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## Evaluation of physicochemical changes of strawberry under modified atmosphere using nanocomposite packaging film

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### ABSTRACT

The perishable nature of strawberry fruit is one of the key factors that limit its consumption, specified by its decreased freshness and shelf life after harvest. The suitable packaging conditions, low temperature storage, and desired atmosphere composition inside packaged are important to preserve the quality attributes and extend the shelf life of perishable fruits. In this study, the packaging films based on PLA (such as neat PLA, PLA/TA10, and PLA/C20A1/TA10) with two different gas mixtures (such as 10 KPa O<sub>2</sub>+15 KPa CO<sub>2</sub>+75 KPa N<sub>2</sub> (MAP-A) and 15 KPa O<sub>2</sub>+10 KPa CO<sub>2</sub>+75 KPa N<sub>2</sub> (MAP-B)) and a control sample without gas injection on fresh strawberry fruit were evaluated. The effects of the mentioned treatments on some physicochemical properties such as weight loss, total soluble solid, titratable acidity, pH, and firmness kept at 4 °C for 23 days of storage period were evaluated based on a completely randomized design. The results showed that the weight loss and firmness of strawberry fruit decreased during storage time, while pH value increased. The total soluble solid and titratable acidity of all the treatments increased throughout the storage time and decreased at the end of the storage time. It has been also reported that fruits packaged in PLA/C20A1/TA10 caused better quality attributes due to lower water vapor permeability and oxygen transmission rate than two films of neat PLA and PLA/TA10. In addition, the gas mixture of MAP-A was more suitable in comparison to MAP-B due to higher carbon dioxide inside packages and lower respiration rate of strawberry fruit. Therefore, the use of nanocomposite film with modified atmosphere has been proposed to maintain strawberry fruit at a low temperature.

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## 1. Introduction

The projected growth of the world population will significantly increase the pressure on natural resources to meet food needs. Achieving food security due to limited resources and climate change without endangering the ecosystem and biodiversity is an important global strategy [1]. Therefore, maintaining the nutritional value and quality characteristics of fresh products is an important challenge [2]. One of the key factors to increase the consumption of strawberry fruit is the presence of healthy and abundant compounds in this fruit. Also, important amounts of fiber and other nutrients such as vitamins, calcium, phosphorus, iron and flavonoids along with free radical absorbing and antioxidant properties have been identified in strawberry fruits. Various studies have shown that these compounds play an important role in human health. However, the abundance of these compounds decreases after harvesting due to the degradation of quality characteristics. One of the important factors in reducing the consumption of strawberry fruit is its perishable nature, which reduces its shelf life during storage. Also, the main factors of strawberry fruit quality reduction are surface dehydration, color change, premature aging, browning, relatively high metabolic activity, presence of microbial fungi and decay. Therefore, it is very important to provide suitable methods to maintain the quality properties and nutritional value of strawberry fruit after harvest [3]. In general, to reduce the high perishability of fresh fruits and vegetables, the levels of cold storage should be used to distribute them along the chain after harvest. In addition to refrigerators, plastic packaging is usually used to preserve fresh products from external factors, which cause environmental problems due to non-renewability. Nowadays, biopolymers as packaging materials have attracted a lot of attention due to their renewable and degradability. Although two packaging technologies and low temperature maintain the quality of the fresh product to some extent, the amount of total waste of fruits and vegetables is still very high, which according to the report of researchers even reaches 40-46% [4]. In recent decades, researchers have made many efforts to produce and develop suitable solutions to reduce losses of fresh fruits and vegetables.. Modified

atmosphere packaging is a promising method to maintain quality, increase shelf life and reduce waste of fresh products [5]. This technology is based on the modification of the gaseous composition inside the package containing the fruit, which reduces the physical and biochemical activities of the product, limits the respiration rate of the product, delays the aging and destruction of the product, and ultimately improves the storage quality, preserves freshness and increases shelf life. Fresh products are packed [6]. Studies have shown that the composition of the equilibrium atmosphere within the package depends on the type of product, storage temperature, product breathability, and film permeability characteristics, and the selection of an inappropriate gas composition leads to a decrease in the shelf life of the product [7]. The mass transfer of compounds with low molecular weight, including water vapor and gases, through the walls of packaging materials plays an important role in controlling food degradation reactions. Also, optimizing the gas conditions inside the package limits oxidation reactions and reduces the growth of aerobic microorganisms, which are the main factors of food spoilage during storage. Therefore, it is very necessary to choose packaging materials with suitable barrier properties to maintain quality indicators and increase the shelf life of freshly packaged products [8; 9]. In addition, temperature control is one of the most important factors for the modified atmosphere system. Temperature strongly affects the growth of pathogens, product respiration rate and gas permeability through packaging films and changes the atmosphere inside the package. Therefore, maintaining the temperature around the package in the range of 4 degrees Celsius or lower is necessary for microbial safety [10]. Researchers found that modified atmosphere treatments containing 5-10% oxygen and 15-20% carbon dioxide at 0-5 degrees Celsius are effective in preserving strawberry fruit [11]. The quality of strawberry fruit can be maintained through storage in a modified atmosphere containing 11-14% oxygen and 9-12% carbon dioxide [12]. The results showed that the concentrations of oxygen and carbon dioxide are about 10% and 10-20%, respectively, to maintain the quality of fresh

raspberry fruit [13]. However, the recommended gas composition for strawberry fruit storage varied according to different reports. This can be related to the type of variety, growth conditions, degree of ripening, storage temperature and selection of quality parameters, which play an important role in determining the most appropriate storage atmosphere [14]. Although the favorable effects of modified atmosphere technology have been used in a wide range for fresh produce, few studies have been conducted for strawberry fruit packaging under modified atmosphere conditions, low storage temperature and the application of bionanocomposite packaging films. Therefore, this combined method can be used as a suitable storage technique for fresh fruits and vegetables. In this research, the following are investigated: 1) investigating the effect of the concentration of gases and different packaging materials on the physicochemical properties of strawberry fruit and 2) providing an effective and optimal method to increase the storage period of strawberry fruit.

## 2- Materials and methods

### 2-1- Required materials

Polylactic acid (PLA<sup>1</sup>) with grade 2003D, specific weight  $g\ cm^{-3}$  1.14, melt flow index  $g/10min$  6 (temperature  $C^{\circ}210$   $\cdot Kg$  16/2) and melt temperature  $C^{\circ}210$  of the company NatureWorks LLC (Minnetonka USA) it was prepared. Also, Triacetin plasticizer (<sup>2</sup>FACING) in liquid form with chemical formula  $C_9H_{14}O_6$ , Molecular Weight  $g\ mol^{-1}$  2/218 and specific gravity  $cm^{-3}$  16/1 from company Sigma Aldrich used. Modified montmorillonite nanoclay type Auditorium 20A (C20A) also as a strengthening agent with Specific weight  $g\ cm^{-3}$  77/1 from Shanghai port company (China) it was prepared.

### 2-2- Film preparation and features

Packaging films including neat PLA, PLA/TA10 and PLA/C20A1/TA10 were produced by melt blowing method in the Polymer and Petrochemical Research Institute of Iran. The mixing of polymer materials was done using a

twin screw extruder (Coperison, Germany) with a length to diameter ratio of 45, a screw diameter of 24 mm and a screw speed of 250 rpm. The pressure and temperature of the melt in different areas of the extruder, from the feeding area to the outlet area, were equal to 70 bar and 180 degrees Celsius, respectively. The ingredients of the film are listed in different compositions according to Table 1. Single screw extruder and extrusion roller were used to produce the final film. At this stage, the polymer mixtures were placed in the feeding area and entered the spiral chamber and melted. The molten material flowed towards the spiral channel and a thin film was formed [15]. Measurement parameters such as mechanical properties, moisture content, water vapor permeability and oxygen transfer rate were determined to evaluate the films. Tensile strength and flexibility at the point of failure were obtained using a texture analyzer TA-XT2 (Stable Micro Systems, UK) equipped with a 25 kg load cell according to the standard method. The initial distance of the grips was 30 mm and the transverse speed was 5 mm/min [7]. The moisture content (in percent) was determined by dividing the weight difference by the initial weight of each film multiplied by 100 [16]. OX-TRAN (Mocon, Model 2/40, USA) were determined. Three samples of each packaging film with a cross-sectional area of  $cm^2$  5 was tested at a temperature of 25°C and a relative humidity of 50% and the average comparison was recorded [6].

**Table 1** The formulation of all compounds in this work.

Code	Composition	PLA	FACING	C20A
P1	Neat PLA	100	-	-
P2	PLAN/TA10	90	10	-
P3	PLA/C20A1/TA10	89	10	1

### 2-3- Sample preparation and packaging of strawberry fruit

Strawberry fruits (Fragaria  $\times$  ananassa Duch.) Camarosa variety<sup>3</sup> They were harvested manually from a local farm in Behnmir city, Mazandaran province. Homogeneous fruits were selected in terms of color, size and lack of physical defects and were immediately

1. Polylactic acid  
2. Triacetin

3. Camarosa

transferred to the post-harvest research laboratory at Sari University of Agricultural Sciences and Natural Resources. Three strawberry fruits were placed in each of the packaging films (100 mm x 100 mm) and weighed. Then the gas compositions were injected into the packages using a gas injection packaging machine (MAP 500D, Jugang Machine Co, China) according to table (2). Three PLA-based films including neat PLA (with a thickness of 65.33  $\mu\text{m}$ ), PLA/TA10 (with a thickness of 62.67  $\mu\text{m}$ ) and PLA/C20A1/TA10 (with a thickness of 63.67  $\mu\text{m}$ ) and two MAP-A gas compositions with a specification of 10 KPa  $\text{O}_2$ +15 KPa  $\text{CO}_2$ +75 KPa  $\text{N}_2$  and MAP-B with a specification of 15 KPa  $\text{O}_2$ +10 KPa  $\text{CO}_2$ +75 KPa  $\text{N}_2$  and a combination without gas injection were used (Table 2).

In all experiments, the package without gas injection was used as a control sample. All films used in this study were made by melt blowing method. The packages were completely pressed and then stored under the same conditions at 4 degrees Celsius with a relative humidity of 90%. The samples were regularly analyzed after 0, 3, 7, 11, 15, 19 and 23 days of storage. The storage time was limited to 23 days due to the perishability of strawberry fruit. Managing the process before harvesting strawberry fruit is effective on its shelf life, which was not considered in this experiment.

**Table 2** Packages of strawberry fruit in this study.

Code	Composition	Conditions inside packages
P1A1	Neat PLA	10 KPa $\text{O}_2$ +15 KPa $\text{CO}_2$ +75 KPa $\text{N}_2$
P2A1	PLAN/TA10	(MAP-A)
P3A1	PLA/C20A1/TA10	
P1A2	Neat PLA	15 KPa $\text{O}_2$ +10 KPa $\text{CO}_2$ +75 KPa $\text{N}_2$
P2A2	PLAN/TA10	(MAP-B)
P3A2	PLA/C20A1/TA10	
P1A3	Neat PLA	Air inside initially
P2A3	PLAN/TA10	(Passive-Blank)
P3A3	PLA/C20A1/TA10	

## 2-4- Qualitative characteristics of strawberry fruit

### 2-4-1- Weight loss (WL<sup>4</sup>)

The weight loss percentage of the packages was determined using a digital scale with an accuracy

4. Weight loss

of  $\pm 0.01$  grams (Gbertini Europe, Italy). Three repetitions for each time period (0, 3, 7, 11, 17, 19 and 23 days) sampling were done and average values were recorded [6].

### 2-4-2- Solution solid materials (<sup>5</sup>TSS)

Soluble solids are an important parameter to determine fruit quality. The amount of dissolved solids was determined in percent using a digital refractometer (Atago, Tokyo, Japan) [17]. In this test, the device was calibrated with distilled water. Three repetitions were done for each package and average values were recorded. TSS value is expressed as Brix index at 25°C.

### 2-4-3- titratable acidity (TA<sup>6</sup>)

Titratable acidity by titrating 2 ml of strawberry juice in 38 ml of distilled water with sodium hydroxide (NaOH) 1%. The mole/liter was determined to reach a pH of 1.8 and was reported as a percentage of citric acid equivalent [17].

### 2-4-4- pH

Strawberry fruits were squeezed with cleaning cloth and the obtained water was analyzed for pH, TSS and TA. The pH value of strawberry fruits was determined using a pH meter (Crison, Barcelon, Spain) at a temperature of 25°C [18].

### 2-4-5- hardness (F<sup>7</sup>)

The texture firmness of strawberry fruits was determined using a texture analyzer TA-XT2 (Stabk Micro Systems, Surrey, UK) equipped with a 25 kg load cell. The penetration speed was 1 mm/s, the diameter of the cylindrical probe was 8 mm, and the penetration depth was 3 mm. Three replicates for each package were evaluated during the storage period and the average value was recorded in Newton [14].

### 2-4-6- Statistical analysis

Analysis of variance (ANOVA) was used to determine the effects of the type of packaging film, modified atmosphere and storage period on the physicochemical properties of strawberry fruit at 4 degrees Celsius. Duncan's test was performed at the 95% probability level ( $P < 0.05$ ) to determine the significant difference between the treatments based on the three-variable

5. Total soluble solid

6. Titratable acidity

7. Firmness

factorial test in the form of a completely randomized design. SPSS software (version 22.0.0, IBM Institute Inc, USA) was used for this purpose and the values were reported as mean.

### 3. Results and Discussion

#### 3-1- General properties of the film

The properties of the packaging materials used in this study are shown in Table 3. Flexibility at the breaking point of the film PLA Pure significantly by adding triacetin plasticizer on the surface 10 wt.% improved while the tensile strength decreased. On the other hand, adding clay nanoparticles C20A leading to improved tensile strength of the film PLAN-TA10 which is consistent with the results of researchers [19].

The moisture content of the film PLA increased by adding plasticizer. Increase in humidity PLA/TA10 film It may be due to the hydrophilic nature of the plasticizer that free carbonyl and hydroxyl groups lead to the upward

movement of water molecules. On the other hand, adding nanoparticles C20A to PLA rate It increased the wettability of the nanocomposite film due to its hydrophilic nature C20A is [20;21]. Water vapor permeability of the film PLA The net content was 6.07%, which increased with the addition of plasticizer. Values of water vapor permeability and gas transfer rate for nanocomposite film PLA/C20A1/TA10 Compared to the movie PLAN/TA10 Decreased. The presence of clay plates lengthened and created spiral paths in the polymer matrix, and as a result, the transfer and penetration of water molecules through the matrix decreased. According to these findings, the use of nanocomposite is a suitable choice to improve the barrier properties, so that the nanocomposite film reinforced with nanoclay particles in the appropriate concentration has a significant improvement in physical properties compared to PLA had net [22; 23].

**Table 3** Tensile strength (TS), elongation at break ( $E_{ab}$ ), Moisture content (MC), oxygen transmission rate ( $O_2TR$ ), and water vapor permeability (WVP) of films.

Code	Composition	TS (MPa)	AND <sub>ab</sub> (%)	MC (%)	$O_2TR$ ( $cm^2 day^{-1} atm^{-1}$ )	WVP ( $\times 10^{-7}$ $g m^{-1} s^{-1} Well^{-1}$ )	$g m^{-1} s^{-1}$
P1	Neat PLA	35.1 $\pm$ 1.5 <sup>a</sup>	7.2 $\pm$ 0.3 <sup>c</sup>	0	260.6 $\pm$ 6.2 <sup>b</sup>	6.07 $\pm$ 0.8	
P2	PLAN/TA10	22.3 $\pm$ 1.3 <sup>c</sup>	14.3 $\pm$ 0.5 <sup>a</sup>	3.25 $\pm$ 0.4 <sup>b</sup>	278.1 $\pm$ 4.5 <sup>a</sup>	6.79 $\pm$ 0.3	
P3	PLA/C20A1/TA10	28.7 $\pm$ 2.1 <sup>b</sup>	10.1 $\pm$ 0.8 <sup>b</sup>	3.88 $\pm$ 0.2 <sup>a</sup>	224.3 $\pm$ 5.8 <sup>c</sup>	5.31 $\pm$ 0.5	

#### 2-3- Weight loss

One of the main problems of strawberry fruit during storage is its high weight loss, which plays an important role in the quality, shelf life and marketability of the fruit [3]. The results of variance analysis of weight loss percentage are summarized in Table 4. According to Table 4, information related to weight loss under the influence of main factors and mutual factors showed a significant difference at the level of one percent probability. The comparison results of the average percent weight loss of strawberry fruit are shown in Table 5. According to these results, the weight loss percentage of strawberry fruit decreased significantly with the passage of

time. In general, fruit weight loss (water loss) depends on various factors such as the type of packaging film, modified atmosphere, increased metabolic activity, respiration, transpiration, rapid microbial growth and tissue degradation during storage [24; 25]. In fact, the highest percentage of strawberry fruit weight loss at the end of the storage period was observed in packaging films without gas injection (control sample). while the lowest is related to samples containing gaseous compounds MAP-A و MAP-B Was. Researchers reported that a modified atmosphere with relatively high humidity in the headspace atmosphere and limited water flow caused less weight loss in fruits [26]. Also

gaseous composition MAP-A Due to having less oxygen, more carbon dioxide, and as a result, the appropriate pressure for the formation of hydrate has less weight loss compared to MAP-B Was. Therefore, the modified atmosphere with a balanced gas composition inside the package has the necessary ability to provide optimal organoleptic properties and ultimately increase the shelf life of the product.[27]. According to the results, the lowest and the highest percentage of weight loss in the movies, respectively PLA/C20A1/TA10 and PLAN/TA10 was observed. Therefore, the film containing nano-clay caused a favorable control of the weight loss process of strawberry fruit during the storage period, because the nano-particle in the polymer matrix not only maintains

the moisture inside the fruit, but also improves the water vapor barrier properties of the packaging film. Therefore, the percentage of weight loss decreases with the reduction of film permeability to water vapor [15; 28]. Researchers showed that nanocomposite packaging films reduced the percentage of fruit weight loss [29; 30]. As a result, film and gaseous composition suitable for storage of strawberry fruit during 23 days respectively were PLA/C20A1/TA10 and MAP-A. Because they limited fruit weight loss at 4°C due to low permeability to moisture. In addition, the accumulation of water inside the package did not spread and the symptoms of the fungus on the fruits were less observed [24].

**Table 4** Analysis of variance for effects of packaging film (P), modified atmosphere (M), and storage day (D) on weight loss for strawberry fruit

Mean square	Df	Variable
7.72**	2	P
9.31**	2	M
164.93**	6	D
0.48**	4	P×M
0.88**	12	P×D
1.63**	12	M×D
0.57**	24	P×M×D
0.004	126	Error

\*: Significant difference at 5% and \*\*: Significant difference at 1%

**Table 5** Effects of packaging film, modified atmosphere, and storage day on weight loss (WL) for strawberry fruit

Code	Storage date (day)						
	0	3	7	11	15	19	23
P1A1	0	0.83 <sup>l</sup>	2 <sup>k</sup>	2.8 <sup>i</sup>	3.94 <sup>g</sup>	5.21 <sup>lt is</sup>	5.94 <sup>d</sup>
P1A2	0	0.83 <sup>l</sup>	1.93 <sup>k</sup>	2.82 <sup>i</sup>	4.02 <sup>h</sup>	5.17 <sup>lt is</sup>	6.08 <sup>c</sup>
P1A3	0	0.77 <sup>m</sup>	2.1 <sup>j</sup>	2.95 <sup>i</sup>	4.24 <sup>f</sup>	6.32 <sup>b</sup>	8.1 <sup>a</sup>

P2A1	0	0.98 <sup>n</sup>	2.27 <sup>l</sup>	3.05 <sup>j</sup>	4.27 <sup>g</sup>	5.56 <sup>lt is</sup>	6.5 <sup>c</sup>
P2A2	0	1 <sup>n</sup>	2.45 <sup>k</sup>	3.47 <sup>i</sup>	4.91 <sup>f</sup>	6.24 <sup>d</sup>	7.21 <sup>b</sup>
P2A3	0	1.22 <sup>m</sup>	2.9 <sup>j</sup>	3.99 <sup>h</sup>	5.65 <sup>lt is</sup>	7.16 <sup>b</sup>	8.32 <sup>a</sup>
P3A1	0	0.73 <sup>n</sup>	1.65 <sup>k</sup>	2.36 <sup>h</sup>	3.33 <sup>f</sup>	4.34 <sup>lt is</sup>	5.02 <sup>d</sup>
P3A2	0	0.88 <sup>m</sup>	2.17 <sup>g</sup>	3.06 <sup>g</sup>	4.42 <sup>lt is</sup>	5.65 <sup>c</sup>	5.92 <sup>b</sup>
P3A3	0	0.92 <sup>l</sup>	2.27 <sup>i</sup>	3.1 <sup>g</sup>	4.48 <sup>lt is</sup>	5.64 <sup>c</sup>	6.53 <sup>a</sup>

### 3-3- Solution solids

Soluble solids are a key factor in determining fruit quality and consumer satisfaction. Sugars are the main soluble metabolites including glucose, fructose and sucrose, which make up 99% of the total sugar content. Soluble solids, which mainly include sugars and acids, are closely related to the taste and flavor of the product and indicate its degree of ripeness. Therefore, soluble solids are expressed to hydrolyze sugars to provide normal respiration [14]. The results of analysis of variance for soluble solids in Table 6 showed that all main and interaction effects were significant at the 1% probability level. The comparison results of

average soluble solids for strawberry fruit during the storage period are shown in Table 7. According to Table 7, the soluble solid matter for strawberry fruit was 5.25% at the time of harvest, and its amount gradually increased and then decreased for all samples during the storage period. The amount of dissolved solids at the end of the storage period for the package without gas injection (control sample) is more than the packages MAP-A And MAP-B Decreased. This is due to the physiological ripening process of the fruit, which determines the accumulation of sugars used in respiration processes. It should be mentioned that this phenomenon was less seen in modified atmosphere samples [26].

**Table 6** Analysis of variance for effects of packaging film, modified atmosphere, and storage day on Total soluble solid (TSS), Titratable acidity (TA), pH, and firmness (F) for strawberry fruit

Mean square				Df	Variable
pH	F (N)	TA (%)	TSS (%)		
0.07 <sup>**</sup>	4.48 <sup>**</sup>	2.69 <sup>**</sup>	0.2 <sup>**</sup>	2	P
0.19 <sup>**</sup>	4.44 <sup>**</sup>	2.49 <sup>**</sup>	8.84 <sup>**</sup>	2	M
0.84 <sup>**</sup>	32.80 <sup>**</sup>	5.18 <sup>**</sup>	24.90 <sup>**</sup>	3	D
0.03 <sup>**</sup>	0.03 <sup>**</sup>	0.10 <sup>**</sup>	0.35 <sup>**</sup>	4	P×M
0.02 <sup>**</sup>	0.52 <sup>**</sup>	0.92 <sup>**</sup>	0.02 <sup>**</sup>	6	P×D
0.08 <sup>**</sup>	1.12 <sup>**</sup>	0.39 <sup>**</sup>	1.98 <sup>**</sup>	6	M×D
0.01 <sup>**</sup>	0.19 <sup>**</sup>	0.18 <sup>**</sup>	0.11 <sup>**</sup>	12	P×M×D
0.00	0.09	0.00	0.05	72	Error

\*: Significant difference at 5% and \*\*: Significant difference at 1%

**Table 7** Effects of packaging film, modified atmosphere, and storage day on Total soluble solid (TSS), Titratable acidity (TA), pH, and firmness (F) for strawberry fruit

Code	Storage date (day)	TSS	FACING	F	pH
P1A1	0	5.25 <sup>f</sup>	3.75 <sup>f</sup>	5.12 <sup>a</sup>	3.47 <sup>lt is</sup>
	7	7 <sup>c</sup>	3.95 <sup>lt is</sup>	4.07 <sup>b</sup>	3.44 <sup>f</sup>
	15	7.5 <sup>a</sup>	5.03 <sup>a</sup>	3.5 <sup>c</sup>	3.64 <sup>d</sup>
	23	7.2 <sup>b</sup>	4.15 <sup>c</sup>	2.77 <sup>d</sup>	3.66 <sup>d</sup>
P1A2	0	5.25 <sup>f</sup>	3.75 <sup>f</sup>	5.12 <sup>a</sup>	3.47 <sup>lt is</sup>
	7	6.8 <sup>d</sup>	3.95 <sup>lt is</sup>	3.4 <sup>c</sup>	3.64 <sup>d</sup>

P1A3	15	7.5 <sup>a</sup>	4.22 <sup>b</sup>	2.7 <sup>d</sup>	3.87 <sup>c</sup>
	23	7 <sup>c</sup>	3.28 <sup>i</sup>	2.5 <sup>lt is</sup>	3.95 <sup>b</sup>
	0	5.25 <sup>f</sup>	3.75 <sup>f</sup>	5.12 <sup>a</sup>	3.47 <sup>lt is</sup>
	7	6.5 <sup>d</sup>	4.02 <sup>d</sup>	2.43 <sup>lt is</sup>	3.63 <sup>d</sup>
	15	7.2 <sup>b</sup>	3.69 <sup>g</sup>	2.11 <sup>f</sup>	3.84 <sup>c</sup>
	23	5.5 <sup>lt is</sup>	3.32 <sup>h</sup>	2 <sup>i</sup>	4.15 <sup>a</sup>
P2A1	0	5.25	3.75 <sup>lt is</sup>	5.12 <sup>a</sup>	3.47 <sup>lt is</sup>
	7	7.5 <sup>c</sup>	4.69 <sup>a</sup>	3.13 <sup>b</sup>	3.44 <sup>f</sup>
	15	8 <sup>a</sup>	4.22 <sup>b</sup>	2.9 <sup>c</sup>	3.65 <sup>c</sup>
	23	7.8 <sup>b</sup>	2.88 <sup>h</sup>	2.47 <sup>d</sup>	3.76 <sup>b</sup>
P2A2	0	5.25 <sup>g</sup>	3.75 <sup>lt is</sup>	5.12 <sup>a</sup>	3.47 <sup>lt is</sup>
	7	7 <sup>lt is</sup>	3.82 <sup>d</sup>	3.17 <sup>b</sup>	3.55 <sup>d</sup>
	15	7.5 <sup>c</sup>	3.48 <sup>g</sup>	2.47 <sup>d</sup>	3.67 <sup>c</sup>
	23	7.2 <sup>d</sup>	2.88 <sup>h</sup>	2.2 <sup>f</sup>	3.78 <sup>b</sup>
P2A3	0	5.25 <sup>g</sup>	3.75 <sup>lt is</sup>	5.12 <sup>a</sup>	3.47 <sup>lt is</sup>
	7	6.5 <sup>f</sup>	4.02 <sup>c</sup>	2.33 <sup>lt is</sup>	3.56 <sup>d</sup>
	15	7.2 <sup>d</sup>	3.69 <sup>f</sup>	2.07 <sup>g</sup>	3.65 <sup>c</sup>
	23	5.3 <sup>g</sup>	2.68 <sup>i</sup>	1.77 <sup>h</sup>	3.89 <sup>a</sup>
	0	5.25	3.75 <sup>h</sup>	5.12 <sup>a</sup>	3.47 <sup>g</sup>
P3A1	7	7.5 <sup>c</sup>	5.36 <sup>a</sup>	4.37 <sup>b</sup>	3.69 <sup>c</sup>
	15	8.5 <sup>a</sup>	4.69 <sup>d</sup>	3.77 <sup>d</sup>	3.58 <sup>lt is</sup>
	23	8.1 <sup>b</sup>	4.22 <sup>lt is</sup>	3.37 <sup>lt is</sup>	3.64 <sup>d</sup>
	0	5.25 <sup>h</sup>	3.75 <sup>h</sup>	5.12 <sup>a</sup>	3.47 <sup>g</sup>
P3A2	7	7 <sup>lt is</sup>	4.82 <sup>b</sup>	4.07 <sup>c</sup>	3.57 <sup>lt is</sup>
	15	7.3 <sup>d</sup>	4.22 <sup>lt is</sup>	3.53 <sup>f</sup>	3.64 <sup>d</sup>
	23	7 <sup>lt is</sup>	3.85 <sup>g</sup>	3.1 <sup>g</sup>	3.79 <sup>b</sup>
	0	5.25 <sup>h</sup>	3.75 <sup>h</sup>	5.12 <sup>a</sup>	3.47 <sup>g</sup>
P3A3	7	6.3 <sup>f</sup>	4.76 <sup>c</sup>	3.17 <sup>g</sup>	3.52 <sup>f</sup>
	15	6.9 <sup>lt is</sup>	3.89 <sup>f</sup>	2.9 <sup>h</sup>	3.55 <sup>f</sup>
	23	5.5 <sup>g</sup>	3.11 <sup>i</sup>	2.37 <sup>i</sup>	4.19 <sup>a</sup>

between the dissolved solids of different treatments. These findings are consistent with the results of other researchers [32].

### 3-4- titratable acidity

Titratable acidity expresses the total amount of fruit juice acids, which is measured as a percentage based on the dominant organic acids of the fruit. The results of the analysis of variance of titratable acidity test for strawberry fruit during the storage period are shown in Table 6. According to Table 6, titratable acidity was affected by all main and mutual factors at the probability level of one percent. According to Table 7, the amount of titratable acidity for strawberry fruit at the time of harvesting was 3.75%, and its amount gradually increased and

In general, modified atmosphere can reduce the reduction of dissolved solids and thus delay the premature aging process of strawberry fruit [31]. As we know, the ripening of fruits is inversely proportional to their respiration rate. It is evident that gases can reduce the rate of respiration and consumption of organic substances. As a result of choosing the optimal gas combination with the amount of oxygen KPa 10 To Better retention of soluble solids during the storage period helped further. Therefore, the use of modified atmosphere creates a significant difference



then decreased for all samples during the storage period. As a result, the quality of strawberry fruit decreased at the end of storage time. Similar results were observed by other researchers that this behavior refers to the lack of solubility of carbon dioxide in the water on the surface of the fruit and the production of carbonic acid in the fruit. The amount of acidity that can be titrated is related to the storage time of the fruit. Therefore, the amount of acidity decreases with the increase of the fruit storage period, which can be seen in all samples at the end of the storage period [33]. Sugars and acids are consumed during the metabolic process of respiration, and thus changes in soluble solids and titratable acidity occur during storage [33]. The film with gaseous composition is likely to maintain more titratable acidity than the control sample due to the reduction of breathing intensity, creating a favorable atmosphere and preventing the consumption of metabolic process acids. So the changes decrease. With the passage of time, it was less in the gas composition compared to the control sample. Also fruits stored in gaseous composition MAP-B due to having higher oxygen and lower carbon dioxide than MAP-A. They have less titratable acidity. At the end of the storage period, the highest amount of titratable acidity (22.4) in fruits packed with nanocomposite film and gaseous composition MAP-A. It was recorded that it had the lowest percentage of weight loss (5.02). It is consistent with the results of other researchers [24].

### 3-5- pH

Possibility of increase pH. It exists by consuming organic acids in fruits for respiration. In general, when fruits are stored, the available sugars and acids are used for metabolic activities such as respiration, leading to changes in titratable acidity and soluble solids. The increase of soluble solids in fruits is caused by the conversion of carbohydrates into sugars and other solvents through metabolic processes during storage. Level pH. For strawberry fruit, it is usually between 3 and 3.9 and it can vary according to the type of variety, degree of ripening, storage conditions and microbial contamination [18]. It is also reported that changes in pH, soluble solids and titratable acidity appeared in fruits covered with plastic film and

low permeability to atmospheric gases due to increased carbon dioxide and decreased respiration [25]. Results of analysis of variance related to pH. Table 6 showed that the main and interaction effects of pH. It was significant at the one percent probability level. Average comparison results. For all samples during storage, it is given in Table 7. The amount of pH. The initial value for strawberry fruit was 47.3, which increased during storage for all samples. On the other hand, the optimal gas composition has an effective role in reducing the growth of aerobic microorganisms and the rate of anaerobic respiration of strawberry fruit, which leads to an increase in pH. It became a fruit. These findings are in agreement with the report of previous researchers [34]. Since the metabolic activity of strawberry fruit decreased under optimal atmospheric conditions during the storage period, the change in pH. It was less in films containing gaseous compounds compared to the control sample. As a result, chemical changes in the fruit tissue occurred at a lower rate. Change in pH. Packages without gas injection (control sample) showed a significant difference with other samples. In fact, this indicates the rate of respiration and higher consumption of organic acids in the control samples [35]. So the highest change in pH. At the end of storage, it was observed in the control samples and the least changes were found in the nanocomposite films. In addition, the nanocomposite film plays a significant role in reducing the amount of breathing inside the package due to its water vapor permeability and low gas transfer rate (according to Table 3), and thus the change in pH. The fruit is reduced [25].

### 3-6- Stiffness

Texture firmness is an important character in relation to the quality and freshness of strawberry fruit. The results of analysis of variance related to the main effects and interaction effects on the firmness of strawberry fruit tissue were significant at the 1% probability level (Table 6). The results showed that the firmness of strawberry fruit texture in all packages significantly ( $P < 0.05$ ) decreased during storage [25; 18]. Hardness has a high negative correlation with fruit weight loss, which is attributed to the reduction of vapor pressure as a result of water transpiration process. In

addition, the destruction of the cell wall of the film can be effective in softening the fruit. Nevertheless, the samples in gaseous composition at the end of the storage time showed a higher degree of stiffness than the control sample (Table 7). This achievement is related to lower weight loss in modified atmosphere packages, which is consistent with the results of other researchers [14]. In fact, the gaseous composition reduces the activity of the enzyme responsible for fruit softening by creating suitable atmospheric conditions [36]. The softening of strawberry fruit occurs as a result of changes in the physical and mechanical properties of the tissue, which are related to changes in the chemical structure of the cell wall of the packaging film [37]. Also, strawberry fruit in packages PLA/C20A1/TA10 It has relatively higher stiffness than the two films PLAN/TA10 And neat PLA It was during the storage period. Because the nanoparticle-containing film has a good barrier property against water vapor. Therefore, changes in firmness are related to changes in strawberry juice content. In general, the packaging film and the modified atmosphere have an effective role in maintaining the firmness of the fruit during the storage period. Maintaining stiffness in the samples packed with nanocomposite film is due to the delay in premature aging, reduction in film permeability and reduction in gas exchange, which happened due to the presence of clay nanoparticles in the polymer matrix [25]. The results of this research revealed that the use of nanocomposite packaging film containing nanoclay has been able to delay the softening process of the fruit during the storage period.

#### 4- General conclusion

There is an increasing interest in the market for fresh fruits and vegetables due to the increasing consumer desire for natural, healthy and fresh products. Strawberries have a short shelf life, are highly perishable and have a high respiration rate. Also, losses and wastes after harvesting are relatively high due to the spread of fungi, mechanical damage, physiological perishability and water loss. The use of packaging film, modified atmosphere and low temperature were used to increase the shelf life of strawberry fruit.

The modified atmosphere system is a dynamic technology that simulates the breathing of packaged products and the permeability of gases through packaging films. Accumulation of carbon dioxide and removal of oxygen with appropriate levels through the application of modified atmosphere were found to increase the shelf life and preserve the value of the product. The effect of three types of packaging films, two gas compositions and one composition without gas injection for 23 days of storage at 4 degrees Celsius was evaluated on the physicochemical properties of strawberry fruit. Parameters such as weight loss, soluble solids, titratable acidity, pH and hardness were evaluated. The results showed that the weight loss percentage of strawberry fruit increased significantly during the storage period. So that the control sample had a higher percentage of weight loss than the gaseous composition at the end of storage. The packaging system with gaseous composition was the best in maintaining titratable acidity, soluble solids and firmness of the fruit texture compared to the control sample. In addition, the PLA/C20A1/TA10 packaging film showed better results in all analyzes compared to the two Neat PLA and PLA/TA10 films, which is related to the barrier properties of the film in the presence of nanoclay. The results of this study confirm that the packaging film containing nanoparticles along with MAP-A gaseous composition caused better preservation of quality properties for strawberry fruit during the storage period. Overall, this study provided a new perspective on the combination of modified atmosphere with nanocomposite packaging film at low temperature to increase the shelf life of strawberry fruit.

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#### 6- Resources

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## ارزیابی تغییرات فیزیکوشیمیایی توت‌فرنگی در اتمسفر اصلاح شده با استفاده از فیلم بسته‌بندی نانوکامپوزیت

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اطلاعات مقاله	چکیده
<p>تاریخ های مقاله :</p> <p>تاریخ دریافت: ۱۴۰۰/۱۱/۱۲</p> <p>تاریخ پذیرش: ۱۴۰۱/۰۹/۲۱</p>	<p>ماهیت فسادپذیری میوه توت‌فرنگی (<i>Fragaria×ananassa Duch.</i>) یک فاکتور کلیدی است که مصرف آن به دلیل کاهش تازگی و ماندگاری پس از برداشت محدود است. شرایط بسته‌بندی مناسب، دمای ذخیره‌سازی پایین و ترکیب اتمسفر مطلوب درون بسته در حفظ ویژگی‌های کیفی و افزایش ماندگاری میوه‌های فسادپذیر ضروری هستند. در این مطالعه، فیلم‌های بسته‌بندی بر پایه پلی‌لاکتیک اسید (شامل neat PLA و PLA/TA10 و PLA/C20A1/TA10) تحت دو ترکیب گازی مختلف (شامل 10 KPa O<sub>2</sub>+15 KPa CO<sub>2</sub>+75 KPa N<sub>2</sub> و (MAP-A) CO<sub>2</sub>+75 KPa N<sub>2</sub>) و یک نمونه شاهد بدون تزریق گاز روی میوه توت‌فرنگی تازه ارزیابی شدند. تأثیر تیمارهای اشاره شده بر برخی خواص فیزیکوشیمیایی میوه توت‌فرنگی تازه نظیر کاهش وزن، مواد جامد محلول، اسیدیته قابل تیتراسیون، pH و سفتی در دمای ۴ °C برای ۲۳ روز ذخیره‌سازی براساس آزمایش فاکتوریل در قالب طرح کاملاً تصادفی مورد آزمون قرار گرفت. نتایج نشان دادند که کاهش وزن و سفتی میوه توت‌فرنگی با گذشت زمان کاهش می‌یابد در حالی که مقدار pH افزایش یافت. مقدار مواد جامد محلول و اسیدیته قابل تیتراسیون همه تیمارها طی زمان ذخیره‌سازی افزایش یافت و در پایان زمان ذخیره‌سازی کاهش یافت. همچنین گزارش شد که میوه‌های بسته‌بندی شده در PLA/C20A1/TA10 به دلیل نفوذپذیری بخار آب و نرخ انتقال اکسیژن کمتر نسبت به دو فیلم neat PLA/TA10 و neat PLA باعث خصوصیات کیفی بهتر شد. همچنین ترکیب گازی MAP-A نسبت به MAP-B به دلیل دی‌اکسید کربن بیشتر درون بسته‌ها و میزان تنفس کمتر برای میوه توت‌فرنگی مناسب‌تر بود. بنابراین استفاده از فیلم نانوکامپوزیت با اتمسفر اصلاح شده برای نگهداری میوه توت‌فرنگی در دمای پایین پیشنهاد می‌شود.</p>
<p>کلمات کلیدی:</p> <p>توت‌فرنگی، بسته‌بندی اتمسفری اصلاح شده، فیلم نانوکامپوزیت، ذخیره‌سازی سرد، پارامترهای کیفی.</p> <p>DOI: 10.22034/FSCT.19.132.341</p> <p>DOR: 20.1001.1.20088787.1401.19.132.25.8</p>	

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