Journal of Food Science and Technology (Iran)

Homepage: www.fsct.modares.ir

Scientific Research

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

Tabatabaeekoloor, R. [1*], YousefniaPasha, H. [2]

1. Department of Biosystem Engineering, Faculty of Agricultural Engineering, Sari Agricultural Sciences and Natural Resources University, Iran.
2. Department of Agricultural Machinery Engineering, Faculty of Agricultural Engineering and Technology, University of Tehran, Karaj, Iran.

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_2+15 KPa CO_2+75 KPa N_2 (MAP-A) and 15 KPa O_2+10 KPa CO_2+75 KPa N_2 (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, tritratable acidity, pH, and firmness kept at 4 ^{0}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 tritratable 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.

ARTICLE INFO

Article History:

Received 2022/ 02/ 01
Accepted 2022/ 12/12

Keywords:

Strawberry,
Modified atmosphere packaging,
Nanocomposite film,
Cold storage,
Quality parameters.

DOI: **10.22034/FSCT.19.132.341**
DOR: **20.1001.1.20088787.1401.19.132.25.8**

*Corresponding Author E-Mail:
r.tabatabaei@sanru.ac.ir

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

[DOR: 20.1001.1.20088787.1401.19.132.25.8]
[DOI: 10.22034/FSCT.19.132.341]

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[1]) with grade 2003D, specific weight g cm^{-3} 1.14, melt flow index g/10min 6 (temperature C°*210* ،Kg *16/2*) and melt temperature C°*210 of the company*NatureWorks LLC *(*Minnetonka USA*) it was prepared. Also, Triestin plasticizer (*[2]FACING*) in liquid form with chemical formula*$C_9H_{14}O_6$, *Molecular Weight*g mol^{-1} 2/218 *and specific gravity*g 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×ananassa Duch.) Camarosa variety[3] 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 µm), PLA/TA10 (with a thickness of 62.67 µm) and PLA/C20A1/TA10 (with a thickness of 63.67 µm) and two MAP-A gas compositions with a specification of 10 KPa O_2+15 KPa CO_2+75 KPa N_2 and MAP-B with a specification of 15 KPa O_2+10 KPa CO_2+75 KPa 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 O_2+15 KPa CO_2+75 KPa N_2 (MAP-A)
P2A1	PLAN/TA10	
P3A1	PLA/C20A1/TA10	
P1A2	Neat PLA	15 KPa O_2+10 KPa CO_2+75 KPa N_2 (MAP-B)
P2A2	PLAN/TA10	
P3A2	PLA/C20A1/TA10	
P1A3	Neat PLA	Air inside initially (Passive-Blank)
P2A3	PLAN/TA10	
P3A3	PLA/C20A1/TA10	

2-4- Qualitative characteristics of strawberry fruit

2-4-1- Weight loss (WL[4])

The weight loss percentage of the packages was determined using a digital scale with an accuracy of ±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 ([5]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[6])

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[7])

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

4. Weight loss

5. Total soluble solid

6. Tritratable acidity

7. Firmness

[DOR: 20.1001.1.20088787.1401.19.132.25.8]
[DOI: 10.22034/FSCT.19.132.341]

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 filmPLA Pure significantly by adding triacetin plasticizer on the surface10 wt.% improved while the tensile strength decreased. On the other hand, adding clay nanoparticlesC20A leading to improved tensile strength of the filmPLAN-TA10 which is consistent with the results of researchers [19].

The moisture content of the filmPLA increased by adding plasticizer. Increase in humidityPLA/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 nanoparticlesC20A to PLA rate It increased the wettability of the nanocomposite film due to its hydrophilic natureC20A is [20;21]. Water vapor permeability of the filmPLA The net content was 6.07%, which increased with the addition of plasticizer. Values of water vapor permeability and gas transfer rate for nanocomposite filmPLA/C20A1/TA10 Compared to the moviePLAN/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 toPLA 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_{ab} (%)	MC (%)	O_2TR ($cm^{-2}day^{-1}atm^{-1}$)	WVP ($\times10^{-7}$ $gm^{-1}s^{-1}Well^{-1}$)
P1	Neat PLA	35.1±1.5^a	7.2±0.3^c	0	260.6±6.2^b	6.07±0.8
P2	PLAN/TA10	22.3±1.3^c	14.3±0.5^a	3.25±0.4^b	278.1±4.5^a	6.79±0.3
P3	PLA/C20A1/TA10	28.7±2.1^b	10.1±0.8^b	3.88±0.2^a	224.3±5.8^c	5.31±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 compoundsMAP-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 compositionMAP-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 toMAP-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, respectivelyPLA/C20A1/TA10 ،Neat PLA AndPLAN/TA10was 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 respectivelywere 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^{l}	2^{k}	2.8^{i}	3.94^{g}	5.21$^{\text{It is}}$	5.94^{d}
P1A2	0	0.83^{l}	1.93^{k}	2.82^{i}	4.02^{h}	5.17$^{\text{It is}}$	6.08^{c}
P1A3	0	0.77^{m}	2.1^{j}	2.95^{i}	4.24^{f}	6.32^{b}	8.1^{a}

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

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 packagesMAP-A AndMAP-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), Tritratable acidity (TA), pH, and firmness (F) for strawberry fruit

Mean square				Df	Variable
pH	F (N)	TA (%)	TSS (%)		
0.07^{**}	4.48^{**}	2.69^{**}	0.2^{**}	2	P
0.19^{**}	4.44^{**}	2.49^{**}	8.84^{**}	2	M
0.84^{**}	32.80^{**}	5.18^{**}	24.90^{**}	3	D
0.03^{**}	0.03^{**}	0.10^{**}	0.35^{**}	4	P×M
0.02^{**}	0.52^{**}	0.92^{**}	0.02^{**}	6	P×D
0.08^{**}	1.12^{**}	0.39^{**}	1.98^{**}	6	M×D
0.01^{**}	0.19^{**}	0.18^{**}	0.11^{**}	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), Tritratable acidity (TA), pH, and firmness (F) for strawberry fruit

Code	Storage date (day)	TSS	FACING	F	pH
P1A1	0	5.25^{f}	3.75^{f}	5.12^{a}	$3.47^{It\ is}$
	7	7^{c}	$3.95^{It\ is}$	4.07^{b}	3.44^{f}
	15	7.5^{a}	5.03^{a}	3.5^{c}	3.64^{d}
	23	7.2^{b}	4.15^{c}	2.77^{d}	3.66^{d}
P1A2	0	5.25^{f}	3.75^{f}	5.12^{a}	$3.47^{It\ is}$
	7	6.8^{d}	$3.95^{It\ is}$	3.4^{c}	3.64^{d}

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

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 oxygenKPa 10 To Better retention of soluble solids during the storage period helped further. Therefore, the use of modified atmosphere creates a significant difference 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

[DOR: 20.1001.1.20088787.1401.19.132.25.8]

[DOI: 10.22034/FSCT.19.132.341]

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 decreaseFACING With the passage of time, it was less in the gas composition compared to the control sample. Also fruits stored in gaseous compositionMAP-B due to having higher oxygen and lower carbon dioxide thanMAP-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 compositionMAP-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 increasepH 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 inpHtitratable 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. LevelpH 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 changespH, 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 tophdr Table 6 showed that the main and interaction effects ofpH It was significant at the one percent probability level. Average comparison resultspH For all samples during storage, it is given in Table 7. the amount ofpH 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 inpH 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 changespH 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. ChangespH 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 changespH 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 changespH 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 packagesPLA/C20A1/TA10 It has relatively higher stiffness than the two filmsPLAN/TA10 Andneat 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.

5- Gratitude

The authors are extremely grateful to the Research Vice-Chancellor of Sari University of Agricultural Sciences and Natural Resources for the financial support of this article, which is derived from the research project code 09-1400-02.

6- Resources

[1] Caldeira, C., De Laurentiis, V., Corrado, S., van Holsteijn, F., & Sala, S. (2019).

[DOR: 20.1001.1.20088787.1401.19.132.25.8]
[DOI: 10.22034/FSCT.19.132.341]

Quantification of food waste per product group along the food supply chain in the European Union: a mass flow analysis. Resources, Conservation and Recycling, 149, 479-488.

[2]] Caleb, O. J., Opara, U. L., & Witthuhn, C. R. (2012). Modified atmosphere packaging of pomegranate fruit and arils: a review. Food and bioprocess technology, 5(1), 15-30.

[3] Fernandez-Leon , M. , Fernandez-Leon , A. , Lozano , M. , Ayuso , M. , Amodio , M. L. , Colelli , G. , & Gonzalez-Gomez , D. (2013). Retention of quality and functional values of 'Parthenon' broccoli stored in modified atmosphere packaging. Food Control, 31(2), 302-313.

[4] Matar, C., Salou, T., Hélias, A., Pénicaud, C., Gaucel, S., Gontard, N., . . . Guillard, V. (2021). Benefit of modified atmosphere packaging on the overall environmental impact of packed strawberries. Postharvest Biology and Technology, 177, 111521.

[5] Li, Y., Ishikawa, Y., Satake, T., Kitazawa, H., Qiu, X., & Rungchang, S. (2014). Effect of active modified atmosphere packaging with different initial gas compositions on nutritional compounds of shiitake mushrooms (Lentinus edodes). Postharvest Biology and Technology, 92, 107-113.

[6] Costa, C., Lucera, A., Conte, A., Mastromatteo, M., Speranza, B., Antonacci, A., & Del Nobile, M. A. (2011). Effects of passive and active modified atmosphere packaging conditions on ready-to-eat table grape. Journal of Food Engineering, 102(2), 115-121.

[7] Banda, K., Caleb, O. J., Jacobs, K., & Opara, U. L. (2015). Effect of active-modified atmosphere packaging on the respiration rate and quality of pomegranate arils (cv. Wonderful). Postharvest Biology and Technology, 109, 97-105.

[8] Guillard, V., Gaucel, S., Fornaciari, C., Angellier-Coussy, H., Buche, P., & Gontard, N. (2018). The next generation of sustainable food packaging to preserve our environment in a circular economy context. Frontiers in nutrition, 5, 121.

[9] Tumwesigye, K., Sousa, A., Oliveira, J., & Sousa-Gallagher, M. (2017). Evaluation of novel bitter cassava film for equilibrium modified atmosphere packaging of cherry tomatoes. Food packaging and shelf life, 13, 1-14.

[10] Oliveira, M., Abadias, M., Usall, J., Torres, R., Teixidó, N., & Viñas, I. (2015). Application of modified atmosphere packaging as a safety approach to fresh-cut fruits and vegetables–A review. Trends in Food Science & Technology, 6(1), 13-26

[11] Soltani, M., Alimardani, R., Mobli, H., & Mohtasebi, S. S. (2015). Modified atmosphere packaging: a progressive technology for shelf-life extension of fruits and vegetables. Journal of Applied Packaging Research, 7(3), 27-38.

[12] Nielsen, T., & Leufvén, A. (2008). The effect of modified atmosphere packaging on the quality of Honeoye and Korona strawberries. Food Chemistry, 107, 1053-1063.

[13] Adobati, A., Uboldi, E., Franzetti, L., & Limbo, S. (2015). Shelf life extension of raspberry: Passive and active modified atmosphere inside master bag solutions. Chemical Engineering Transactions, 44, 337-342.

[14] Zhao, X., Xia, M., Wei, X., Xu, C., Luo, Z., & Mao, L. (2019). Consolidated cold and modified atmosphere package system for fresh strawberry supply chains. Lwt, 109, 207-215.

[15] Barikloo, H., & Ahmadi, E. (2018). Shelf life extension of strawberry by temperatures conditioning, chitosan coating, modified atmosphere, and clay and silica nanocomposite packaging. Scientia Horticulturae, 2. 496-508, 40

[16] Khodayari, M., Basti, A. A., Khanjari, A., Misaghi, A., Kamkar, A., Shotorbani, P. M., & Hamedi, H. (2019). Effect of poly (lactic acid) films incorporated with different concentrations of Tanacetum balsamita essential oil, propolis ethanolic extract and cellulose nanocrystals on shelf life extension of vacuum-packed cooked sausages. Food packaging and shelf life, 19, 200-209.

[17] Selcuk, N., & Erkan, M. (2014). Changes in antioxidant activity and postharvest quality of sweet pomegranates cv. Hicrannar under modified atmosphere packaging. Postharvest Biology and Technology, 9, 29-36.

[18] Khodaei, D., Hamidi-Esfahani, Z., & Rahmati, E. (2021). Effect of edible coatings on the shelf-life of fresh strawberries: A comparative study using topsis-shannon

entropy method. NFS Journal, 23, 17-23.

[19] Ozdemir, E., & Hacaloglu, J. (2017). Characterizations of PLA-PEG blends involving organically modified montmorillonite. Journal of Analytical and Applied Pyrolysis, 127, 343-349. Bharti, S. K., Pathak, V., Arya, A., Alam, T.,

[20] Rajkumar, V., & Verma, A. K. (2021). Packaging potential of Ipomoea batatas and κ-carrageenan biobased composite edible film: Its rheological, physicomechanical, barrier and optical characterization. Journal of Food Processing and Preservation, 45(2), e15153.

[21] Ozkoc, G., & Kemaloglu, S. (2009). Morphology, biodegradability, mechanical, and thermal properties of nanocomposite films based on PLA and plasticized PLA. Journal of Applied Polymer Science, 114(4), 2481-2487.

[22] Scatto, M., Salmini, E., Castiello, S., Coltelli, M. B., Conzatti, L., Stagnaro, P., . . . Bronco, S. (2013). Plasticized and nanofilled poly (lactic acid)-based cast films: Effect of plasticizer and organoclay on processability and final properties. Journal of Applied Polymer Science, 127(6), 4947-4956.

[23] Briano, R., Giuggioli, N. R., Girgenti, V., & Peano, C. (2015). Biodegradable and Compostable Film and Modified Atmosphere Packaging in Postharvest Supply Chain of Raspberry Fruits (cv. G randeur). Journal of Food Processing and Preservation, 39(6), 2061-2073.

[24] Ebrahimi, H., Abedi, B., Bodaghi, H., Davarynejad, G., Haratizadeh, H., & Conte, A. (2018). Investigation of developed clay-nanocomposite packaging film on quality of peach fruit (Prunus persica Cv. Alberta) during cold storage. Journal of Food Processing and Preservation, 42(2), e13466.

[25] Tinebra, I., Sortino, G., Inglese, P., Fretto, S., & Farina, V. (2021). Effect of Different Modified Atmosphere Packaging on the Quality of Mulberry Fruit (Morus alba L. cv Kokuso 21). International Journal of Food Science.

[26] Akbudak, B., & Eris, A. (2004). Physical and chemical changes in peaches and nectarines during the modified atmosphere storage. Food Control, 15(4), 307-313.

[27] Conte, A., Scrocco, C., Lecce, L., Mastromatteo, M., & Del Nobile, M. (2009). Ready-to-eat sweet cherries: Study on different packaging systems. Innovative Food Science & Emerging Technologies, 10(4), 564-571.

[28] Zandi, K., Weisany, W., Ahmadi, H., Bazargan, I & Naseri, L. (2013). Effect of Nanocomposite-Based Packaging on Postharvest Quality of Strawberry during Storage.

[29] Zhou, L., Lv, S., He, G., He, Q., & Shi, B. (2011). Effect of pe/ag2o nano-packaging on the quality of apple slices. Journal of Food Quality, 34(3), 171-176.

[30] Afifi, E. H. (2016). Effect of active and passive modified atmosphere packaging on quality attributes of strawberry fruits during cold storage. Arab Universities Journal of Agricultural Sciences, 24(1), 157-168.

[31] Zandi, M., Ganjloo, A., Bimakr, M., Moradi, N., & Nikoomanesh, N. (2021). Effect of active coating containing radish leaf extract with or without vacuum packaging on the postharvest changes of sweet lemon during cold storage. Journal of Food Processing and Preservation, 45(3), e15252.

[32] Caner, C., & Aday, M. S. (2009). Maintaining quality of fresh strawberries through various modified atmosphere packaging. Packaging Technology and Science: An International Journal, 22(2), 115-122.

[33] Lyn, F. H., Adilah, Z. M., Nor-Khaizura, M., Jamilah, B., & Hanani, Z. N. (2020). Application of modified atmosphere and active packaging for oyster mushroom (Pleurotus ostreatus). Food packaging and shelf life, 23, 100451.

[34] Malakou, A., & Nanos, G. D. (2005). A combination of hot water treatment and modified atmosphere packaging maintains quality of advanced maturity ‘Caldesi 2000’nectarines and ‘Royal Glory’peaches. Postharvest Biology and Technology, 38(2), 106-114.

[35] Karabulut, O. A., & Baykal, N. (2004). Integrated control of postharvest diseases of peaches with a yeast antagonist, hot water and modified atmosphere packaging. Crop Protection, 23(5), 431-435.

[36] Azodanlou, R., Darbellay, C., Luisier, J.-L., Villettaz, J.-C., & Amadò, R. (2004). Changes in flavour and texture during the

ripening of strawberries. European Food Research and Technology, 218(2), 167-172

[37]] Hu, Q., Fang, Y., Yang, Y., Ma, N., & Zhao, L. (2011). Effect of nanocomposite-based packaging on postharvest quality of ethylene-treated kiwifruit (Actinidia deliciosa) during cold storage. Food research international, 44(6), 1589-1596.

مجله علوم و صنایع غذایی ایران

سایت مجله: www.fsct.modares.ac.ir

مقاله علمی_پژوهشی

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

رضا طباطبایی کلور[۱*]، حسن یوسف نیا پاشا[۲]

۱- گروه مهندسی مکانیک بیوسیستم، دانشکده مهندسی زراعی، دانشگاه علوم کشاورزی و منابع طبیعی ساری، ایران.

۲- گروه مهندسی ماشین‌های کشاورزی، دانشکده مهندسی و فناوری کشاورزی، پردیس کشاورزی و منابع طبیعی، دانشگاه تهران، کرج، ایران.

اطلاعات مقاله

تاریخ های مقاله :

تاریخ دریافت: ۱۴۰۰/ ۱۱/۱۲

تاریخ پذیرش: ۱۴۰۱/۰۹/۲۱

کلمات کلیدی:

توت‌فرنگی،

بسته‌بندی اتمسفری اصلاح شده،

فیلم نانوکامپوزیت،

ذخیره‌سازی سرد،

پارامترهای کیفی.

DOI: 10.22034/FSCT.19.132.341

DOR: 20.1001.1.20088787.1401.19.132.25.8

* مسئول مکاتبات:

r.tabatabaei@sanru.ac.ir

چکیده

ماهیت فسادپذیری میوه توت‌فرنگی (Fragaria×ananassa Duch.) یک فاکتور کلیدی است که مصرف آن به‌دلیل 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، PLA/TA10 و PLA/C20A1/TA10) تحت دو ترکیب گازی مختلف (شامل 10 KPa O_2+15 KPa CO_2+75 KPa N_2 (MAP-A) و 15 KPa O_2+10 KPa CO_2+75 KPa N_2 (MAP-B)) 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 $4\ ^0C$ 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 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.