Received: 28 February 2017 | Revised: 7 August 2017 | Accepted: 8 August 2017
DOI: 10.1111/jfpp.13466

ORIGINAL ARTICLE

WILEY Journal of Food Processing and Preservation Institute of Food Science + Technology ifst

Investigation of developed clay-nanocomposite packaging film on quality of peach fruit (*Prunus persica* Cv. Alberta) during cold storage

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Abstract

A nanocomposite packaging film (NPF) prepared by blending polyethylene (PE) with nanoclay (closite 20A) was used. The effects of NPF on the quality parameters of mature peach fruit were investigated during 42 d of storage at 2°C. The results showed that barrier properties of active film properly suited fruit respiration and significantly inhibited bacterial growth. The weight loss, softening and internal browning of peach fruit were also significantly inhibited by 42%, 28%, and 15%, respectively, which indicated that NPF could delay peach ripening. In addition, pH, total soluble solid, and titratable acidity of fruit in the neat PE film and the unpacked fruit changed more significantly compared with the NPF-packed fruit. Additionally, peach in NPF exhibited lower polyphenol oxidase and higher peroxidase and catalase activities than the others. These results shown that NPF may be an applicable method to control fruit loss and prolong quality of peach during storage.

Practical applications

In this study a clay-nanocomposite film with modified barrier and unti-microbial properties on storage of peach fruit was investigated. The barrier properties of the nanocomposite film improved compared to the neat LDPE film so that causes to decrease the respiration rate of the product. Also it is capable to increase the shelf life and storage life of the product. In addition this nanocomposite film can be used as an active packaging with anti-microbial property. Furthermore, the melt blending extrusion for developing of the nanocomposite film can be used as an industrial and cost effective method for reduction of the product losses in postharvest period.

1 | INTRODUCTION

Peach fruit (*Prunus persica* L.) is an important commercial product in the gardening industry (Bassi & Monet, 2008). Iran is among the major peach producers, while its production has increased to reach a cultivation surface of 24,408 hectares in recent years (FAO, 2014). Beside its favorable taste, peach possesses high nutritional values like vitamins A and C, potassium, carbohydrates, organic acids, and anti-oxidants (Kader & Mitchell, 1989; Wang, Chen, Kong, Li, & Archbold, 2006). Peach as a climacteric fruit possesses autocatalytic ethylene production, so that the fruit is sensitive to exogenous ethylene to promote softening and ripening process (Gupta, Jawandha, & Singh-Gill, 2011). Among other postharvest problems of peach, the damages done to the fruit during harvest and transportation, pathogenic attacks and their damages, changes in its organoleptic features, and a decline in its quality could be mentioned. It should be noticed that the physiological and synthetic changes could be due to natural, unnatural, and environmental metabolisms that hinder the product selling process (Lurie & Crisosto, 2005). Owing to a limited time for supplying peach in each region and a greater supply than demand, meeting the market needs during the year is only possible by means of the product long-term storage. Therefore, managing the product is not only important, but also valuable and thus using adequate methods and techniques to increase its durability during the storage or export periods is necessary (Bassi & Monet, 2008).

Temperature decrease for preserving the product is one of the most effective methods to not only slow down ripening process, but also enhance the fruit longevity in the postharvest. The main problem during the storage period is that keeping peach under temperatures near zero leads to a decrease of fruit quality and an increase of its physiologic disorders, like cooling injury or internal browning (Lurie & Crisosto, 2005). A lot of attendances are used, among which storage under modified atmosphere packaging (MAP) could be named. Basically, atmosphere alongside oxygen decrease and carbon dioxide increase play important roles in the physiological behaviors of packed fruits and lead to prolonged shelf-life (Mir & Beaudry, 2001).

There are lots of reports regarding the effects of different packaging films on peach storage time. Akbudak and Eris (2004) have studied the effect of MAP with two plastic films on peach physicochemical features and reported that a polypropylene film leads to a better preservation of the fruit flesh firmness, total soluble solids (TSSs), titratable acidity (TA), and overall appearance compared to a propylene film. Today, new and diverse technologies such as application of biodegradable films contribute to the food industry and production storage. It should be mentioned that the use of biodegradable films has been limited due to their barrier weaknesses and mechanical properties (Periera de Abreu, PaseiroLosada, Anguloand, & Cruz, 2007). Therefore, discovering substitute technologies to prevent inappropriate physiological and physicochemical changes is necessary during the storage time. In recent years, organic and nonorganic nanoparticles have attracted a lot of attention in a vast range of research, especially in food packaging science (Periera de Abreu et al., 2007). For example, the use of PVC-TiO_2 in packaging Fuji apples at 0–1 °C for 208 days showed high firmness of fruit packed with nanocomposite films, with no carbon dioxide damages at the end of the storage period. Furthermore, relevant increase in film tensional resistance and significant respiration rate reduction were also seen found (Chen, Li, & Hu, 2001). Hu and Fu (2003) reported that packaging with nanoparticles could better preserve vitamin C, chlorophyll, polyphenols, and amino-acids in green tea compared to normal packaging.

Regarding the fact that peach is usually served fresh and considering its problems in the postharvest period, using alternative methods and technologies to increase its durability is necessary. Since there has never been an exhaustive study on the development and characterization of nanocomposite packaging film (NPF) on peach shelf life, the purpose of this research was to investigate the effect of clay-nanocomposite films on peach qualitative and quantitative properties during storage under cold storage conditions.

2 | MATERIALS AND METHODS

2.1 | Preparation and characterization of nanocomposite packaging film

The method for developing clay nanocomposite PE-based film (5% nanoclay) with specific physicochemical properties was reported in the work of Bodaghi, Mostofi, Oromiehie, Ghanbarzadeh, and Ghasimi Hagh (2015). In this study, Water Vapor Transmission Rate (WVTR) was measured with a tester, model L80–500, equipped with a very sensitive and reliable humidity sensor, directly located in the measuring chamber to control temperature and relative humidity. Oxygen and carbon dioxide transmission rates through the PE films (with and without the nanoparticles) were obtained using an OX-TRAN 2/21 and a PERMATRAN-C 4/41 (MOCON, Minneapolis, MN) at 25 °C and 1 atm. The instrument detection limit was 0.05 cc-mil m^{-2} day^{-1}.

The morphological characterization of the NPF was carried out by a Scanning Electron Microscopy (SEM). Gold deposition was run on the cryogenic fracture surfaces of the samples. SEM investigation was made up by a scanning electron microscope (S-3000N, Hitachi High-Technologies Corporation, Japan) at an accelerating voltage of 20 kV.

2.2 | Sample preparation

Peach fruits (*Prunus persica* cv. Alberta) were chosen from the trees in a garden near Shahrood city in the commercial maturity stage. Uniform fruits in size and shapes were selected and transported immediately to the laboratory. After selecting the fruits without defects, they were precooled at 4 °C before treatment. The harvested fruits were washed with 1% hypochloride sodium and dried at room temperature. After that, 5 peaches (approximately 300 g) were randomly packaged in normal PE and nanocomposite films, which were then sealed with a heat sealer and 5 fruits in uncovered PE trays were considered as unpacked fruits. All samples were stored at 2 °C and a humidity of 90% for 48 days. Initially and 7, 14, 21, 28, 35, and 42 days after storage, sample were analyzed to assess postharvest physiological and biochemical indexes. The unpacked fruits and fruits in normal PE film were used as the controls.

2.3 | Firmness measurement

The peach tissue hardness was measured by a penetrometer (GY-2 model, Made in China) with the cylinder diameter of 2 mm at kg cm^{-2} in centimeters. For the measurement, at 2 points on the fruit equator, two circles were made on the skin with a diameter of 1 cm and the hardness was then measured for 3 fruits (Akbudak and Eris, 2004).

2.4 | Weight loss measurement

To measure the weight loss, the peach fruits were weighed on a digital scale (Adam, ACB plus 1000, Made in England) at the beginning of the experiment and thereinafter every 7 d during the storage period. The weight loss was expressed as the percentage loss of the initial total weight.

2.5 | Internal browning determination

Measurement of the amount of internal browning was done according to the Baloch and Edward's method (1973), which was based on the extraction of brown pigments using 50 mm acetic-acid:formaldehyde (at a volume ratio of 2:1) and absorbance measurement at 420 and 600 nm. To this aim, 5 g of each sample were weighed and poured in Erlenmeyer flasks and then, 50 mm of acetic-acid formaldehyde was mixed with the samples. The Erlenmeyer flasks were kept in the lab closets for 72 hr so that the brown pigments were completely extracted. After, the colored solutions of the samples were filtered through Whatman's filter paper (12.5 cm) and the amounts of absorbance at 420 and 600 nm were measured by a spectrophotometer. The wavelengths of 420 and 600 nm were the yellow and brown areas, respectively. The absorbance difference at these two wavelengths was considered as the internal browning index.

2.6 | Total bacterial count

The analysis of mesophilic bacteria was done as described by Del Nobile et al. (2009). Every 7 days, approximately 25 g of the peach pieces (cut into vertical and horizontal slices per part of the peel) were randomly collected and placed into 225 mL of saline solution and agitated in a stomacher bag for 120 s. Decimal dilutions were made in a sterile saline solution and 0.1 mL of the undiluted and diluted solutions were plated. For the total counts of mesophilic bacteria, the samples were plated on Plate Count Agar (Oxoid) (PCA) and incubated at 30 °C for 48 hr. A number of 3 plates were used for each dilution. The number of colonies was reported as CFU/g of peach.

2.7 | Acidity, total soluble solid, and titratable acidity

The fruit samples from each treatment were pooled off and juiced for the determination of pH, TSS, and TA. The pH measurement was done with a pH-meter (WT model, Made in Germany), TSS was measured using a handheld refractometer (ATAGO master 5EM, Made in Japan) and shown in Brix degrees, TA was determined through the fruit juice titration with 0.1 N NaOH up to pH 8.2 using 1 mL of the juice diluted with 10 mL distilled water and expressed as malic acid percentage.

2.8 | Determination of polyphenol oxidase activity

Enzymatic activity was assayed by determining the increase rate of absorbance at 420 nm by UV/VIS spectrophotometer (Unico 2150, Made in China). The reaction mixture contained 3.0 mL of catechol substrate and the solution was freshly prepared in 0.05 sodium phosphate buffer at pH 6.5 and fixed quantity of PPO. The reference cuvette only contained the catechol substrate solution. The reaction was conducted at 25 °C. The linear section of the activity curve as function of time was used to determine the PPO activity (U/mg protein/min). The PPO activity unit was defined as an absorbance change of 0.001 under the assay conditions (Pizzocaro, Torreggiani, & Gilardi, 1993).

2.9 | Determination of catalase and peroxidase activities

CAT activity was measured using a method adapted from that of Aebi (1984) in a reaction mixture containing 50 mM phosphate buffer (pH 7.0), 15 mM H_2O_2, and 20 μL of the sample supernatant. The activity was evaluated by measuring the decrease in the reaction rate at 240 nm. POD activity was measured using guaiacol as substrate, a reaction mixture (3.4 mL) containing 0.2 mL of enzyme solution, 2 mL of 50 mM sodium phosphate buffer (pH 6.5), 0.2 mL of 0.25M H_2O_2, and 1 mL of 50 mM guaiacol. The absorbance increase at 470 nm caused by guaiacol oxidation was recorded for 2 min. One POD unit was defined as an absorbance increase of 0.001 per second. The specific POD activity was expressed as U μg^{-1} protein. The enzymatic protein preparation was assayed according to the Bradford method, by bovine serum albumin as the standard (Bradford, 1976).

2.10 | Statistical analysis

Data were analyzed using a bi-factorial model (storage time × kind of films) ANOVA within SAS Statistical Software (SAS Institute Inc., Cary, NC, USA). Three different samples (packed fruit in PE and nanocomposite film and unpacked fruit) were analyzed in each replication. Duncan's multiple-range test ($p < .05$) was used to determine the difference in means.

3 | RESULTS AND DISCUSSION

3.1 | Film properties

The morphological characteristics of the normal packaging and clay NPF are clearly illustrated in Figure 1a, b, respectively. The particle size was between 100 and 200 nm in diameter, a smaller number of them were less than 100 nm and some of them were larger as well. All the particles had a good distribution, as rectangular nanoparticles in extruded PE were quite well distributed like rectangular nanoparticles in molten PE, indicating good dispersion and adhesion between the matrix and the filler. However, the commercial range of nanopowders was within 20–80 nm, indicating that some nanoparticles were subjected to modest agglomerations during nanocomposite development. Compared to other additive agents, clay nanoparticles received only recently great attention by scientific researchers due to the fine properties including good stability, environmental impact, and wide antibiotic activity (Costa, Conte, Buonocore, & Del Nobile, 2011; Hu, Fang, Yang, Ma, & Zhao, 2011; Incoronato, Buonocore, Conte, Lavorgna, & Del Nobile, 2010).

O_2 and CO_2 transmission and (water vapor permeability) WVP were measured as function of the nanoparticles. As shown in Table 1, gas transmission and WVP of the neat PE films were 16,303.18, 41,344.25 cc-mil m^{-2} day^{-1}, and 3.03 g mm kpa^{-1} $hr^{-1}m^{-2}$, respectively, while the values of the nanocomposite films reduced by 51.48%, 42.88%, and 40.32%, respectively. According to our findings, use of the nanocomposite conception has been shown to be a favorable choice to improve barrier properties (Avella et al., 2005). It could be noted that the gas transmission and WVP of the films could be affected by montmorillonite exfoliation, which could provide significant physical advantages to improve the polymeric system. Generally, clay-filled polymer composite exhibits extraordinary enhancement of physical properties at a low level of filler concentration in comparison to pure polymer (Zenkiewicz, Richert, & Roanski, 2010).

3.2 | Fruit softening

Modified atmosphere created by the adopted packaging showed a significant effect on the tissue firmness during the storage. In general, tissue firmness in the fruits decreased during time. However, a fast reduction in the firmness of the control fruits was found on the 14th day in a way that it changed from 2.82 on the first day to 0.07 kg

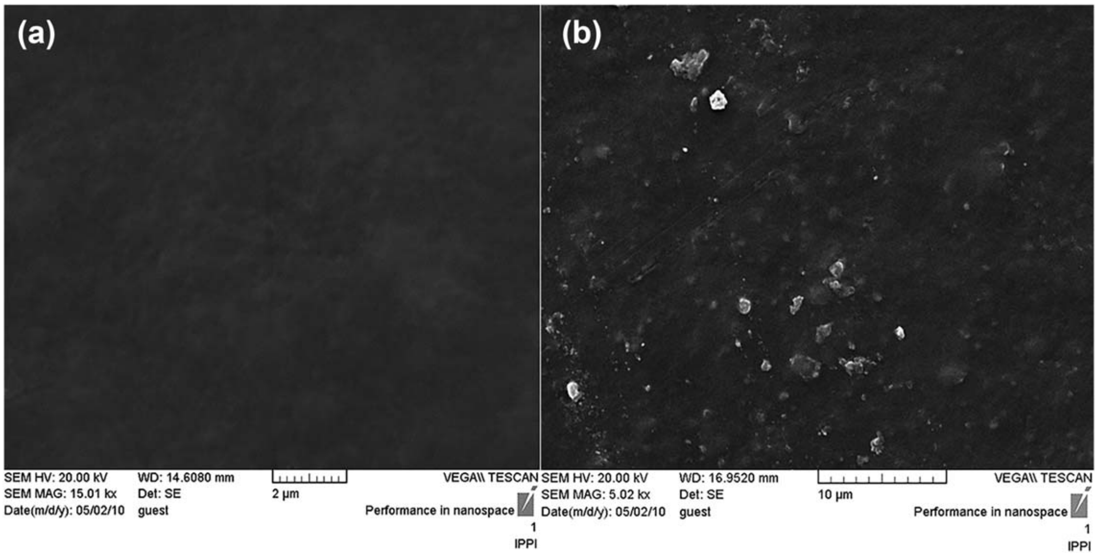

FIGURE 1 SEM micrographs of normal packaging (a) and nanocomposite packaging films (b)

cm^{-2} on the last day (Figure 2). Pretel, Serrano, Amoros, and Romojaro (1999) also showed that firmness in unpacked apricots rapidly reduced within the first 14 days compared to packed fruits. The reduction in firmness might be also caused by polygalacturonase enzyme activity that resulted in the destruction of the polymers in the cell walls (Pretel et al., 1999). Firmness preservation in the samples packed with the nanocomposite film was due to delay in the process of aging caused by the presence of clay nanoparticles in the polymer matrix, reduction of film permeability and consequent reduction of gas exchange (Figure 3). The results of this research are in accordance with those of Hu et al. (2011) who also reported that using clay nanocomposite films the softening process in kiwi fruits was abundantly delayed during 42 days of storage. The peaches stored in the modified atmosphere packaging faced lesser softening, especially, during the first 21 days of storage.

3.3 | Weight loss

The fruit weight loss increased during storage time (Figure 4). There was no significant difference between the fruits packed with PE and nanocomposite films until the 35th day. The highest weight reduction can be seen in the control fruits (approximately 8.11% after the last experimental period) in a way that the reduction was intensified from the 14th day. The above results are in accordance with the reports of Muftuoglu, Ayhan, and Esturk (2010), where in a modified atmosphere, existence of the covers around the fruits caused water vapor accumulation in the films, thus allowing the fruits showing less weight losses caused by water loss (Karabulut & Baykal, 2004).

3.4 | Internal browning

Internal browning is one of the most important factors in the qualitative features of stored fruits. In this research, the results demonstrated that both storage time and packaging material had some effects on the fruit internal browning (Table 2). As the amounts of the extracted pigments at the wavelengths of 420 nm (related to yellow area) and 600 nm (relevant to brown area) were measured, it might be possible that, on the one hand, the enzyme and nonenzyme activities leading to internal browning had increased during the storage time and, on the other hand, the nanocomposite films affecting the reduction of metabolic activities of the fruits had led to their reduction of internal browning in the packages. It seemed that the internal browning of the fruits packed with neat PE film and the control fruits occurred due to the polyphenol oxidase (PPO) enzyme activity in pulp cells and consequent oxidation of phenolic combinations and brown pigment production (Veltman, Lentheric, Van der Plasand, & Peppelenbos, 2003). It was found that PPO enzyme activity reduced in the fruits packed with the nanocomposite film, most probably due to O_2 permeability reduction. The results are in accordance with those of Guan and Dou (2010), who studied MAP effect on plum properties and internal browning at low temperatures.

3.5 | Total bacterial count

Using of active PE film for packing the fruits demonstrated a significant enhancement in mesophilic bacteria colonies compared with the fruits packed in the control film. The fruits stored at 2 °C had initial colonies accounting for about 2.5 log CFU/g (Table 2). With the passage of

TABLE 1 Physical properties of nanocomposite-based packaging and normal packaging films

Films	O_2 Transmission (cc-mil m^{-2} day^{-1})	CO_2 Transmission (cc-mil m^{-2} day^{-1})	Water vapor permeability (g mm kpa^{-1} hr^{-1} m^{-2})
Normal packaging	16,303.18	41,344.25	3.03
NCP	7909.364	23,615.41	2.48

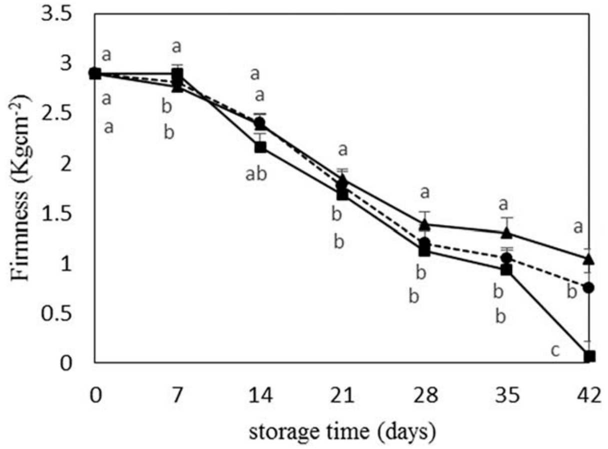

FIGURE 2 Effects of nanocomposite packaging films on firmness of peach during 2 °C storage (■ control, • normal packaging; ▲ nanocomposite packaging films). The same letter are not significantly ($p > .05$) different according to the Duncan's multiple range test. Error bar represents the standard deviation ($n = 3$)

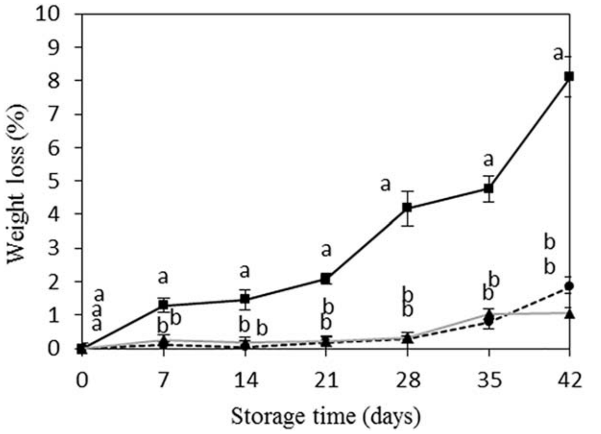

FIGURE 4 Effects of nanocomposite packaging films on weight loss of peach during 2 °C storage (■ control, • normal packaging; ▲ nanocomposite packaging film). The same letter are not significantly ($p > .05$) different according to the Duncan's multiple range test. Error bar represents the standard deviation. ($n = 3$)

time, the populations of bacterial colonies increased to 7.5 and 6.6 log CFU/g in the fruits stored in the PE film and in the unpackaged peaches, respectively. High enhancement was observed in the last days because the number of bacterial colonies in the fruits packaged in presence of clay nanocomposite was 5.1 log CFU/g, thus showing to contain less than 6.0 log CFU/g of aerobic mesophilic bacteria, which can be considered safe for consumption (Jeddi et al., 2014). The microorganism growth prevention in the clay nanocomposite treatment might be due to the antibacterial properties of clay nanoparticles in the PE matrix. This result indicated that the nanoclay can be used not only as a filler to improve the film properties but also as an antimicrobial agent. The nanoclay antimicrobial activity might be attributed by the direct surface contact of food material (Hong & Rhim, 2008; Rhim, Hong, & Ha, 2009). Furthermore, the manufacturer of nanoclays claimed that the nanoclay (Cloisite 20A) has been approved by the (U. S. Food and Drug Administration) FDA for food contact. Therefore, NPF films have the potential to be used to control microbial growth. This property would be of a high value for packaging a variety of fresh foods such as meat, fish, poultry, cereals, cheese, fruits, and vegetables (Incoronato, Conte, Buonocore, & Del Nobile, 2011; Longano et al., 2012).

3.6 | pH, total suspended solids, and titratable acidity

In all the fruits including control fruits, there was the possibility of measuring pH, TA, and TSS due to the existence of enough water and lack of much humidity loss. The primary pH of the fruits was 3.6 (Figure 5a). The pH values increased at the end of the storage time in all the samples. Evaluation of pH changes in the packed fruits showed a significant difference with the control samples ($p \leq 5\%$). The highest pH change at the end of the storage time was seen in the control fruits (4.54) and the lowest changes were found in the clay nanocomposite and in the PE film (4.39 and 4.41, respectively). The pH values rose until the 28th day and then showed no significant changes.

In the control fruits, TA and TSS decreased (Figure 5b) and increased (Figure 5c) from the 14th day, respectively. Application of modified atmosphere packaging displayed a significant difference between packed and unpacked fruits based on TSS amount. At the end of the experiment, the highest TA was recorded in the fruits packed with the nanocomposite (0.2%) and in the normal PE-packaged fruit (0.17%), while that of the control was 0.14%. It was possible that the pH increase was caused by the consumption of organic acids existing in

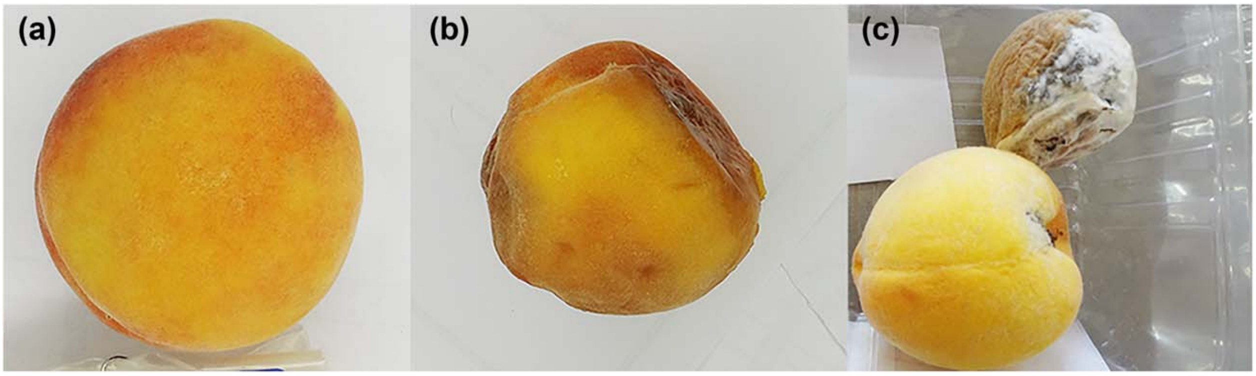

FIGURE 3 Appearance and firmness preservation in the fruits packed with nanocomposite packaging films versus the control fruits after 28 days [(a) peach fruit packed with nanocomposite packaging films; (b) peach fruit packed with neat PE films; (c) unpacked peach fruit]

TABLE 2 Effects of nanocomposite-based packaging on browning index and cell loads of mesophilic bacteria of peach during 2 °C storage

	Browning index			Germination rate (CFU/g)		
Days	Control	Normal	NCP	Control	Normal	NCP
0	0.01* ± 0.008^{Af}	0.01 ± 0.009^{Af}	0.01 ± 0.008^{Af}	2.5 ± 0.27^{Ae}	2.5 ± 0.2^{Ae}	2.5 ± 0.25^{Ad}
7	0.013 ± 0.01^{Bf}	0.02 ± 0.011^{Af}	0.02 ± 0.012^{Af}	3.8 ± 0.22^{Ad}	3 ± 0.23^{Cd}	3.5 ± 0.18^{Bc}
14	0.063 ± 0.012^{Ae}	0.05 ± 0.012^{Ae}	0.06 ± 0.015^{Ae}	4.5 ± 0.24^{Bcd}	5.1 ± 0.25^{Ac}	3.9 ± 0.21^{Cb}
21	0.14 ± 0.011^{Ad}	0.16 ± 0.009^{Ad}	0.16 ± 0.09^{Ad}	4.9 ± 0.27^{Bc}	6.8 ± 0.28^{Ab}	4.1 ± 0.22^{Cb}
28	0.25 ± 0.019^{Ac}	0.23 ± 0.011^{ABc}	0.21 ± 0.006^{Cc}	5.6 ± 0.29^{Bb}	6.9 ± 0.26^{Ab}	4.5 ± 0.24^{Cab}
35	0.35 ± 0.017^{Ab}	0.35 ± 0.008^{Ab}	0.25 ± 0.007^{Bb}	5.9 ± 0.22^{Bb}	7.3 ± 0.21^{Aa}	4.8 ± 0.25^{Ca}
42	0.44 ± 0.009^{Aa}	0.45 ± 0.005^{Aa}	0.32 ± 0.004^{Ba}	6.6 ± 0.23^{Ba}	7.5 ± 0.24^{Aa}	5.1 ± 0.2^{Ca}

*Each value represents the mean of three replicates ± standard deviation.

^{AB,ab}Different letters indicate statistically significant differences at $p < .05$ between unpacked fruit (normal), neat LDPE film (normal), and NCP samples and between storage time, respectively.

the fruits, due to respiration. The results of this research are congruent with those of Rodriguez, Villanueva, and Tenorio (1999). Generally, when fruits are stored, the available sugars and acids are used due to the metabolic activities like respiration, which lead to changes in pH, TA, and TSS (Kader & Ben-Yehoshua, 2000). TSS increase in fruits is caused by the conversion of carbohydrates to sugars and other solvents, through metabolic processes during the storage (Ishaq, Rathore, Masud, & Ali, 2009). It has been also reported that in the fruits with plastic film covers less permeable to atmosphere gases, less pH, TA, and TSS changes occur because of carbon dioxide increase and respiration decrease (Devlieghere & Jacxsens, 2000). Fruits in NPF showed significantly higher values of TA ($p \leq .01$) though no further enhancement in TA was observed after 4 weeks of storage, thus explaining that NPF was associated with their slower ripening (Crisosto & Crisosto, 2001).

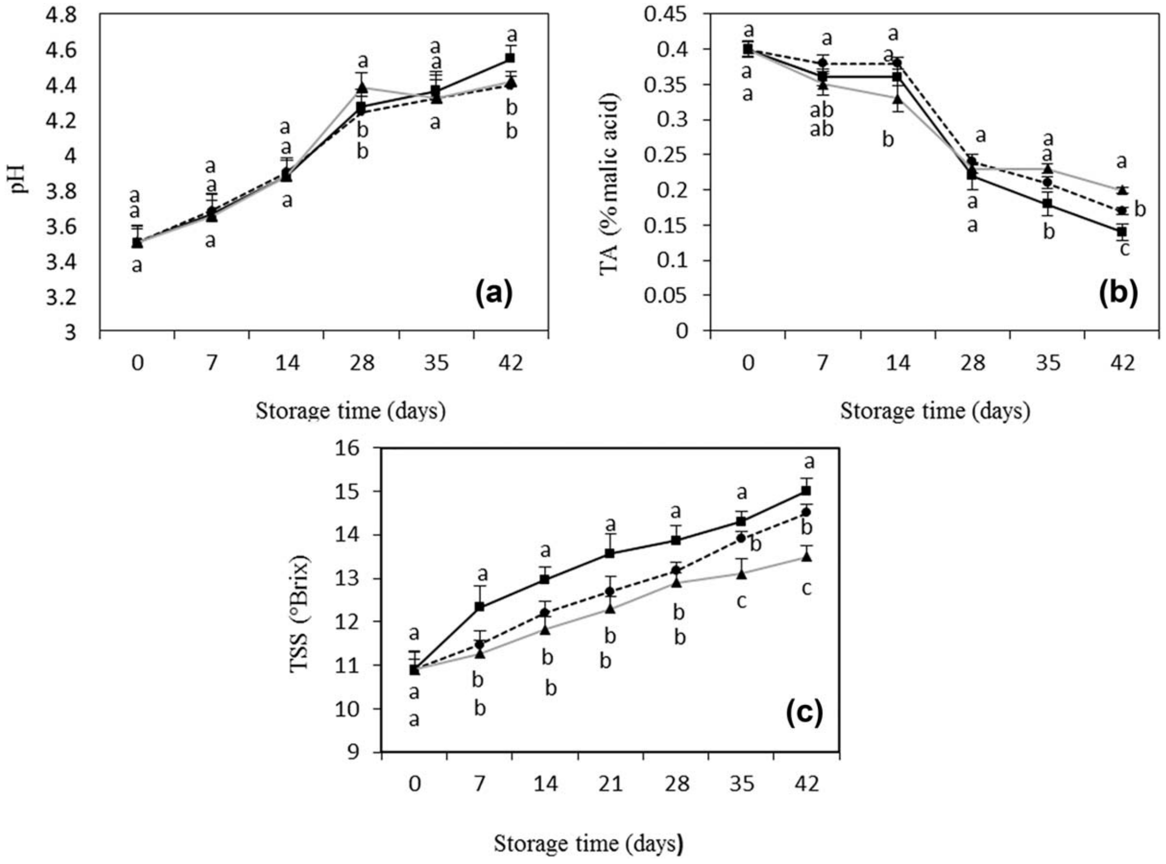

FIGURE 5 Effects of nanocomposite packaging films on organoleptic characteristics of peach during 2 °C storage (■ control, ● normal packaging; ▲ nanocomposite packaging films). (a), pH; (b), titrable acidity; and (c), TSS. The same letter are not significantly ($p > .05$) different according to the Duncan's multiple range test. Error bar represents the standard deviation ($n = 3$)

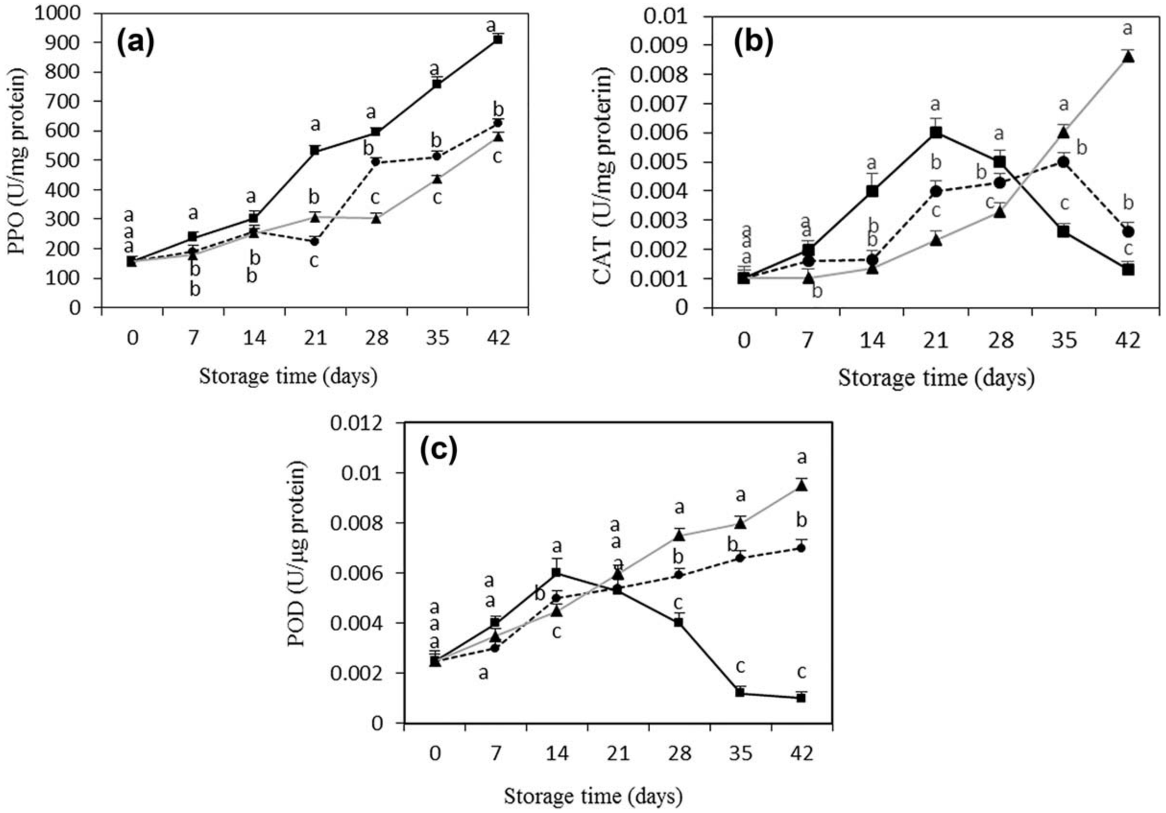

FIGURE 6 Effects of nanocomposite packaging films on physiological index of peach during 2°C storage (■ control, • normal packaging; ▲ nanocomposite packaging films). (a), PPO activity; (b), CAT activity; and (c), POD activity. The same letter are not significantly ($p > .05$) different according to the Duncan's multiple range test Error bar represents the standard deviation ($n = 3$)

3.7 | Polyphenolase oxidase activity

PPO is the most effective enzyme on fruit longevity in the postharvest period and has a basic role in the browning amount of fruit flesh (Dijkstra & Walker, 1991). The effect of NPF on PPO activity is shown in Figure 6a. PPO activity gradually increased up to the 14th day and excessively enhanced afterwards till the end of the observation period, especially in the control fruits. PPO activity in the peach with NPF was maintained at a significantly low level during storage at 2°C, which implied a lower oxidation activity in them. PPOs and polyphenols are found in the different organelles of plant cells. When a tissue is damaged, they meet and reacts each other (Altunkaya & Gokmen, 2008). The inhibitors such as ascorbic acid can be used to prevent fruit browning. Thus, NPF inhibited peach PPO activity and contributed to the better preservation quality.

3.8 | Catalase and peroxidase activities

The results indicated that the storage time and packaging films had significant effects on catalase enzyme activity in fruits (Figure 6b). These findings revealed that the highest catalase activity was recorded in the fruits packed with nanocomposite films while increasing with the passage of time; however, catalase activity in the control fruits enhanced up to the 21st day and then reduced. The reduction of catalase activity in the control fruits might be caused by the cooling injury in the control and neat PE-packed fruits. The findings are in agreement with the results of Xihong, Yun, Fan, Xing, and Tang (2011) who reported catalase activity reduction in frosted sweet pepper. Using passive MAP preserved catalase activity to a great extent through cooling damage reduction, ripening process retardation, and prevention of plasma membrane destruction. The effects of NPF films on peach showed a significant difference between the control and other fruits based on POD activity (Figure 6c). With the passage of time, POD activity was found to increase, while decreasing in the control fruits from the 14th day of the experimental period. After 6 weeks of storage at 2°C, its activity in the fruits attended with the nanocomposite films augmented twice as much as in the control fruits. The reason of this reduction might be the occurrence of cooling injury at low temperatures. The results correspond with those of Safizadeh (2013). High POD activities in the nanocomposite film indicated that the adopted active film is more suitable for reducing the destructive effects of hydrogen peroxide, thus increasing the fruit lifetime in the postharvest period.

4 | CONCLUSIONS

Overall, the beneficial effects of NPF on the quality of peach fruits were highlighted. NPF was proven to be efficient for preventing physiologic changes, delaying ripening, and thus extending peach shelf-life. Therefore, nanocomposite-based films can be new packaging strategies to retard ripening and improve the preservation quality of peach. The promising application as antimicrobial material with suitable barrier properties also suggest that this active system could be also explored as new packaging for other fresh horticultural products with great advantages in terms of quality assurance.

ACKNOWLEDGMENTS

The authors gratefully acknowledge financial support from the College of Agriculture, Ferdowsi University of Mashhad, and Shahrood University of Technology.

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How to cite this article: Ebrahimi H, Abedi B, Bodaghi H, Davarynejad G, Haratizadeh H, Conte A. Investigation of developed clay-nanocomposite packaging film on quality of peach fruit (*Prunus persica* Cv. Alberta) during cold storage. *J Food Process Preserv*. 2017;e13466. https://doi.org/10.1111/jfpp.13466