

Effects of Polyethylene Thickness, Gas Combination and Temperature on Shelf Life and Quality of Strawberry

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Abstract

In this research, the effect of modified atmosphere packaging on the quality and shelf life of strawberries was investigated. For packing strawberries 3 gas compositions (air, N₂75%+CO₂15%+O₂10% and N₂75%+CO₂10%+O₂15%), polyethylene lining in 3 thickness of 30, 50 and 90 μ m and 2 storage temperatures 4 \pm 1 and 8 \pm 1 $^{\circ}$ C were used. The effect of treatments on weight loss, firmness, soluble solids, titratable acidity and pH in strawberries at 20 days after storage was studied in a completely randomized design with factorial experiment in 3 replications. Results showed that the effects of gas composition and temperature on all of the mentioned factors are significant ($P \leq 0.01$), but the effect of the thickness of the polyethylene (PE) lining is only significant on the percentage of weight loss, soluble solids and titratable acidity ($P \leq 0.01$). The quality and quantity characteristics of strawberries were maintained better at temperature of 4 $^{\circ}$ C due to reduced breathing, evaporation and transpiration. The polyethylene lining at thickness of 90 μ m, maintained the qualitative and quantitative qualities of the product due to low permeability and maintaining the moisture around the product within the package. The first gas composition (N₂75%+CO₂15%+O₂10%) was more suitable for keeping the qualitative and quantitative characteristics of strawberries due to more CO₂ and reduced respiration. As a result, strawberries packed in a 90 μ m thick polyethylene lining and a gas mixture (N₂75%+CO₂10%+O₂15%) at 4 $^{\circ}$ C had the best quality and highest durability.

Received: 02.01.2018

Accepted: 11.08.2018

Keywords

Gas Composition
Modified Atmosphere
Strawberry
Temperature

Introduction

Diet rich in fruits and vegetables provides protection against some diseases such as inflammatory, cancer and cardiovascular and due in particular to their antioxidant content include anthocyanins, flavonoids, flavonols and catechins, which can protect the human

body against oxidation reactions and have antifungal, antioxidants and anticancer properties (Scalzo *et al.*, 2005).

Fresh-cut fruits and vegetables are perishable due to respiratory and microbiological activity after harvest,

which reduce the shelf life of these products (Gross *et al.*, 2004).

Postharvest vegetable and fruit start to ripen due to enzymes activities, which results in the production of ethylene and increasing the speed of ripening. At this time the produce's quality first increases and then, quite immediately, diminishes (Thompson *et al.*, 1972).

Equilibrium modified atmospheres within plastic packages can be beneficial in maintaining quality of the fresh-cut product and retail product. Equilibrium modified atmosphere packaging within control of gas combination (by a combination of increasing carbon dioxide and decreasing oxygen concentrations) reduce texture firmness, respiration rate and ethylene protection (Kader, 2002).

Ayhan *et al.* (2008) examined the effect of modified atmosphere packaging on the quality and shelf life of fresh-cut carrots. The dried carrots were packed in polypropylene bags using three different gas compositions: air (passive), high oxygen ($O_2 80\% + CO_2 10\% + N_2 10\%$) and low oxygen ($O_2 5\% + CO_2 10\% + N_2 85\%$). The packs were stored for 21 days in 4 °C. The results showed that packs with air and oxygen with high density had better qualities.

Nielsen & Leufven (2008) examined the effect of modified atmosphere packaging on the quality of strawberries. Strawberries were stored in polyethylene bags at 5 °C for 10 days. The packed strawberries showed no sign of weight loss; however, the unpacked ones lost 1.5% of their weight per day. The results showed that strawberry storage in a modified atmosphere 11-14% O_2 and 9-12% CO_2 can be used to maintain the quality for a longer time, than if kept in air in open containers.

Jing-jun *et al.* (2012) examined effects of active modified atmosphere

packaging on quality of mushrooms stored at cold temperature (4 °C). The gas components were EMAP1: $O_2 2\% + CO_2 7\%$, EMAP2: $O_2 2\% + CO_2 10\%$ and EMAP3: $O_2 2\% + CO_2 13\%$. The results showed that active modified atmosphere packaging could increase the shelf life of mushrooms to 17 days and the high concentration of CO_2 could improve the postharvest quality of mushrooms. EMAP2 treatment with decreased respiration rate, delayed decrease in firmness, soluble sugar and vitamin C, and with reduction in the activities of the poly phenoloxidase (PPO) and browning of the mushrooms guarantees better quality.

Caner *et al.* (2008) investigated the impact of equilibrium-modified atmosphere packaging (EMAP) technology on extension quality (pH, acidity, brix, color) and texture profile analyses of fresh strawberries during storage. The overall results expressed that strawberry quality can be maintained effectively at least for 10 days using various polymeric lid films. PET/EVOH-LAF and CPP were much more effective than LLDPE due to barrier properties during storage periods. Quality of strawberry packaged with suitable high-barrier lid films have been prolonged significantly.

Juki & Khazaei (2014) examined the effect of low-dose gamma radiation and active modified atmosphere packaging EMAP1: $CO_2 10\%$, $O_2 5\%$ and $N_2 85\%$ and EMAP2: $CO_2 5\%$, $O_2 10\%$, $N_2 85\%$ on quality of strawberry fruits stored at 4 °C. Quality parameters were analyzed on days 1, 7, 14 and 21. Result showed strawberries kept in active EMAP1 maintained their texture and appearance better than those packaged under air and EMAP2. The strawberries packed in packages with active compounds EMPA1 and EMPA2 were firmer than those stored in air during the storage time (21 days). The irradiated strawberry was not attacked by fungus

(*Botrytis cinerea*) during 7 days of storage time. Also, the result showed low-dose gamma irradiation in combination with EMAP retained quality.

Finally, it can be claimed that gamma radiation as well as active gas compound increases the post-harvest longevity of strawberries to 14 days without fungus attack. Maghoumi *et al.* (2009) studied effect of modified atmosphere packing with high CO₂ on storing features of the strawberry cv. selva. They used two types of packaging, polyethylene and polyamide, as well as a two-gas combination, (air and O₂2% with CO₂15% and N₂83%), for packaging the strawberries. The samples were stored in a temperature of 4 °C and the relative humidity of 85-90% for 20 days, while their features were being checked every 5 days. The results showed that packing with modified atmosphere considerably reduced the weight loss and perishing of the produce. CO₂ with high density and polyethylene retained the quality of the fruit better than other treatments (Maghoumi *et al.*, 2009). Another way to preserve the freshness of the fruits and vegetables in storage is storing the produce in equilibrium modified atmospheres and storing in low pressure atmosphere (vacuuming) and packing the produce in modified atmosphere. Storage in low pressure affects the breathing and ethylene production of the fruits and increases the longevity of the produce by reducing the waste during the storage. However, aforementioned storing methods are not economically reasonable and can be adopt to store fruits in large scale, not for retailing. As after releasing from the storing condition the breathing and microbial activities reignite, which in terms, reduces the longevity of the fruits in retailing. Hence, packaging in small scales as well as controlling the conditions in the packages is deemed

the best way to increase the longevity of the product (Kader, 2002). The objectives of the present study were to evaluate the effects of polyethylene thickness, active and inactive gas combination and temperature on weight loss, firmness, soluble solid, titratable acidity, pH, shelf life and quality of strawberry.

Material and methods

Strawberries from cultivar Paros grown in greenhouse of Gardening Department of Sari University of Agricultural Sciences and Natural Resources were harvested. They were transported in to the laboratory. The strawberries were sorted to eliminate premature and rotten berries as well as any samples with obvious defects. 6 strawberries were placed in every bag. The controlled treatment was unpackaged and placed under normal conditions. 6 bags of strawberries stored at 4 °C and other stored at 8 °C.

In the present study polyethylene bags with three different thicknesses were used. The bags were 30, 50 and 90 μ m. The packing was done in modified atmosphere. Two gas compounds, active and inactive, were used to pack the product. For the active compound three different gases oxygen, carbon dioxide and nitrogen with two different combinations were applied in packing the treatments.

The first combination included O₂ 10%, CO₂ in 15% and the rest uneffective gas, nitrogen (N₂75%+CO₂15%+O₂10%).

The second combination included O₂ 15%, CO₂ in 10% and the rest uneffective gas, nitrogen (N₂75%+CO₂1.0%+O₂15%).

To conduct the research, the samples were after placing the product in the desired coatings, weighed strawberries then placed in a vacuum packing machine (DZQ-400/2E, China).

First, considering the program of the device the gases existing in the vacuum and the packages were extracted and

then the gases, having been already combined in the cylinders connected to the device, were injected to the device after that the packages were automatically sealed. In inactive approach micron-size pores are made on the packing. In the present study applying a manual approach with a needle which had a tip of 80 μm diameter, 6 pores (3 on each side) were made on the pack. Having placed the packages in the environment the gases were emptied and they were packed without inserting gas. After packing all the samples, they were all weighed and prepared, along with control samples, to be placed in refrigerator with 4 ± 1 °C and the other half in a refrigerator with 8 ± 1 °C. The weight of all the bags was recorded the first day of storage and during the test. The weighing process was conducted by a digital scale (JADEVER, Taiwan), with precision of 0.01, and then the samples were put under the two temperature treatments, the weights of the packages were weighed daily by a scale of 0.01 with a precision. Method of Mostofi & Najafi (2004) were used to calculate the weight loss.

A texture analyzer, model FG-5020, connected with a testing tensile was used to measure the firmness of fruit texture applying a cylindrical penetration probe connected to the testing tensile from the tip. The maximum mean of the data were digitally recorded and reported according to Newtonian metric system. Total soluble solids (TSS) were measured in an atago digital refractometer (DBR0090, China), and the results are expressed in Brix (%).

The percentage of titratable acidity with 0.01 of normal caustic soda was measured. In this test 5 mL of filtered juice was mixed with distilled water to reach 100 cc, and then it was titrated with reagent phenolphthalein, titrated

with a normal 0.01 soda. Every mL with 0.01 of normal caustic soda was deemed equal to 0.0067 g of citric acid (Parvane, 1992).

The pH of the strawberry homogenate was analyzed by a pH meter (Sartorius PB-11, USA) in duplicate measurements. The pH meter was calibrated with buffer solutions of 4.1, 7 and 9.2 and then the fruit extract was poured into beaker and after calibrating electrodes in the mixture, the pH was read. Having read each electrode, they were washed by distilled water and then passed through filter paper (Mostofi & Najafi, 2004).

The present study was conducted applying completely randomized design with factorial experiment in three replications tests. The treatments used in the study were two active gas combinations ($\text{CO}_2 15\% + \text{O}_2 10\%$ and $\text{CO}_2 10\% + \text{O}_2 15\%$) as well as an inactive gas combination (air). Polyethylene bags with 3 different thicknesses were used. The bags were 30, 50 and 90 μm in 4 and 8 °C.

Completely randomized design with factorial experiment in three replications test was used for multiple comparison and separation of means. Statistical analysis was carried out using the general linear models procedure of SAS (version 9) and Genstat (version 12).

Result and discussion

This study showed the important role played by polyethylene thickness, temperature and gas combination for determining the shelf life and quality of strawberry (Table 1). All major effects on the measured traits at the probability level of ($P \leq 0.01$) were significant, except the effect of coating thickness on texture firmness and pH that was non-significant. Some of interaction effects on the measured traits at the probability levels of ($P \leq 0.05$) or ($P \leq 0.01$) were significant.

Table 1. Effect of modified atmosphere packaging on quantity and quality properties of strawberry

Statistical sources	DF	Mean of squares				
		Weight loss (%)	Texture firmness (n)	Soluble solids (brix)	Titrateable acidity (%)	pH
Gas combination	2	0.003144**	0.00274**	2.02374**	1.85096**	0.129980**
Temperature	1	0.014569**	1.81134**	13.48001**	2.29402**	0.248067**
Thickness	2	0.009124**	0.0458 ^{ns}	1.64067**	0.95045**	0.002230 ^{ns}
Temperature×Gas combination	2	0.000009 ^{ns}	0.12647**	4.98624**	0.36987*	0.006939 ^{ns}
Gas combination×Thickness	4	0.000330 ^{ns}	0.87377**	1.01431**	1.02597**	0.112063**
Thickness×Temperature	2	0.000810*	0.16010**	0.09060*	0.06511 ^{ns}	0.097067**
Gas combination×Thickness×Temperature	4	0.000079 ^{ns}	0.31488**	0.42611**	0.20161*	0.76389**
Error	36	0.000128	0.01429	0.02488	0.04833	0.003937
coefficient of variations	2	17.2	4.5	1.4	2.9	1.4

ns: non-significant, *($P \leq 0.05$) and ** ($P \leq 0.01$)

Weight loss percentage

The analysis of variance (Table 1) showed that there was a significant difference between different thicknesses of polyethylene, gas compositions and storage temperature at 1% level.

The strawberries packed with EMAP1 (CO₂15%+O₂10%) lost little weight compared to other gas combinations. Polyethylene with thickness of 90 μ m lost very little weight compared to other thickness.

After storage at 4 °C, the weight of the strawberries was reduced by 0.49% whereas the weight of the strawberries at 8 °C decreased by 0.82%.

Statistical interactions between thickness and temperature indicated a significant effect on weight loss ($P \leq 0.05$) and interaction between gas combination and temperature, thickness and gas combination and three-way interactions among gas combination, temperature and thickness had no significant effect on weight loss. Figure (1) showed interactions between polyethylene with thickness of 50 and 90 μ m and temperature at 4 and 8 °C had an insignificant effect. The lowest weight loss between two temperatures of 4 and 8 °C was observed in coating with the thicknesses of 90 and 50 μ m at the temperature of 4 °C and the highest

weight loss was observed in the control case at the temperature of 8 °C.

Low permeability of packaging coatings reduces the weight loss and creates an appropriate atmosphere for protecting fruits (Anon, 2003). Packaging coatings, with increased relative humidity around the product and decreased air velocity on the product surface, create a stable layer around the product and decrease pressure difference between environment and product texture followed by decreased evaporation and water and weight loss (Liu *et al.*, 2004)

Martinez & Artes (1999) examined the effects of polypropylene coatings with the thicknesses of 30 and 40 μ m as perforated and unperforated with cooling by vacuum and active modified atmosphere with O₂5% and CO₂0% on lettuce and concluded that unperforated polypropylene coating (40 μ m) without active modified atmosphere has the best performance in maintaining the appearance, preventing weight loss, and wilting of lettuce. At the temperature of 4 °C, since respiration, transpiration, and metabolic processes are slow, qualitative and quantitative properties of strawberries were preserved better compared with the temperature of 8 °C.

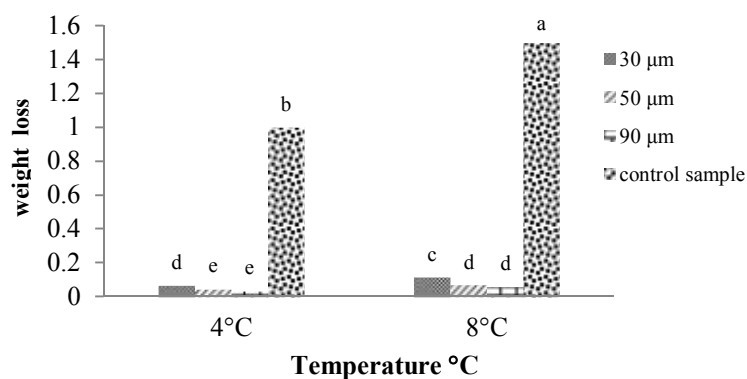


Figure 1. The interaction effect of temperature and coating thickness on strawberry weight loss percentage (Non-similar letters indicate a significant difference between treatments)

Texture firmness

Table (1) showed that temperature and gas combination had a significant effect on strawberry texture firmness ($P \leq 0.01$), but the effect of coating thickness on texture firmness was not significant. Mean comparison results showed that all treatments were softened during the storage period and reduced their stiffness. The first gas composition ($\text{CO}_2 15\% + \text{O}_2 10\%$) and control treatment showed the lowest texture firmness and the firmness level between the second gas composition ($\text{CO}_2 10\% + \text{O}_2 15\%$) and the inactive gas composition had no significant difference. The temperature of 4 °C was more suitable compared with the temperature of 8 °C to maintain strawberry texture firmness.

All mutual effects of temperature and gas composition and temperature and coating thickness and gas composition and coating thickness and also the interaction effect of temperature and gas composition and coating thickness on strawberry texture thickness were significant at the probability level of ($P \leq 0.01$) (Table 1). The first gas composition ($\text{CO}_2 15\% + \text{O}_2 10\%$) in the coating with the thickness of 90 µm with the maintenance of texture firmness as 45% showed a better performance compared the control case (Figure 2-A).

Storage of products in packages with

higher CO_2 leads to decreased texture firmness that is consistent with the findings of Herner (1987) who concluded that tomato softening will be delayed with decreased respiration through increased CO_2 concentration

Jouki & Khazaei (2014) found that strawberry packaged by gas composition with higher CO_2 concentration, maintained texture and appearance of strawberry better compared with inactive composition and gas composition with lower CO_2 concentration.

Martinez-Romero *et al.* (2003) stated that increased CO_2 concentration and decreased O_2 concentration minimize respiration and metabolic activities of the fruit and packaging in the modified atmosphere with the prevention of pectin degrading enzymes activities leads to fruit texture firmness. According to the interaction effect of temperature and gas composition on texture firmness, no significant difference existed between the first gas composition ($\text{CO}_2 15\% + \text{O}_2 10\%$) and the second gas composition ($\text{CO}_2 10\% + \text{O}_2 15\%$) and inactive gas composition at the temperature of 4 °C and the best performance in texture firmness maintenance was observed. Also, the control case showed strawberry texture softening at the temperature of 8 °C (Figure 2-B).

Generally, low temperature facilitates

decreased respiration, microorganism growth, and delay in metabolic activity of the plant texture (Villaescusa & Gill, 2003; Ooraikul & Stilles, 1991; Paine & Paine, 1992; Zagory & Kader, 1988). The interaction effect of temperature

and polyethylene coating thickness on strawberry texture firmness showed that the thickness of 90 μm at the temperature of 4 $^{\circ}\text{C}$ prevented strawberry texture softening better than other thicknesses (Figure 2-C).

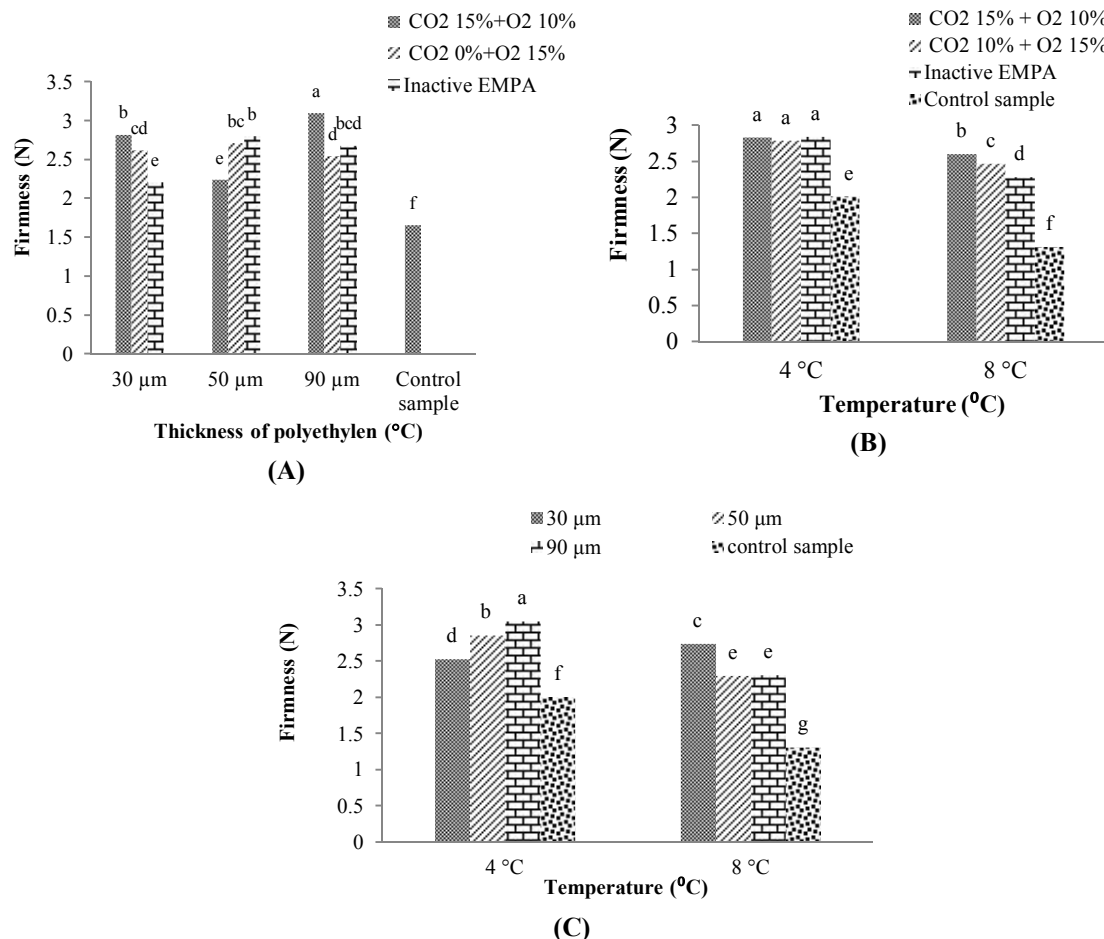


Figure 2. The interaction effect of (A) polyethylene coating thickness and gas composition on strawberry, (B) temperature and gas composition, (C) temperature and polyethylene coating thickness; on strawberry texture firmness

(Non-similar letters indicate a significant difference between treatments)

Ghorbani *et al.* (2017) found that by increasing the storage time and temperature, texture firmness decreases. In coatings with higher thickness, due to low permeability and humidity maintenance inside the package, qualitative and quantitative properties of the product are preserved better. Esmaeili (2012) found that polyethylene with the thickness of 50 μm compared with the thickness of 20 μm was more efficient in maintenance of texture firmness and decreased weight loss of

packaged tomato.

The interactions among temperature, gas combination and coating thickness showed the passive inactive gas combination and first gas combination (CO₂15%+O₂10%) with polyethylene bags (50 and 90 μm thickness) at 4 $^{\circ}\text{C}$ retained firmness compared to other treatments Figure (3). Alonso & Alique (2003) used two types of coatings with different permeability for cherry packaging and the results showed that coating with smaller pores and low

permeability maintains acidity and firmness in packaged cherry and it turns

black followed by decreased quality and increased decay.

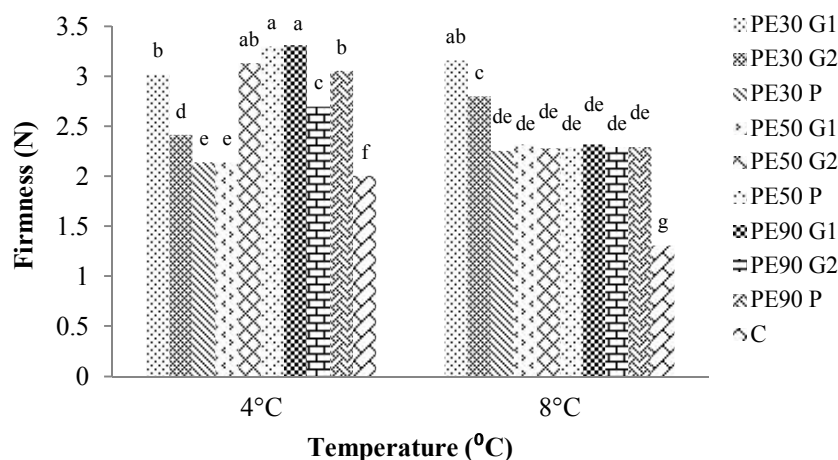


Figure 3. The interaction effect of temperature and gas composition and polyethylene coating thickness on strawberry (texture firmness PE30G1, PE50G1 and PE90G1: Polyethylene with thickness of 30, 50 and 90 μm respectively under first gas composition ($\text{CO}_2 15\% + \text{O}_2 10\%$); PE30G2, PE50G2 and PE90 G2: Polyethylene with thickness of 30, 50 and 90 μm respectively under second gas composition ($\text{CO}_2 10\% + \text{O}_2 15\%$) and PE30, PE50 and PE90: Polyethylene with thickness of 30, 50 and 90 μm respectively under inactive gas composition) (Non-similar letters indicate a significant difference between treatments)

Soluble solids

The results of analysis of variance showed that temperature, gas component and thickness had significant effects ($P \leq 0.01$) on total soluble solids of strawberries (Table 1). The results of analysis of variance showed that strawberry soluble solids increased in all treatments at the end of the storage period. It seems that this is due to the product respiration during the storage period and conversion of sugar to starch metabolism. In the second gas composition ($\text{CO}_2 10\% + \text{O}_2 15\%$), soluble solid showed minimum increase and the control treatment showed the maximum increase. In the coating with the thickness of 30 μm , soluble solids showed minimum increase that is probably due to desirable atmospheric conditions for the product in the package. The temperature of 4 °C is better for the maintenance of soluble solids compared with the temperature of 8 °C. The interaction effect of temperature and gas composition and gas composition and coating thickness and the interaction effect of

temperature, gas composition and coating thickness at the probability level of ($P \leq 0.01$) showed a significant difference but the interaction effect of temperature and coating thickness at the probability level of ($P \leq 0.05$) had a significant effect on soluble solids. In investigating the interaction effect of coating thickness and gas composition of the second gas composition ($\text{CO}_2 10\% + \text{O}_2 15\%$), in the thickness of 30 μm , the soluble solids have been maintained better than other soluble solids and the control treatment showed the highest increase in soluble solids (Figure 4-A).

Aminzadeh *et al.* (2014) observed that thin packaging coatings maintain soluble solids better. Mohebi *et al.* (2015) found that gas composition with lower CO_2 percentage maintains soluble solids better. The interaction effect of temperature and gas composition of the second gas composition ($\text{CO}_2 10\% + \text{O}_2 15\%$) at the temperature of 4 °C showed the minimum increase in soluble solids (Figure 4-B).

According to the interaction effect of temperature and coating thickness, the thickness of 30 μm at the temperature of 4 $^{\circ}\text{C}$ showed the best performance in the maintenance of soluble solids

(Figure 4-C). At the temperature of 4 $^{\circ}\text{C}$ with decreased respiration and evaporation, better atmospheric condition is provided to maintain soluble solids.

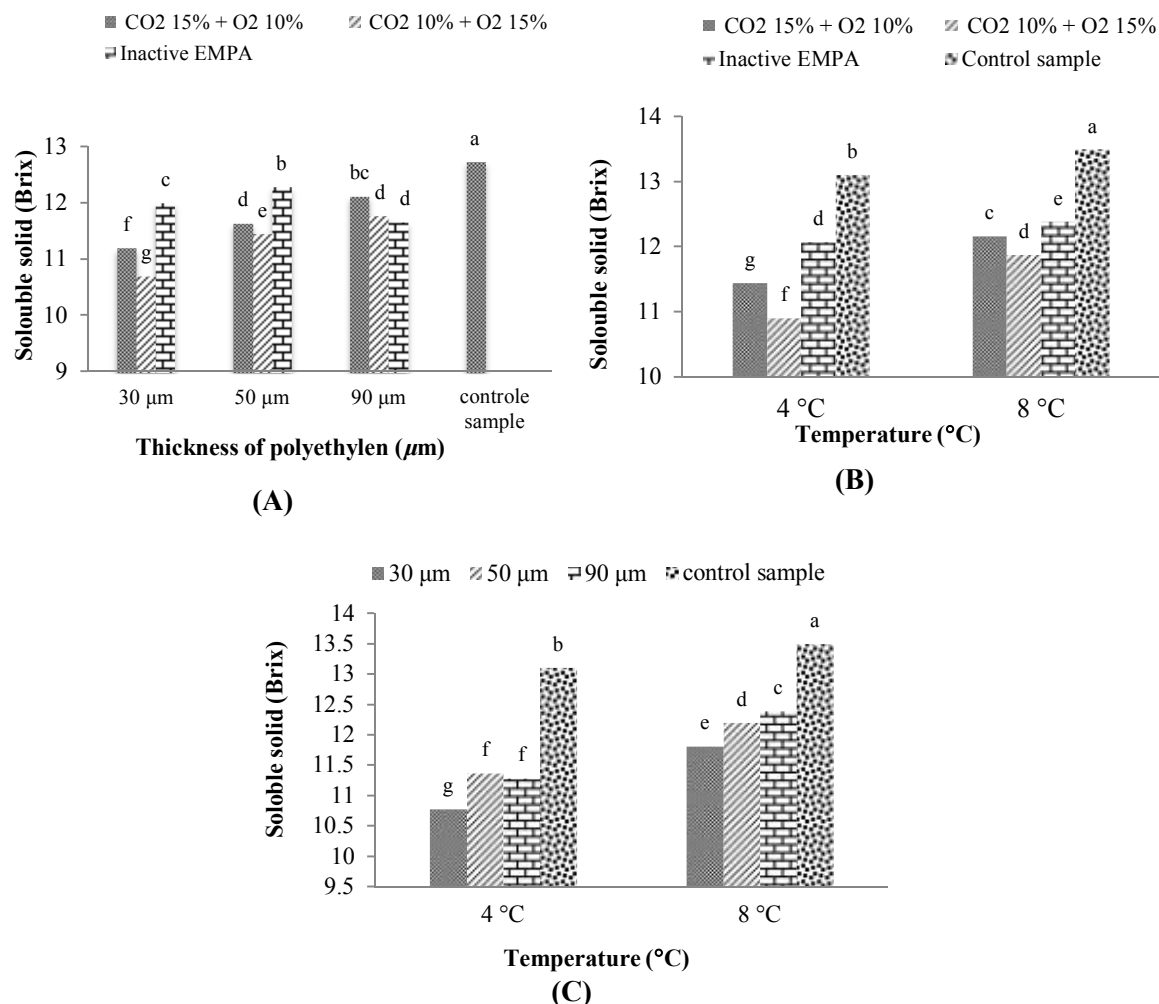


Figure 4. The interaction effect of (A) gas composition and polyethylene coating thickness, (B) temperature and gas composition, (C) temperature and polyethylene coating thickness; on strawberry soluble solids

(Non-similar letters indicate a significant difference between treatments)

In investigating the interaction effect of temperature, gas composition and coating thickness, the thickness of 30 μm in the second gas composition (CO₂10%+O₂15%) and the temperature of 4 $^{\circ}\text{C}$ showed the best performance in the maintenance of soluble solids (Figure 5). The modified atmosphere packaging led to the maintenance of soluble solids and prevention of its increase and also prevention of the

metabolism related to the conversion of starch to sugar. Batu & Thompson (1994) reported that in a study, they found that the use of 50 μm polyethylene coating in tomato, after 60 days of storage in the cool warehouse led to the maintenance of soluble solids compared with uncoated samples. Aminzadeh *et al.* (2014) observed that thin packaging coatings maintain soluble solids better.

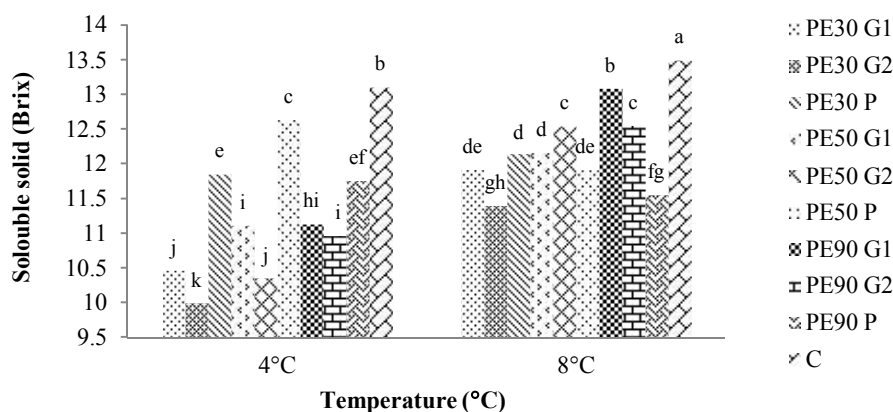


Figure 5. The effect of temperature and gas composition and polyethylene coating thickness on strawberry soluble solids (PE30G1, PE50G1 and PE90G1: Polyethylene with thickness of 30, 50 and 90 μm respectively under first gas composition ($\text{CO}_2 15\% + \text{O}_2 10\%$); PE30G2, PE50G2 and PE90G2: Polyethylene with thickness of 30, 50 and 90 μm respectively under second gas composition ($\text{CO}_2 10\% + \text{O}_2 15\%$) and PE30, PE50 and PE90: Polyethylene with thickness of 30, 50 and 90 μm respectively under inactive gas composition)

(Non-similar letters indicate a significant difference between treatments)

Titratable acidity

Strawberry titratable acidity decreased in all treatments at the end of the storage period. Titratable acidity decreases in ripe fruits. Investigating the results of analysis of variance in Table (1) showed that temperature, gas composition and polyethylene thickness had a significant on strawberry titratable acidity ($P \leq 0.01$).

The second gas composition ($\text{CO}_2 10\% + \text{O}_2 15\%$) performed better than the first gas composition and inactive composition in titratable acidity maintenance. Coating with the thickness of 90 μm showed the best performance in preventing decreased titratable acidity. The temperature of 4 $^{\circ}\text{C}$ showed the best performance compared with the temperature of 8 $^{\circ}\text{C}$ in the maintenance of titratable acidity. Among interaction effects, the effect of temperature and gas composition and also the interaction effect of temperature, gas composition and polyethylene coating at the probability level of ($P \leq 0.05$) and the interaction effect of composition and coating thickness at the probability level of ($P \leq 0.01$) had a significant effect on titratable acidity. The interaction effect of coating thickness and temperature did not show any significant effect on titratable acidity. According to the interaction effect of coating thickness

and gas composition (Figure 6-A), the second gas composition ($\text{CO}_2 10\% + \text{O}_2 15\%$) at 90 and 50 μm has the best performance in keeping the titres of acidity possible.

Nakhasi *et al.* (1991) reported the strawberries packed with modified atmosphere packaging lost little titratable acidity compared to controlled treatment. Alonso & Alique (2003) found that edible packaging with low permeability was useful to preserve quality of cherries through losses of titratable acidity.

Interaction of temperature and gas combination (Figure 6-B) showed second gas composition ($\text{CO}_2 10\% + \text{O}_2 15\%$) at 4 $^{\circ}\text{C}$ lost little titratable acidity compared to other treatments.

Mohebi *et al.* (2015) concluded that titratable acidity is maintained better in the gas composition with low CO_2 percentage.

In interaction effect investigation among temperature, gas combination and polyethylene thickness showed strawberries sealed within polypropylene with thickness of 50 and 90 μm retained titratable acidity under second gas composition at ($\text{CO}_2 10\% + \text{O}_2 15\%$) at 4 $^{\circ}\text{C}$ compared to other treatment (Figure 6-C). with increased coating thickness,

permeability decreased and as a result, respiration decreased and ripening delayed and acidity reduction was prevented. In a study by Batu & Thompson (1996) on tomato packaged under modified atmosphere and also studies by Majidi *et al.* (2011) and

Tasdelen & Bayindirli (1998), titratable acidity in packaging coatings was maintained better. Tefera *et al.* (2007) stated that increased temperature decreased weight loss and enhanced qualitative properties of fruit such as pH and acidity.

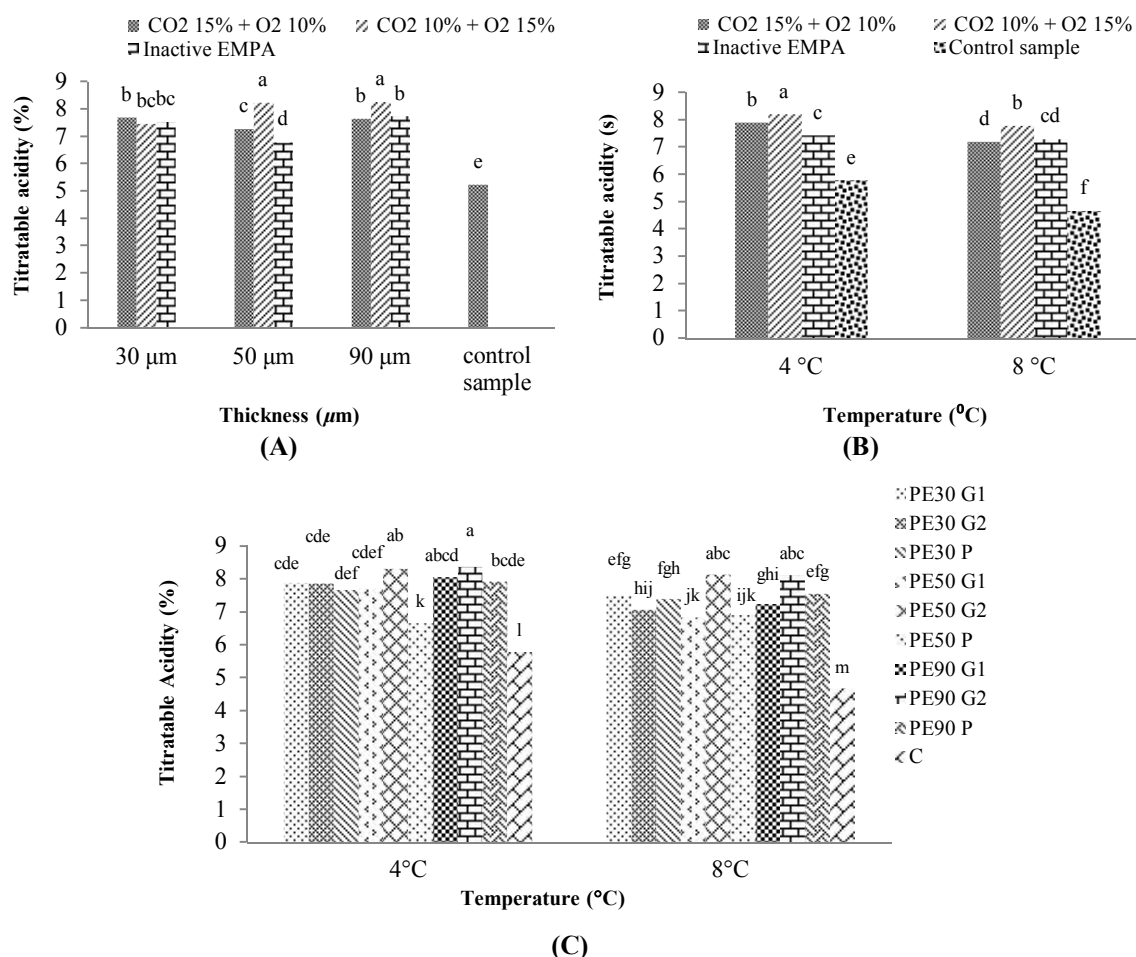


Figure 6. The interaction effect of (A) gas composition and polyethylene coating thickness, (B) gas composition and temperature, (C) temperature and gas composition and polyethylene coating thickness on strawberry titratable acidity (PE30G1, PE50G1 and PE90G1: Polyethylene with thickness of 30, 50 and 90 μm respectively under first gas composition (CO₂15%+O₂10%); PE30G2, PE50G2 and PE90G2: Polyethylene with thickness of 30, 50 and 90 μm respectively under second gas composition (CO₂10%+O₂15%) and PE30, PE50 and PE90: Polyethylene with thickness of 30, 50 and 90 μm respectively under inactive gas composition) (Non-similar letters indicate a significant difference between treatments)

pH

pH of all samples increased during storage time. Results indicated that temperature and gas combination had a significant effect ($P \leq 0.01$) on pH value of strawberries (Table 1). Thickness of polyethylene had an insignificant effect on pH value. Strawberries under active first gas composition (CO₂15%+O₂10%) had lower pH than strawberries

packaged under air and the control case had the highest increase in strawberry pH. Changes in pH at 4 $^{\circ}\text{C}$ were lower than changes at 8 $^{\circ}\text{C}$. In investigating the interaction effects regarding pH, it was observed that except the interaction effect of temperature and gas composition that did not have any significant effect on pH, other interaction effects had a significant

effect on strawberry pH at the level of ($P \leq 0.01$). Investigating the effect of gas composition and coating thickness showed that the first gas composition ($\text{CO}_2 15\% + \text{O}_2 10\%$) at the thickness of $90 \mu\text{m}$ had the best performance in pH maintenance (Figure 7-A).

High concentration of CO_2 due lower respiration rate retained pH value. These results are in agreement with the observation of Tabatabaekoloor *et al.* (2016) who reported that inactive gas combination with high concentration of CO_2 retained pH of tomatoes at 4 and 20°C . Interaction between thickness and temperature showed polypropylene with thickness of 30 and $90 \mu\text{m}$ at 4°C had lower pH value (Figure 7-B) and

the control treatment at the temperature of 8°C showed the highest increase in pH. The temperature of 4°C showed lower respiration, transpiration, and evaporation and is more suitable.

In the study of the interplay of the interactions among gas combination, temperature and coating thickness it was observed first gas combination ($\text{CO}_2 15\% + \text{O}_2 10\%$) in coating with a thickness of $90 \mu\text{m}$ at 4°C was better than other treatments it prevents the increase of pH (Figure 7-C). In coatings with a thickness of $90 \mu\text{m}$ due to low permeability, products have better quality. Tefera *et al.* (2007) reported the decrease of temperature retained pH value.

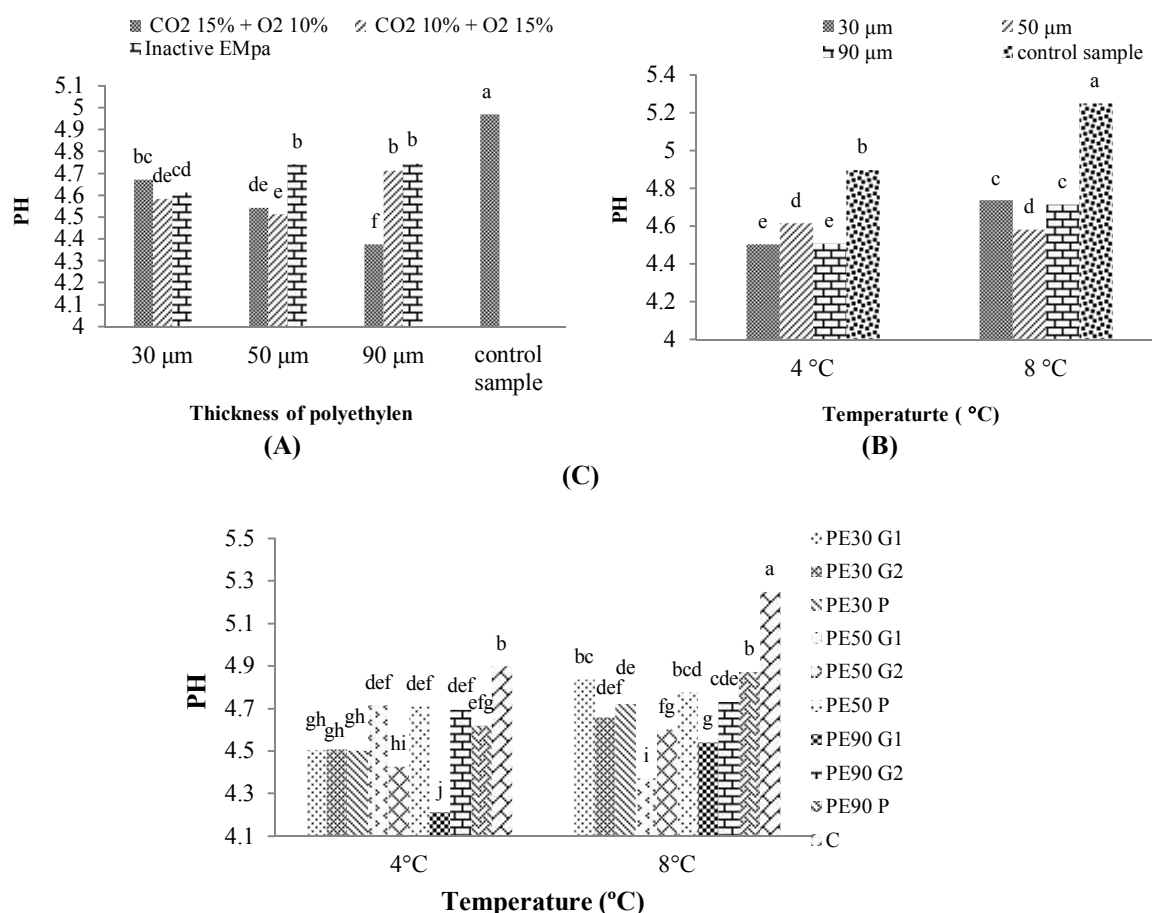


Figure 7. The interaction effect of (A) gas composition and polyethylene coating thickness, (B) polyethylene coating thickness and temperature, (C) gas composition and temperature and polyethylene coating thickness; on strawberry pH (PE30G1, PE50G1 and PE90G1: Polyethylene with thickness of 30, 50 and $90 \mu\text{m}$ respectively under first gas composition ($\text{CO}_2 15\% + \text{O}_2 10\%$); PE30G2, PE50G2 and PE90G2: Polyethylene with thickness of 30, 50 and $90 \mu\text{m}$ respectively under second gas composition ($\text{CO}_2 10\% + \text{O}_2 15\%$) and PE30, PE50 and PE90: Polyethylene with thickness of 30, 50 and $90 \mu\text{m}$ respectively under inactive gas composition) (Non-similar letters indicate a significant difference between treatments)

Conclusion

The results of this study showed that between two temperatures that tests were conducted at, the temperature of 4 °C due to decreased respiration, transpiration and evaporation in maintaining qualitative and quantitative properties of strawberry was better than the temperature of 8 °C. The polyethylene lining at thickness of 90 µm, maintained the qualitative and quantitative qualities of the product due

to low permeability and maintaining the moisture around the product within the package. The first gas combination was more suitable for keeping the qualitative and quantitative characteristics of strawberries due to more CO₂ and reduced respiration. As a result, strawberries packed in a 90 µm thickness of polyethylene and first gas combination (N₂75%+CO₂15%+O₂10%) at 4 °C had the best quality and highest durability.

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بررسی تأثیر ضخامت پلی اتیلن، ترکیب گازی و دما بر زمان ماندگاری و کیفیت توت فرنگی

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چکیده

در این پژوهش، تأثیر بسته بندی تحت اتمسفر اصلاح شده بر کیفیت و طول عمر توت فرنگی مورد بررسی قرار گرفت. برای بسته بندی توت فرنگی ها از سه ترکیب گازی (هوا، ترکیب گازی اول: ۷۵ درصد نیتروژن + ۱۵ درصد دی اکسید کربن + ۱۰ درصد اکسیژن و ترکیب گازی دوم: ۷۵ درصد نیتروژن + ۱۰ درصد دی اکسید کربن + ۱۵ درصد اکسیژن)، کیسه های پلی اتیلن در سه ضخامت ۳۰، ۵۰ و ۹۰ میکرون و دو دمای نگهداری 4 ± 1 و 8 ± 1 درجه سانتی گراد استفاده شد. تأثیر تیمارهای یاد شده در قالب طرح کاملاً تصادفی با آزمایش فاکتوریل در سه تکرار بر پارامترهای درصد کاهش وزن، سفتی بافت، مواد جامد محلول، اسیدیته قابل تیتراسیون و pH در توت فرنگی در پایان روز ۲۰ام از زمان نگهداری بررسی شد. نتایج آنالیز واریانس نشان داد که تأثیر ترکیب گازی و دما بر تمامی فاکتورهای مورد اشاره در سطح ۱ درصد معنی دار است، ولی اثر ضخامت پوشش پلی اتیلن فقط بر درصد کاهش وزن، مقدار مواد جامد محلول و اسیدیته قابل تیتر در سطح ۱ درصد معنی دار بود. در بین دو دمایی که آزمایش در آن دامنه صورت گرفت، دمای ۴ درجه سانتی گراد به دلیل کاهش تنفس، تبخیر و تعرق در حفظ خصوصیات کمی و کیفی توت فرنگی بهتر از دمای ۸ درجه سانتی گراد عمل کرد. پوشش پلی اتیلن در ضخامت ۹۰ میکرون به دلیل نفوذپذیری کم و حفظ رطوبت اطراف محصول درون بسته خصوصیات کیفی و کمی محصول را بهتر حفظ نمود. ترکیب گازی اول به دلیل داشتن CO₂ بیشتر و کاهش تنفس برای حفظ خصوصیات کیفی و کمی توت فرنگی مناسب تر است. در نتیجه توت فرنگی هایی که در پوشش پلی اتیلن با ضخامت ۹۰ میکرون و ترکیب گازی اول در دمای ۴ درجه سانتی گراد بسته بندی شدند بهترین کیفیت و بالاترین ماندگاری را داشتند.

واژه های کلیدی: اتمسفر اصلاح شده، ترکیب گازی، توت فرنگی، دما