Korean J Food Preserv, 29(4), 577-589 (2022)
https://doi.org/10.11002/kjfp.2022.29.4.577
pISSN: 1738-7248, eISSN: 2287-7428

Korean Journal of Food Preservation

Research Article

Effects of zeolite-based functional paper packaging on the quality of the *kawanakajima* white peach during storage

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Abstract The purpose of this study was to improve the shelf life of packaged peach using inorganic materials. The functional paper package consisted of 4 inorganic materials (zeolite, diatomite, bentonite, calcium carbonate). Experimental samples were paper-packaged peach (CON), functional paper-packaged peach (FUN), and expanded polyethylene terephthalate-packaged (commercial package) peach (PET). The samples were stored at 20℃ for 10 days. At every 2-3 days, the physicochemical properties, microbiological, sensory qualities of the samples were analyzed. The results showed that FUN compared to CON, significant differences were can be seen in antibacterial effect, physical characteristics (strength and hardness), and color characteristics, especially in the sensory evaluation. But FUN had no effect on weight reduction. Overall, this study showed that FUN was a means of improving the storage quality of peach.

Keywords *kawanakajima*, *cheonjungdo* white peach, functional packaging, quality, storage

Citation: Kim JY, Choi JY, Kim JS, Moon KD. Effects of zeolite- based functional paper packaging on the quality of the *kawanakajima* white peach during storage. Korean J Food Preserv, 29(4), 577-589 (2022)

Received: January 18, 2022
Revised: June 01, 2022
Accepted: June 03, 2022

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1. Introduction

Peaches are one of Korea's five major fruit crops; they are harvested in summer and are widely appreciated by consumers for their rich sweetness and juiciness. Peach trees, belonging to the family Rosaceae (subfamily Prunoideae, genus *Prunus*, subgenus *Amygdalus*) are deciduous and bear climacteric fruits (Kwon et al., 2013). All climacteric fruits, such as peaches, apples, pears, bananas, mangos, papayas, and guavas, exhibit climacteric respiration, which is marked by a rapid increase in respiration rate at some point during fruit maturation or ripening. Hence, ethylene production dramatically increases in climacteric fruits during storage after harvesting, resulting in significant changes in color, texture, flavor, and aroma that influence the overall fruit quality (Trainotti et al., 2006). As both freshness and storability decrease sharply through this process, 10-30% of peaches are discarded during distribution, making timely shipment essential during harvest to avoid severe price fluctuations and economic loss (Kwon et al., 2013). According to the Rural Development Administration's revised Agricultural Technology Guide for Peach Cultivation (2021), the *kawanakajima* white peach is a popular type of hairy peach that is widely cultivated in South Korea. It is characterized by its dense flesh and soft pulp. Because the peel and flesh of this white peach are paler and brighter than those of the yellow peach, appearance changes such as browning are prominent. Therefore, it is particularly critical to maintain the quality of the *kawanakajima* white peach during storage and transportation using food packaging.

The general objective of food packaging is to provide safe and hygienic food to consumers by commercializing agricultural, marine, and livestock products and preventing their physical, chemical, and biochemical deterioration under various environmental conditions during the distribution process (Guilbert, 2000). The primary function of food packaging is therefore to improve sales and distribution while ensuring the protection, safety, and convenience of the packaged contents (Kwon et al., 2013a). Recently, the development of food packaging has expanded to consider additional food storage, hygiene, and environmental impacts, which is expected to result in added value (Kwon et al., 2013a). The demand for agricultural packaging materials with diverse functionalities has grown accordingly. In particular, there is increasing demand for packaging functionality that protects the product, promotes sales, and enables more convenient distribution (Singh et al., 2011). Hence, the processed packaging material market has recently developed in the food industry to overcome disadvantages specifically associated with low product storability thereby minimizing economic loss. In agricultural applications, processed packaging material is not designed to directly alter fruits or vegetables but rather to produce packaging materials that ensure excellent quality and storability of produce in its natural state, thereby increasing consumer satisfaction.

Most previous research on packaging materials for agricultural products has focused on product protection, logistics standardization, and packaging design; few studies have investigated product quality improvement and maintenance of freshness through the adsorption of harmful bacteria or gasses by the packaging materials. In the case of peaches, the outer packaging is currently standardized by paper and inner packaging such as Styrofoam is used for padding. However, this packaging arrangement does not provide a fundamental solution to the difficulties of peach distribution in terms of storability and maintenance of freshness. As a result, previous studies have investigated the carbon monoxide treatment of modified atmosphere packed peaches to improve storability (Chung et al., 2002) and evaluated the physicochemical and antioxidant activity of peaches dried under cold air pressure according to pretreatment conditions (Kwon et al., 2013). However, no research has been conducted to investigate the characteristics of fresh peaches according to the packaging materials in which they are stored.

A novel functional packaging material combining zeolite, diatomite, calcium carbonate, and plant adhesive with paper pulp was therefore applied in this study to improve peach storage quality. Zeolite combines aluminum oxide and silicic acid oxide (Kim, 2016) in a three-dimensional network structure with uniform pores approximately 3-20 Å in size; it is known to exhibit a high cation exchange capacity and high selective adsorption capacity for gas (Park, 1994). Though numerous studies have been conducted on the adsorption of zeolite (Lee et al., 2003; Otker et al., 2005), none have applied it to food packaging materials. The functional paper

https://doi.org/10.11002/kjfp.2022.29.4.577

packaging material evaluated in this study therefore represents an eco-friendly material that may improve the marketability, economic feasibility, and export potential of peaches. To determine the capabilities of this material, *kawanakajima* white peaches were packed in a conventional paper packaging material, the proposed functional packaging material, or a commercial polyethylene terephthalate packaging material, then stored in a controlled environment. The change in the quality of the peaches over time was then quantified to investigate the possibility of extending their shelf life using the functional packaging material.

2. Materials and methods

2.1. Materials, storage conditions, and sampling

The *kawanakajima* white peaches used in this study were purchased in September at a supermarket in Daegu metropolitan city. The peaches were then stored in a general paper packaging material (CON), the proposed functional paper packaging material (FUN), or a polyethylene terephthalate packaging material (PET). The FUN employed in this study was made by mixing natural inorganic raw materials including zeolite (65%), diatomite (20%), bentonite (10%), and calcium carbonate (5%) with paper pulp. FUN packaging materials used in the experiment were provided by Nature Packaging Co., Ltd. Nine *kawanakajima* white peaches were packed in each material and analyzed over 10 days of storage at 20℃. Samples were collected after 0, 2, 4, 7, and 10 days of storage to quantify the change in moisture content, pH and soluble solids content, color, strength and hardness, total phenolic content, microorganism quantities, and sensory impressions.

2.2. Measurement of moisture content

The moisture content of each peach was obtained using the air-oven method specified in the South Korean Food Code and Specification Regulation (2020). In this process, a 3 g sample of flesh from a peach stored in each packaging material was spread on an aluminum foil plate, dried in a drying oven at 105℃ for 5 hours, and then cooled in a desiccator for 30 minutes. The change in moisture content was then measured and expressed as a percentage (%) according to the following equation.

$$\text{Moisture content (\%)} = (w_0 - ws) / w_0 \times 100$$

w_0: Initial sample weight (g)

ws: Sample weight after drying (g)

2.3. Measurement of pH and soluble solid content

After removing the peel samples from each peach for color measurement, a 5 g sample of flesh was diluted 10-fold with distilled water. The resulting solution was then filtered through filter paper (Whatman No. 2). The pH value for each filtered solution was determined as the average of three repeated measurements using a pH meter (Orion 3 Star, Thermo Electron Co., Waltham, MA, USA), and the soluble solid contents within were observed with a refractometer (Maste-α, Atago Co., Tokyo, Japan).

2.4. Color measurement

Peach peel samples were randomly cut from the storage specimens at 1.5 cm below the stem to measure the color of the cut surface. The average L^* (lightness), a^* (redness), and b^* (yellowness) values were determined from 10 measurements obtained using a colorimeter (CR0400, Minolta, Tokyo, Japan) calibrated with a white plate (L^*=97.79, a^*=-0.38, b^*=0.25).

2.5. Measurement of strength and hardness

The strengths and hardnesses of the peaches were measured using a rheometer (Compac-100Ⅱ, Sun Scientific Co., Tokyo, Japan) with Probe No. 5 (Ø5 mm); the test conditions were set to test mode 20, a probe entry distance of 20%, a table speed of 180 mm/min, and a maximum load cell stress of 2 kg. After the peel samples were removed 1.5 cm below the stem of each peach, measurements were collected from 10 locations within the exposed cut surface; the average values were then reported as the strength and hardness.

2.6. Determination of total phenolic compound content

The total phenolic compound (TPC) content was quantified by applying the Folin-Ciocalteu method (Kim and Youn, 2012), in which 3 g of *kawanakajima* white peach flesh from each storage condition was mixed with 15 mL of 80% ethanol, homogenized for 30 sec using a hand mixer, and then filtered through filter paper (Whatman No. 2). After diluting 1 mL of the filtrate with 10 mL of distilled water, 1 mL of the diluted solution was mixed with 1 mL of 50% Folin-Ciocalteu's reagent and left in the dark for 15 min before adding 1 mL of 10% Na_2CO_3 solution. After leaving this solution in the dark for 1 h, the absorbance at 760 nm was measured using a UV-visible spectrophotometer (Evolution 201, Thermo Fisher Scientific Inc., Madison, WI, USA). A standard curve was then prepared with gallic acid to determine the TPC content.

2.7. Microbial enumeration

The numbers of general bacteria, molds, and yeasts on the surface of each peach were determined as these microorganisms that can compromise the quality of the *kawanakajima* white peach. First, 20 g of the peel and pulp of the fruit was collected; then, 180 mL of 0.1% peptone water was added and the solution homogenized. The diluted medium was subsequently transferred to a Petri dish using the pour plate method. Normal bacteria were then cultured for 48 h in an incubator at 37±1℃ using plate count agar (Plate count agar, Difco, USA); yeasts and molds were cultured for 5 days in an incubator at 25±1℃ using potato dextrose agar (Potato dextrose agar, MBcell, USA). The number of colonies generated in each Petri dish was then visually counted and expressed in terms of log CFU (colony-forming unit)/g to quantify the microorganisms present on each peach.

2.8. Sensory evaluation

A sensory impressions test evaluating the off-flavor, discoloration, corruption, and weakness of the peaches was performed by 10 Kyungpook National University students using a seven-point scale (1: none, 7: very severe) to determine the overall acceptability on another seven-point scale (1: very poor, 7: very good). The limit of marketability was set at a score of 2 on the acceptability scale. Three *kawanakajima* white peaches stored in each packaging material were provided as samples for the testers: one was not cut, and the other two were cut starting 1.5 cm from the stem on both sides. This sensory test was safely carried out after receiving final approval (registration number: KNU-2021-0144) from the Bioethics Review Committee of Kyungpook National University.

2.9. Statistical analysis

A one-way analysis of variance (ANOVA) was

https://doi.org/10.11002/kjfp.2022.29.4.577

performed on all results using the Statistical Package for Social Sciences (SPSS, SPSS Inc., Chicago, IL, USA) software package. Significant differences between samples were verified by Duncan's multiple range test ($p<0.05$).

3. Results and discussion

3.1. Moisture content

Table 1 shows the change in the moisture content of the *kawanakajima* white peaches during storage in the different packaging materials. The moisture content of all fruits began at 85.25% and initially increased before decreasing by various degrees: the moisture content of the peaches stored in CON increased to 86.62% at day 7 before decreasing to 83.31% at day 10; that of the peaches stored in FUN increased to 88.70% at day 2 before decreasing considerably to 81.05% at day 10; and that of the peaches stored in PET increased to 87.57% at day 4 before remaining at approximately 87% subsequently. Therefore, it was concluded that FUN was unable to maintain the moisture content in the packaged fruit. Zeolite is known to selectively adsorb adsorbate molecules according to the size and polarity of the micropores regularly formed within its structure. It particularly adsorbs hydrophilic and polar molecules well (Lee et al.,

Table 1. Changes in physicochemical characteristics of *kawanakajima* white peach packaged with different materials during storage

		Storage period (day)				
		0	2	4	7	10
Moisture contents (%)	CON[1)]	85.35±0.11$^{2)bA}$	86.48±0.14$^{b3)A}$	85.55±0.59$^{bA4)}$	86.62±1.76^{bA}	83.31±0.12^{aB}
	FUN	85.35±0.11^{cA}	88.70±1.04^{dB}	88.28±0.23^{dC}	83.59±0.55^{bA}	81.05±0.61^{aA}
	PET	85.35±0.11^{aA}	87.30±0.29^{cA}	87.57±0.20^{cB}	86.73±0.29^{bA}	87.46±0.13^{cC}
pH	CON	4.53±0.09^{aA}	4.81±0.07^{bA}	4.61±0.07^{aA}	5.00±0.03^{cB}	5.23±0.01^{dB}
	FUN	4.53±0.09^{aA}	5.20±0.02^{cC}	5.20±0.09^{cB}	4.80±0.09^{bA}	5.32±0.21^{cB}
	PET	4.53±0.09^{aA}	5.02±0.05^{B}	5.05±0.09^{bB}	5.18±0.02^{cC}	4.59±0.05^{aA}
Total soluble solid (°Brix)	CON	1.17±0.06^{bA}	1.10±0.00^{a}	1.10±0.00^{aA}	1.20±0.00^{bA}	1.20±0.00^{bA}
	FUN	1.17±0.06^{aA}	1.20±0.00^{a}	1.23±0.06^{abB}	1.20±0.00^{aA}	1.23±0.06^{abA}
	PET	1.17±0.06^{abA}	1.10±0.00^{a}	1.17±0.06^{abAB}	1.23±0.06^{bcA}	1.27±0.06^{cA}
L^*	CON	70.87±1.51^{cA}	68.35±2.29^{bcC}	66.69±2.48^{bA}	66.80±2.46^{bB}	61.72±4.81^{aA}
	FUN	70.87±1.51^{cA}	63.69±2.63^{bB}	65.38±2.33^{bA}	63.45±2.96^{bA}	63.63±3.18^{bA}
	PET	70.87±1.51^{dA}	60.92±3.99^{aA}	65.05±3.04^{bcA}	67.09±3.05^{cB}	62.62±2.92^{abA}
a^*	CON	−1.77±0.64^{aA}	0.06±2.34^{bA}	−0.12±1.50^{bA}	−0.25±1.10^{bA}	2.04±1.42^{cC}
	FUN	−1.77±0.64^{abA}	1.94±0.75^{bAB}	−2.34±8.76^{aA}	−1.10±0.78^{abA}	−0.96±1.55^{abB}
	PET	−1.77±0.64^{aA}	1.33±2.12^{cB}	−0.73±1.17^{abA}	−0.59±2.36^{abA}	0.30±1.02^{bcA}
b^*	CON	13.96±0.55^{aA}	17.40±1.16^{bA}	19.31±1.38^{dA}	19.76±1.10^{eB}	18.66±0.72^{cdB}
	FUN	13.96±0.55^{aA}	17.90±0.74^{bA}	20.25±1.65^{cAB}	17.98±2.03^{bA}	17.43±1.16^{bAB}
	PET	13.96±0.55^{aA}	20.88±1.11^{cB}	21.68±2.80^{cB}	17.43±1.16^{bA}	16.53±1.89^{bA}

[1)]CON, no treatment; FUN, functional paper-packaging; PET, polyethylene terephthalate-packaged (commercial package) peach.
[2)]Values are mean±standard deviation.
[3)a-d]Significantly different between storage period by Duncan's multi-range test ($p<0.05$).
[4)A-C]Significantly different between storage condition by Duncan's multi-range test ($p<0.05$).

1999; Lee et al., 2011). Furthermore, diatomite is a type of sedimentary aggregate made up of floating algae shells called diatoms; because it also has pores, it also functions as an adsorbent (Lvanov and Belyakov, 2008). Therefore, the longer the storage period, the more likely it is that the ingredients in FUN will absorb moisture from the *kawanakajima* white peach, as indicated by the decreasing moisture content.

Moisture loss from a fruit shrinks it and reduces the juice within, thereby harming its texture and taste. Park et al. (1999) found that peaches stored at room temperature after sealing with a film made by mixing low density polyethylene (LDPE) and zeolite showed a significantly smaller weight loss compared to peaches in the unsealed control group because the moisture evaporation was controlled by the film. Thus, additional packaging would be required to prevent moisture loss when using FUN packaging to store and transport the *kawanakajima* white peach.

3.2. pH and soluble solid content

Table 1 shows the changes in pH and total soluble solid content of *kawanakajima* white peach pulp according to the packaging materials used for storage. The pH values generally increased from an initial value of 4.53 in all groups over time. The pH of the peaches stored in CON consistently increased up to 5.23 and that of the peaches stored in FUN eventually increased to 5.32 by day 10; the pH of the peaches stored in PET increased to 5.18 on day 7 before decreasing to 4.59 by day 10. Jang et al. (2012) found that the pH of peaches generally increased with storage time, which is partially consistent with these results. Overall, the type of packaging material does not appear to have significantly affected the pH change of the peaches.

The main sugar components in peach fruit are sucrose, fructose, glucose, and sorbitol (Eum et al., 2009). As peaches are climacteric fruits (Cha et al., 2006), respiration and ethylene production temporarily increase with the progression of ripening, leading to various changes such as softening of the pulp and increase in soluble solids. In addition, the sucrose content has been found to significantly increase in proportion to the degree of ripening (Chung et al., 2002). As shown in Table 1, on storage day 0 in this study, the soluble solid (sugar) content was 1.17 °Brix, and slightly increased with ongoing storage time in all three packaging materials, reaching 1.20 °Brix for CON, 1.23 °Brix for FUN, and 1.27 °Brix for PET at day 10. Therefore, similar to the findings for pH, there was no significant difference in soluble solid content depending on the packaging material used. The ripening speed and taste change of the *kawanakajima* white peach is accordingly not significantly affected by the use of FUN.

3.3. Color

As peach ripening progresses, anthocyanin pigments accumulate in the peel and chlorophyll is lost, resulting in the development of variety-specific colors (Rural Development Administration, 2021). The color of a peach is one of the most critical factors in judging the quality of its appearance, and has a direct effect on consumer purchase intention. The color change of the *kawanakajima* white peach during the ripening process is shown in Table 1. The peaches stored in CON and FUN tended to exhibit a decrease in L^* value with ongoing storage time, whereas an initial decrease in L^* value was followed by an increase for the peaches stored in PET. Notably, the peaches stored in PET generally maintained a higher L^* than those stored in FUN or

https://doi.org/10.11002/kjfp.2022.29.4.577

CON from day 7 onward. By day 10, the L^* values for peaches stored in all three packaging materials were lesser than their initial values, with the most significant decrease observed in the case of FUN. The a^* value of the peaches stored in CON significantly increased on storage day 2 and remained generally consistent up to day 10. The peaches stored in FUN and PET exhibited initial increases in a^* value followed by decreases without following a clear trend. However, the peaches stored in FUN exhibited a smaller overall change in a^* than those stored in PET, with the lowest a^* observed on day 4. The b^* value significantly increased in the peaches stored in FUN and PET from day 2 to day 4, then remained substantially unchanged up to day 10, whereas the b* value of the peaches stored in CON increased significantly up to day 7, then decreased subsequently.

According to Kim et al. (2012), the change in peach color during storage occurs through a non-enzymatic browning reaction, including the Maillard reaction; packaging and storage methods can therefore play a role in maintaining the brightness and redness of peaches. In fact, the results obtained in this study indicate that the a^* values of the peaches stored in FUN were generally maintained. In addition, Kim et al. (2009) reported that the L^* value of peaches decreased and their b* value increased as the storage period increased, which is similar to the observations in this experiment. Therefore, the results obtained in this study suggest that FUN is particularly effective in maintaining the redness of the *kawanakajima* white peach. This will likely exert a positive effect on the consumer's judgment of storage quality.

3.4. Strength and hardness

The peach shows rapid softening at room temperature; changes in hardness and strength during storage are therefore critical indicators of storage quality. Table 2 shows the strengths and hardnesses of peaches stored in the three different types of packaging materials. Strength refers to the overall material resistance to a general applied load, whereas hardness refers to the resistance of the outer part of the material to a point load; that is, the hardness of the material's surface. The strengths and hardnesses of all peaches significantly decreased as the storage period increased, regardless of packaging material. This occurred because

Table 2. Changes in texture of differently-packaged *kawanakajima* white peach during storage (gf/cm^2)

		Storage period (day)				
		0	2	4	7	10
Strength	CON[1)]	1,833.00±415.08[2)dA]	751.72±86.94[c3)B]	795.20±59.61[cA4)]	582.63±75.07[bB]	815.89±52.87[cA]
	FUN	1,833.00±415.08[cA]	894.83±201.98[bA]	778.70±63.81[abAB]	655.46±78.34[aAB]	633.56±133.8[aB]
	PET	1,833.00±415.08[cA]	642.28±123.41[aA]	859.68±98.78[bB]	562.77±78.05[aA]	617.78±48.1[aA]
Hardness	CON	28,932.00±13,011.12[cA]	8,747.00±3,812.08[abA]	11,394.50±2,997.99[bA]	9,059.64±2,176.29[abB]	5,388.84±1,128.60[aA]
	FUN	28,932.00±13,011.12[dA]	9,236.70±5,447.82[bcA]	12,550.00±1,025.91[cAB]	5,283.76±1,488.39[abA]	5,040.01±426.74[abA]
	PET	28,932.00±13,011.12[cA]	6,239.30±1,980.98[aA]	14,655.00±3,037.46[bB]	3,887.74±1,605.76[aA]	5,725.51±2,338.42[aA]

[1)]CON, no treatment; FUN, functional paper-packaging; PET, polyethylene terephthalate-packaged (commercial package) peach.
[2)]Values are mean±standard deviation.
[3)a-d]Significantly different between storage period by Duncan's multi-range test ($p<0.05$).
[4)A,B]Significantly different between storage condition by Duncan's multi-range test ($p<0.05$).

peaches have soft tissues in which the ethylene generated during the ripening process leads to cell wall collapse, increasing the contents of enzymes such as polygalacturonase and cellulase and resulting in compositional changes that weaken the pulp (Fisher and Bennett, 1991; Lieberman, 1979). Ahrens and Huber (1990) similarly concluded that the decrease in fruit hardness is related to changes in cell wall composition owing to the action of ethylene. By day 7, the strengths of peaches stored in CON, FUN, and PET decreased from 1,833 gf/cm^2 to 582.63 gf/cm^2, 655.46 gf/cm^2, and 562.77 gf/cm^2, respectively. The peaches stored in FUN generally maintained a higher strength than those stored in PET, and tracked the strength change of peaches stored in CON. The excellent performance of FUN is a result of zeolite adsorption of the ethylene continuously generated by the peach during storage, which enables respiration and limits ripening to delay softening. The variation in hardness was more significant than that in strength. In particular, the hardness of the peaches stored in PET decreased from an initial value of 28,932.00 gf/cm^2 to 3,887.74 gf/cm^2 at day 7, with the softening of the pulp proceeding rapidly as the storage time increased. Therefore, the results of the hardness and strength tests indicate that packaging in FUN effectively maintains the physical properties of the *kawanakajima* white peach.

3.5. Total phenolic compound content

According to Zhao et al. (2015), the representative polyphenolic compounds present in peach fruits include neochlorogenic acid, chlorogenic acid, catechin, and quercetin-3-*O*-galactoside. These compounds provide antioxidant, anticancer, anti-inflammatory, and visual acuity enhancement effects (Chung, 2014). Table 3 shows the TPC contents of *kawanakajima* white peaches according to packaging material. The TPC contents of peaches stored in FUN and PET varied without a clear trend throughout the storage period, whereas those of peaches stored in CON remained fairly consistent. According to Kim et al. (2009), the TPC content of peaches tends to increase as the storage period increases. However, the data obtained in this study suggest that an increase in antioxidant activity owing to an increase in TPC content is less likely when storing peaches in FUN.

3.6. Microbial enumeration

Because spoilage has emerged as a considerable problem in the distribution of peaches, an analysis was conducted to determine the change in the quantity of microorganisms present in both the peel and pulp over 10 days of storage in various

Table 3. Changes in total phenol contents (TPC) of differently-packaged *kawanakajima* white peach during storage (mg/g)

		Storage period (day)				
		0	2	4	7	10
TPC	CON[1)]	0.56±0.04[2)bA]	0.39±0.08[a3)A]	0.51±0.11[aA4)]	0.57±0.04[bB]	0.56±0.07[bA]
	FUN	0.56±0.04[bA]	0.34±0.07[aA]	0.47±0.06[abA]	0.49±0.06[abAB]	0.67±0.20[cB]
	PET	0.56±0.04[bA]	0.40±0.12[aA]	0.62±0.06[cB]	0.40±0.07[aA]	0.55±0.05[bA]

[1)]CON, no treatment; FUN, functional paper-packaging; PET, polyethylene terephthalate-packaged (commercial package) peach.
[2)]Values are mean±standard deviation.
[3)a-d]Significantly different between storage period by Duncan's multi-range test ($p<0.05$).
[4)A,B]Significantly different between storage condition by Duncan's multi-range test ($p<0.05$).

https://doi.org/10.11002/kjfp.2022.29.4.577

packaging materials. The results are shown in Fig. 1. For the peaches stored in CON, the number of common bacteria showed a steady increase by day 7, whereas the number of common bacteria in the peaches stored in FUN remained similar to the initial value in the range 1.17-1.90 log/CFU and exhibited the smallest quantity of bacteria on all days. The quantity of common bacteria for peaches stored in PET was lower than that for peaches stored in CON, but higher than that for peaches stored in FUN.

The quantity of yeast and mold generally tended to increase from its initial value regardless of packaging material. From day 2 on, peaches stored in CON showed a yeast and mold quantity range of 2.70-3.26 log/CFU whereas peaches stored in FUN showed a range of 2.57-2.70 log/CFU.

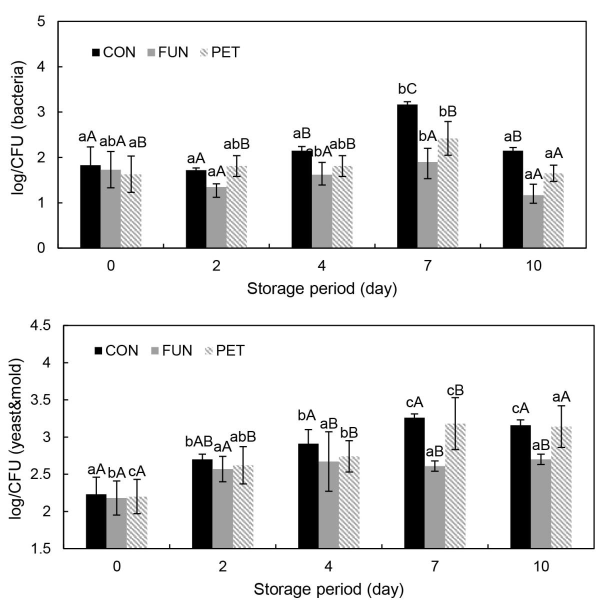

Fig. 1. Changes in microorganisms of differently-packaged *kawanakajima* white peach during storage. [1)]CON, no treatment; FUN, functional paper-packaging; PET, polyethylene terephthalate-packaged (commercial package) peach. [2)]Values are mean± standard deviation. [3)a-c]Significantly different between storage period by Duncan's multi-range test ($p<0.05$). [4)A-C]Significantly different between storage condition by Duncan's multi-range test ($p<0.05$).

Microbial growth was therefore slowest for the peaches stored in FUN. It is likely that zeolite, the primary component of FUN, imbues the packaging material with an antibacterial effect; this interpretation is supported by results reported by Lee et al. (2017). In fact, zeolite is known to remove ammonia nitrogen rapidly and stably (Bernal and Lopez-Real, 1993). Furthermore, zeolite in which some portion of the cations is substituted with anions has been used as a food quality maintenance or freshness retention agent because of its antibacterial properties. Critically, among the microorganisms that cause putrefaction in peaches after harvest, fungi such as *Penicillium hirsutum* and *Monilinia laxa* can grow even at -4℃, when most crops freeze (Choi et al., 2005). Thus, whereas refrigerating the fruit will not completely suppress putrefaction, packaging in FUN can reduce the growth of microorganisms that lead to putrefaction.

3.7. Sensory evaluation

Table 4 shows the sensory impression test results for *kawanakajima* white peaches stored in different materials. Fig. 2 depicts photographs of the change in the cut sections of *kawanakajima* white peaches with ongoing storage time. No significant difference in the off-flavor evaluation was observed for peaches stored in any type of packaging until day 4; they all increased rapidly after day 7. In particular, the off-flavor score for peaches stored in CON was 5.6 on day 10, the most severe among the three sets of peaches (the corresponding off-flavor score for peaches stored in FUN was 2.6 that for peaches stored in PET was 2.8). On the one hand, the discoloration score for the peaches stored in CON continuously increased with time such that it was severe at a score of 5.0 or higher by day 10. On the other hand, the discoloration

Table 4. Changes in sensory scores of differently-packaged *kawanakajima* white peach during storage

	Storage period (day)	Sensory evaluation				
		Off-flavor	Discoloration	Corruption	Weakness	Overall acceptability
CON[1)]	0	1.0±0.0[2)]^{aA}	1.0±0.0[3)]^{aA}	1.0±0.0^{aA}[4)]	1.2±0.4^{aA}	6.9±0.3^{cA}
	2	1.6±1.1^{abA}	2.5±1.0^{bA}	2.7±1.3^{bA}	3.4±1.6^{bcA}	4.1±1.5^{bA}
	4	1.1±0.3^{aAB}	2.7±0.8^{bA}	2.0±1.1^{abB}	3.0±1.2^{bA}	4.9±1.5^{bA}
	7	2.3±1.3^{bAB}	5.4±1.3^{cA}	5.0±1.5^{cA}	4.6±2.0^{cdA}	1.7±0.7^{aB}
	10	5.6±1.4^{cB}	6.2±0.8^{dB}	6.2±1.1^{dB}	5.0±1.4^{dB}	1.4±0.5^{aA}
FUN	0	1.0±0.0^{aA}	1.0±0.0^{aA}	1.0±0.0^{aA}	1.2±0.4^{aA}	6.9±0.3^{dA}
	2	1.3±0.7^{aA}	2.7±1.3^{bA}	2.0±0.8^{bA}	3.1±1.2^{bA}	4.6±1.8^{cA}
	4	1.4±0.7^{aA}	3.7±1.3^{cA}	3.7±1.3^{bA}	4.6±1.7^{bA}	3.4±0.7^{bB}
	7	1.5±0.5^{aB}	2.8±1.0^{bB}	2.4±1.1^{bB}	3.5±1.6^{bA}	3.9±1.0^{bcA}
	10	2.6±1.2^{bB}	4.0±0.7^{dB}	4.2±0.6^{dB}	3.6±1.0^{bB}	4.5±0.9^{aA}
PET	0	1.0±0.0^{aA}	1.0±0.0^{aA}	1.0±0.0^{aA}	1.2±0.4^{aA}	6.9±0.3^{cA}
	2	1.4±0.5^{abA}	2.8±1.0^{bcA}	2.5±1.1^{bA}	2.3±1.3^{bA}	4.5±1.5^{bA}
	4	1.9±0.9^{bB}	3.6±1.4^{cA}	3.6±1.4^{cB}	4.9±1.4^{dB}	2.4±1.2^{bA}
	7	1.3±0.7^{abA}	2.4±1.3^{bA}	2.3±1.3^{bA}	4.0±1.1^{cdA}	3.8±1.4^{bB}
	10	2.8±0.8^{cA}	2.5±0.7^{bA}	4.6±0.7^{dA}	3.2±1.1^{bcA}	4.2±0.8^{aB}

[1)]CON, no treatment; FUN, functional paper-packaging; PET, polyethylene terephthalate-packaged (commercial package) peach.
[2)]Values are mean±standard deviation.
[3)a-d]Significantly different between storage period by Duncan's multi-range test ($p<0.05$).
[4)A,B]Significantly different between storage condition by Duncan's multi-range test ($p<0.05$).

Fig. 2. **Appearance of differently packaged *cheonjungdo* white peach during storage.** [1)]CON, no treatment; FUN, functional paper-packaging; PET, polyethylene terephthalate-packaged (commercial package) peach.

 https://doi.org/10.11002/kjfp.2022.29.4.577

scores for the peaches stored in FUN and PET exhibited temporary increases on day 4, but were generally maintained thereafter. The corruption score for the peaches stored in CON was 5.0 on day 7 and 6.2 on day 10, indicating severe putrefaction, whereas the peaches stored in FUN maintained a corruption score in the range of 2.0-3.7 up to day 10, when significant putrefaction occurred with a score of 4.2. The corruption score for the peaches stored in PET was generally maintained at a low overall value, but increased rapidly on day 10. The degree of weakness increased rapidly on day 4 for the peaches stored in all three packaging materials. Finally, the overall acceptability of peaches stored in CON decreased rapidly with ongoing storage time; after day 7, the overall acceptability dropped to 1 (very poor). For peaches stored in FUN and PET, the overall acceptability only dropped to 4 by day 10. Therefore, FUN and PET both maintained a higher product value until the end of the experiment. These results suggest that the overall appearance and quality characteristics of the peaches stored in FUN were more likely to be considered excellent by consumers. In other words, packaging *kawanakajima* white peaches in FUN could help to maintain their quality characteristics for an extended period of time.

4. Conclusions

The objective of this study was to evaluate the suitability of a novel zeolite-based functional packaging material for increasing the shelf life of the *kawanakajima* white peach, a climacteric fruit. An increased shelf life was considered to be the result of maintaining quality until consumption, thereby increasing consumer satisfaction. Three packaging materials were evaluated: a conventional paper packaging (CON), the proposed functional packaging (FUN), and a commercial polyethylene terephthalate packaging (PET). The qualities of peaches stored in each type of material were evaluated in terms moisture content, pH and soluble solids content, color, strength and hardness, total phenolic content, microorganism quantities, and sensory impressions. The use of FUN resulted in significant improvements in appearance quality, antibacterial effect, physical properties (strength and hardness), and color characteristics compared to the use of CON. Furthermore, a high preference for peaches stored in FUN was indicated by the results of the sensory impressions test. Therefore, the use of FUN is expected to improve the storage quality of the *kawanakajima* white peach. In addition, because the zeolite and diatomite used as raw materials in FUN are environmentally friendly and harmless to the human body, they can also serve as eco-friendly packaging materials. Furthermore, a paper packaging material coated with a solution containing zeolite powder and diatomite powder, such as that employed in this study, can be easily mass produced. Thus, food freshness and preservation can be improved by capitalizing on the excellent moisture adsorption and gas binding properties of the proposed zeolite-based functional packaging.

Conflict of interests

The authors declare no potential conflicts of interest.

Author contributions

Conceptualization: Kim JY. Data curation: Kim JS. Formal analysis: Kim JY, Kim JS. Methodology: Kim JY, Kim JS. Validation: Kim JY, Choi JY, Kim JS. Writing - original draft: Choi JY. Writing - review & editing: Kim JY, Kim JS, Moon KD.

Ethics approval

The sensory evaluation of this research was safely carried out with the approval of exemption (No. KNU-2021-0144) from the IRB of Kyungpook National University.

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