the means showed that the highest mean pH index 4.48 was for tomatoes on day 30. In addition, according to Table 3, it is known that the type of film is effective at 99% confidence level on the pH of tomatoes. Regarding the average pH of the five substrate treatments in the 0- day (4.197), and reaching this mean to 4.56 and 4.40 for LDPE and nanosilicon-polyethylene films respectively at the end of the maintenance period, can be concluded that the nanosilicon-polyethylene had less pH changes than polyethylene films.

Table 3. Variance analysis of various factors effect on tomato pH

Source of Variation	Sum of squares	Freedom degree	Mean Squares	F	Sig
Substrate	1.12	4	0.281	19.99	0.000***
Film	0.191	1	0.191	13.62	0.000***
Time	1.44	3	0.480	34.19	0.000***
Substrate*film	0.087	4	0.022	1.55	0.197 ns
Substrate*time	0.158	12	0.013	0.937	0.515 ns
Film*time	0.138	3	0.046	3.28	0.025*
Substrate*film*time	0.084	12	0.007	0.501	0.908 ns
Error	1.12	80	0.014		
Total	2273.74	120			

*** The effect of the factor on pH of tomatoes ($P<0.001$)
* The effect of the factor on the pH of tomatoes ($P<0.05$)
ns: The effect of the factor on pH of tomatoes is not significant.

In general, various factors such as type of product, cultivar, total acid, ripening stage, seasonal variations, cultivation area, transfer and storage operations, and salt effect on pH of tomato and its products. The pH of the product depends on the hydrogen ion present in the solution. However, pH levels in tomatoes increase during fruit storage time (Mazaheri tehrani *et al*., 2007). According to the results of this study, the pH of the tomato increased during storage. Generally, organic acids decrease when ripening occurred due to respiration or converting to sugars. Acids can be considered as a source of energy in fruits. Therefore, it can be expected that in the process of fruit ripening, increased metabolic activity of cells decreases the cellular acidity and increases the pH of the product (Rahemi, 1998). In fact, pH changes may be due to the titratable acid variations and increased glycolysis citric acid activity during ripening period or the conversion of sugars during storage (Rathore *et al*., 2007). The reduction of acids during storage time in some fruits leads to an increase in pH, but this increase is different in most fruits (Perkins-Vaezie, 2007). Kader and Watkins (2000) stated that the difference between pH in the researchers' findings may depend on the amount of respiration. Tabatabaei Klour *et al*. (2016) reported that the packaging of tomato with modified atmosphere (gas combination of $CO_2$8% + $O_2$4% in polypropylene film) was effective in reducing respiration and delaying qualitative changes including pH.

- *Total soluble solids (TSS)*

There was an increasing trend of TSS in packaged tomatoes during storage time. Table 4 shows that substrate and storage time were effective on the TSS content ($P<0.001$) but the film factor did not affect that.

According the comparison of means, the highest mean of TSS content (5.59%) was for cultivated tomatoes on the culture medium containing 75% compost tea, and the lowest (4.79%) belonged to grown tomatoes on substrate without compost tea. Therefore, the presence of compost tea in the formulation of the substrate has increased the TSS content of the crop. This result is in line with the result of Javanmardy and Hasanshahian (2014) research. In their work to study the effect of humic acid and compost tea-based fertilizers on the quality of Pepino (*Solanum muricatum*), the highest amount of TSS was found in compost tea-based medium (about 40% higher than other treatments). According to Table 4, the effect of storage time on the TSS content of tomatoes was also significant. Means comparison showed that the lowest TSS content (5.10%) was for tomatoes on 0-day and the highest amount (5.49%) was for tomatoes on 30- days storage. Although Table 3 indicated that the film factor did not affect the amount of tomato TSS, due to a minor change in the average amount of TSS from 5.10% to 5.60% and 5.37% for polyethylene and nanosilicon-polyethylene, respectively, at the end of the maintenance period, it can be concluded that the changes in the TSS at nanosilicon-polyethylene are less than the polyethylene film.

The results of this study showed that the amount of tomato TSS in all samples increased over storage time. This is due to the viability of the fruit and the continuation of physiological processes such as respiration and transpiration during its maintenance. Most of the TSS in fruits includes sugars and a small percentage of amino acids, organic acids, vitamins and minerals. Usually, the fruit's ripening and the loss of moisture in the fruit increase the amount of soluble solids in it, since macro molecules such as starch are converted into micro molecules such as glucose, maltose and dextrin. Also, the moisture content of the product decreases, which ultimately leads to a rise in TSS (Rahemi, 1998). The results of this study are in agreement with the results of Sammi and Masoud (2007), Majidi *et al*. (2012), and Tabatabaei Klour *et al*. (2016) for the effect of MAP on the optimum preservation of TSS.

- *Titratable acidity*

Table 5 shows that various factors affect the TA index of tomatoes (P<0.01), but only the interaction between substrate and film had significant effect on the TA of tomatoes (P<0.05).

Table 4. Variance analysis of various factors effect on tomato TSS

Source of Variation	Sum of squares	Freedom degree	Mean Squares	F	Sig
Substrate	9.75	4	2.44	28.09	0.000***
Film	0.159	1	0.159	1.83	0.179 ns
Time	2.49	3	0.829	9.55	0.000***
Substrate*film	0.096	4	0.024	0.277	0.892 ns
Substrate*time	0.190	12	0.016	0.182	0.999 ns
Film*time	0.252	3	0.084	0.968	0.412 ns
Substrate*film*time	0.083	12	0.007	0.080	1.00 ns
Error	6.94	80			
Total	3373.08	120			

*** The effect of factor on TSS of tomatoes (P<0.001)
ns: The effect of factor on TSS of tomatoes is not significant

Table 5. Variance analysis of various factors effect on tomato TA

Source of Variation	Sum of squares	Freedom degree	Mean Squares	F	Sig
Substrate	2.07	4	0.517	39.27	0.000***
Film	0.124	1	0.124	9.43	0.003**
Time	2.05	3	0.683	51.87	0.001**
Substrate*film	0.175	4	0.044	2.33	0.014*
Substrate*time	0.143	12	0.012	0.906	0.545ns
Film*time	0.059	3	0.020	1.50	0.221ns
Substrate*film*time	0.114	12	0.009	0.720	0.727ns
Error	1.05	80	0.013		
Total	222.60	120			

*** The effect of factor on TA of tomatoes (P<0.001)
** The effect of factor on TA of tomatoes (P<0.01)
* The effect of factor on TA of tomatoes (P<0.05)
ns: The effect of the factor on TA of tomatoes is not significant

Considering the significance effect of the substrate factor (Table 5), the means comparison showed that the highest mean acidity index (1.57%) was related to grown tomatoes on the medium containing 50% compost tea and the lowest (1.19%) belonged to grown tomatoes on the medium containing 75% compost tea. As the effect of storage time on the acidity index was significant (Table 5), the means comparison showed that the highest acidity index 1.52% was related to 0-day and the lowest 1.18% related to tomatoes storage after 30 days. Since, according to Table 4, the effect of the type of film was also significant ($P<0.01$), the average acidity obtained from five substrate treatments in 0-day (1.52%), and reaching this means to 1.12% and 1.23% respectively for the polyethylene and nano silicon-polyethylene at the end of the maintenance period, it can be concluded that the nano silicon-polyethylene has less acidity changes than polyethylene film.

Tomato organic acids are mainly citric and malic acids. In general, organic acids account for 10 percent of the dry matter of tomato. The concentration of citric acid, at the mature green stage, has reached its maximum and remains constant while ripening, whereas the concentration of malic acid decreases (Mazaheri Tehrani *et al*., 2007). TA index is often regarded as a crop's ripening marker. Organic acids can be considered as a source of energy in fruits. Usually at ripening, the amount of organic acids decreases as a result of respiration or by converting to sugar. Therefore, it can be expected that, during the process of fruit ripening, increased metabolism activity, reduce the acidity of the cell (Rahemi, 1998). The results of this study showed that the TA in all samples decreased over time. Reduced acidity is due to the consumption of some organic acids as result of respiration, or due to the converting to the sugars, during maintenance. In studying based on the effect of film type on the percentage of TA of the fruit, it seems that nanosilicon-polyethylene film due to better ability to create and maintain the atmosphere with higher carbon dioxide than polyethylene film, is effective treatment to control the degree of acidity reduction of tomato during the maintenance period. Although, Li *et al*. (2011) stated that nano-polymer packages tended to maintain a higher percentage of organic acids during the storage period of freshly cut Fuji apples than the other polymer packages, Yang *et al*. (2010) reported there was no significant difference in TA of strawberry fruit placed in the nano-polymer packaging and the other polymer packs during the maintenance period. However, it should be noted that the apple and strawberry are climacteric and non-climacteric fruits, respectively.

- *Ascorbic acid content*

According to Table 6, it is known that the substrate and storage time are effective on the ascorbic acid content of tomato ($P<0.001$) but the film factor, the interaction between the film and the substrate, and the interaction of substrate and the time had not significant effect on the amount of ascorbic acid. However, the interaction of film and storage time was also significant ($P<0.01$) on tomato ascorbic acid content.

Regarding the significance effect of the substrate factor (Table 6), comparison of means indicated that the highest index of ascorbic acid content (42.29 mg/100 g) was related to grown tomatoes in the culture medium containing 25% compost tea and the lowest (39.36 mg/100 g) was for tomato obtained from a non-compost tea substrate. The result of this study, namely, high levels of ascorbic acid in compost tea treatments compared to non-compost tea treatments, is consistent with the results of the study by El-Hanafi Sebti (2005). He showed that the amount of ascorbic acid in two tomato varties (Vespro and Multiplo) grown on compost tea has increased. Considering the significance effect of the storage time on ascorbic acid index of tomato (P<0.001), the highest means of vitamin C index (44.26 mg/100 g) was seen on tomatoes on 0-day and the lowest (37.81 mg/100 g) was observed in tomatoes stored after 30 days. The type of film factor was not effective on the ascorbic acid content of tomato but according to the ascorbic acid content obtained from five substrate treatments on 0-day (44.26 mg/100 g), and reaching this means to 36.77 and 38.85 mg/100 g for polyethylene and nano silicon-polyethylene, respectively, at the end of the maintenance period, it can be concluded that the nano silicon-polyethylene had less variation in ascorbic acid content than polyethylene film.

In general, the results of this study showed that ascorbic acid in all samples decreased over time. During the maintenance or ripening of tomatoes, ascorbic acid gradually decomposes and reduces due to the activity of enzymes such as phenol oxidase and ascorbic oxidase. Li *et al*. (2009) reported that ascorbic acid content in strawberry and kiwi fruit with nano-packaging is better than conventional packaging.

- *Texture*

Table 7 indicates that the substrate and storage time affect significantly the tomato texture (P<0.001), but the film factor and the interaction between all treatments, had not effect on its texture during storage time.

Table 6. Variance analyses of various factors effect on tomato ascorbic acid content

Source of Variation	Sum of squares	Freedom degree	Mean Squares	F	Sig
Substrate	100.57	4	25.14	12.39	0.000***
Film	4.33	1	4.33	2.13	0.148 ns
Time	670.02	3	223.34	110.04	0.000***
Substrate*film	18.56	4	4.64	2.287	0.067 ns
Substrate*time	22.94	12	1.91	0.942	0.510 ns
Film*time	32.56	3	10.85	5.35	0.002**
Substrate*film*time	20.89	12	1.74	0.858	0.592 ns
Error	162.37	80	2.030		
Total	20444.33	120			

*** The effect of factor on tomato vitamin C content (P<0.001)
** The effect of factor on tomato vitamin C content (P<0.01)
ns: The effect of the factor on the tomato vitamin C content is not significant.

Table 7. Variance analysis of various factors effect on tomato texture

Source of Variation	Sum of squares	Freedom degree	Mean Squares	F	Sig
Substrate	54.31	4	13.58	41.41	0.000***
Film	0.746	1	0.746	2.27	0.135 ns
Time	83.55	3	27.85	84.96	0.000***
Substrate*film	0.380	4	0.095	0.290	0.884 ns
Substrate*time	6.33	12	0.527	1.61	0.106 ns
Film*time	1.51	3	0.504	1.54	0.212 ns
Substrate*film*time	0.859	12	0.072	0.218	0.997 ns
Error	26.23	80	0.328		
Total	3936.66	120			

** The effect of the factor on tomato texture (P<0.001)
ns: The effect of the factor on tomato texture is not significant.

Considering the significance effect of the substrate (Table 7), the means comparison showed that, except for tomatoes obtained from free compost tea medium, tomatoes grown on all media containing different amounts of compost tea had no significant differences and were placed in the same category. The highest force introduced to tomato tissue (i.e. 6.09 N) was for tomatoes grown on a substrate containing 25% compost tea and the lowest 4.28 N belonged to grown tomato in a non-compost tea medium. Since the effect of the storage time factor on the texture of the tomato was significant ($P<0.001$), the comparison of means indicated that the maximum mean force introduced on tomato texture (6.67 N) was related to 0-day and the lowest (4.59 N) was for tomatoes stored after 30 days. In general, with the passage of time, the firmness of tomato fruit tissue decreased in all treatments, and these changes were increasing over time. This trend is attributed to an increase in the activity of enzymes, changes in pectin and an increase in water-soluble pectin polysaccharides, usually associated with a general decrease in galactose, arabinose, and uronic acid in the lamella of the cell wall during the fruit storage period (Themman *et al*., 1982). According to Table 7, the type of film is not effective on the amount of force exerted on the tomato tissue. However, based on the average force introduced on tomato texture obtained from five substrate treatments on 0-day (6.67 N), and reaching this average to 4.42 and 4.76 N, respectively, for polyethylene film and nanosilicon-polyethylene film at the end of the maintenance period, it can be concluded that nanosilicon-polyethylene film is an effective treatment to control the process of reducing the stiffness of the tissue during the maintenance period compared to the polyethylene film probably due to better ability to maintain an adequate atmosphere.

- *Respiration rate*

The respiration rate of each fruit is a very good indicator for the tissues metabolic activities and, hence, is a good indicator for its storage capacity. In this study, the changes in respiratory rate in all treatments increased from 0-day to 10-days and after about 10 days, they entered into climacteric phase, i.e., the respiration rate reached their maximum point. From the 10-days to the end of the maintenance period, changes in respiratory rate were decreasing. According to the latest classifications, fruits and vegetables are categorized in six classes in term of respiration as very low (<5), low (5-10), moderate (10-20), high (20-40), very high (40-60), and very extreme (60>) mg CO_2/kg.h; tomatoes are among the products of the moderate class (Gross *et al*., 2016). The results of this study also show that the respiration rate of different treatments with a slight difference is in this category. Table 8 shows the results of analysis of variance resulting from the effect of different factors on the level of tomatoes respiration rate. According to this table, the medium and storage time factors at 99% confidence level affect significantly tomato respiration. The effect of the type of film on the respiration of the fruit is not significant, but the interaction between film and storage time is effective on its respiration rate ($P<0.05$).

According to the significance effect of the substrate (Table 8), means comparison showed that the highest amount of tomato respiration 12.59 mg CO_2/kg.h was related to the tomatoes grown on the substrate containing 50% compost tea and the lowest respiration 11.28 mg CO_2/kg.h, belonged to tomatoes grown in a medium containing 100% compost tea. During the maintenance period, other than the day 10 that showed respiratory peak, the tomatoes respiration rate decreased. Comparison of means showed that the highest amount of tomatoes respiration rate 13.33 mg CO_2/kg.h was related to the day 10 and the lowest 10.83 mg CO_2/kg.h belonged to the tomatoes stored after 30 days. That is, the packaging and use of the gas mixture is an important factor in reducing the product's respiration. However, the effect of the film on the respiration rate of tomatoes was not significant (Table 8), according to the lower respiration rate of packed tomatoes in nanosilicon-polyethylene than LDPE, nano silicon-polyethylene seems to have been more effective in controlling tomatoes respiration due to its better ability to maintain adequate atmospheres. The MAP method reduces respiration rates and reduces the production and sensitivity to ethylene and decrease the risk of fruit spoiling and physiological changes such as oxidation (Bakhtiari *et al*., 2010). The results of this study also showed a reduction in tomato respiration rate during storage in a package with MAP.

Conclusion

The effect of MAP (MA: 88%N_2+8%CO_2+4%O_2) with two LDPE and nanosilicon-polyethylene bags were applied to investigate the postharvest shelf life of greenhouse-grown tomatoes on media containing different amounts of compost tea at 5°C. Some indices including moisture content, pH, TSS, TA, vitamin C content, texture (stiffness), and respiration rate were measured during 30 days of storage. In the study of the effect of different substrates on some indices of tomatoes, the results showed that compost tea treatments have a significant effect on tomatoes characteristics in comparison to non-compost tea substrates. It is worth noting that all characteristics of greenhouse-grown tomatoes on media containing different amounts of compost tea are in the defined standards domain for these characteristics. In term of storage time, most of the traits had a decreasing trend, but due to the use of MAP, this reduction was in some cases minor and still lies within the range of defined standards for these features. In the study of all treatments to compare the effect of film type on characteristics of tomatoes, it was observed that the nanosilicon-polyethylene film creates a favorable atmosphere, led to effective control of all tomato samples during storage. In general, packaging greenhouse-grown tomatoes on the compost tea substrate with modified atmosphere has maintained the quality and prolonged shelf life of this crop.

Table 8. Variance analyses of various factors effect on tomato respiration rate

Source of Variation	Sum of squares	Freedom degree	Mean Squares	F	Sig
Substrate	30.59	4	7.65	7.06	0.000***
Film	0.110	1	0.110	0.102	0.751 ns
Time	94.85	3	31.61	29.17	0.000***
Substrate*film	0.824	4	0.206	0.190	0.943 ns
Substrate*time	11.12	12	0.927	0.885	0.595 ns
Film*time	9.34	3	3.11	2.87	0.041*
Substrate*film*time	3.76	12	0.313	.289	0.990 ns
Error	86.71	80	1.08		
Total	17482.66	120			

*** The effect of the factor on the tomato respiration rate (P<0.001)
* The effect of the factor on the tomato respiration rate (P<0.05)
ns: The effect of the factor on the tomato respiration rate is not significant.

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