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RESEARCH ARTICLE

Effects of packaging and temperature abuse on the quality of red pepper (*Capsicum annuum* L.) powder

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Abstract
Storage stability of pepper (*Capsicum annuum* L.) powder packaged using 2 different film pouches of Ny/PE and PET/Al/PE inserted with moisture absorbent and oxygen scavenger was investigated during storage at 25 °C for 5 months and at 40 °C for 14 days. The moisture content of red pepper powder did not change significantly in PET/Al/PE packaging but decreased significantly in Ny/PE packaging after the abuse of storage temperature. The color of red pepper powder was quite stable in all packaging treatments. Other quality characteristics of all packaged pepper powder, including microbial cell count, capsaicinoids, ascorbic acid, and free sugar content, were also maintained near their initial levels with no appreciable changes during storage. Red pepper powder with a moisture content of 13–14% and packaged with a film with high gas-barrier properties can be stored for more than 5 months even if there is an unexpected temperature abuse during storage.

Keywords Red pepper powder · Gas-barrier film · Gas absorber · Temperature abuse · Storage stability

Introduction

Red pepper (*Capsicum annuum* L.) is one of the most widely used food coloring and flavoring substances for culinary and industrial purposes (Choi et al., 2023; Kim et al., 2022; Ordóñez-Santos et al., 2014). Red pepper powder has been widely used not only as a seasoning but also in traditional Korean foods such as *gochujang* (hot pepper paste or red chili paste), *kimchi* (fermented vegetables), and *jeotgal* (salted seafood) due to its attractive red color, unique sweet taste, and zest. Unlike bell peppers, which are usually consumed fresh, most red peppers are used as a spice in Korean food in dry powder form (Hwang et al., 2001; Kim et al., 2022). Dried powdered foods are easier to store than fresh foods, but dried red pepper powder may change color and other quality characteristics due to ambient conditions such as light, oxygen, and moisture (Biacs et al., 1992; Kim et al., 2004).

Plastic films are commonly used in dry food packaging, where gas permeability and transparency play an important role in maintaining the quality factors of packaged dehydrated food. As a typical packaging material for red pepper powder, polyethylene (PE) or nylon/polyethylene (Ny/PE) films with excellent moisture barrier and transparency are used according to consumer preferences (Jeong et al., 2013). On the other hand, in the case of powdered food, an active packaging method in which an oxygen scavenger or a moisture absorber is inserted to delay deterioration in quality is widely used (Merxis and Kontominas, 2010; Tsuzuki et al., 2014).

Since red pepper powder is typically exposed to various environmental conditions during storage and distribution, it requires adequate protection against moisture and oxygen (Rhim and Hong, 2011). If the moisture content of dried red pepper powder is too high or too low, lumps and discoloration may occur during storage and distribution (Hartmann and Palzer, 2011; Rhim and Hong, 2011; Topuz, 2008). In particular, the discoloration of red pepper

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powder is an important factor in determining product value (Ordóñez-Santos et al., 2014). On the other hand, the ascorbic acid in dried red pepper acts as a natural antioxidant and functions as the first oxidation barrier of the product, reacting with oxygen within packages, and consequently, the content of ascorbic acid decreases during storage (Daood et al., 1996; Iqbal et al., 2015).

Several studies have reported the effect of packaging dried peppers in plastic bags with different gas permeability at different storage temperatures on quality during storage (Choi et al., 2018; Iqbal et al., 2015; Lee et al., 2003; Ordóñez-Santos et al., 2014). However, few studies have applied plastic film packages with gas scavengers to maintain the quality attributes of red pepper powder during long-term storage at room temperature. Therefore, in this study, the effect of plastic film packaging and gas absorbent on the quality change of red pepper powder was investigated to determine an efficient packaging method to extend shelf life under storage conditions with temperature abuse to simulate export overland and marine transportation.

Materials and methods

Experimental materials

Clean dried red pepper (several cultivars including *Keum-Dang*, *Keum-Na-Ra*, *Il-Dang-Baek*, and *Kun-Cho-Wang*; Asian pod type, 11–13 g pod weight, 12–14 cm pod length, pungency levels of 500 to 1,000 Scoville heat units) packed in plastic film (nylon laminated polyethylene, 65 µm thick) was purchased from the Yeongyang Red Pepper Distribution Co. in Kyongbuk province, Republic of Korea. Plastic packaging films such as nylon laminated polyethylene (Ny/PE, a mean thickness of 70 µm, an O_2 transfer rate of 54.8 ± 2.7 mL/m^2·day·atm at 25 °C, 0% RH, and a water vapor transmission rate of 4.5 ± 0.8 g/m^2·day at 25 °C, 90% RH, Taeyang Chem. Co., Seoul, Korea) and polyethylene terephthalate laminated aluminum with polyethylene (PET/Al/PE, the mean thickness of 100 µm, the O_2 transfer rate of less than 0.5 mL/m^2·day·atm at 25 °C, 0% RH and water vapor transmission rate of less than 0.3 g/m^2·day at 25 °C, 90% RH, Whasung Chem. Co., Seoul, Korea) are used. Gas absorbers used for packaging were an oxygen scavenger (self-reactive type HLS60, 300 mL of air capacity, Lipmen Co., Incheon, Korea) and a moisture absorber (silica gel in non-woven bag, Lipmen Co., Incheon, Korea). The weight of each sachet of the moisture absorber was 3.0 g, and the dried silica gels' maximum water vapor absorption capacity was 0.35% of their weight at a relative humidity of 90%.

Preparation of red pepper powder

Red pepper powder was made by separating the seeds from the pods by hand and then grinding the pods and seeds separately into a powder using a roll mill (Kyongchang Machinery Co., Gwangju, Korea). Powdered pods were passed through a commercial sieve (ASTM mesh #30, mesh size: 0.6 mm) using a Ro-Tap sieve shaker (Cheong-gesa, CG-213, Seoul, Korea). Finely ground seeds (average particle size: 0.3–0.4 mm) were added to the pod powder for mixing in a fixed ratio of 90% pods and 10% seeds. An additional drying process was performed at 60 °C using a drying oven (Il-Shin Co., Seoul, Korea) to adjust the initial moisture content to 13–14% (dry basis).

Packaging and storage

About 45 g of red pepper powder was packaged in a plastic film pouch (11×16.5 cm^2) of 4 packaging treatments of Ny/PE film and PET/Al/PE film packaging (Ny/PE and PET/Al/PE), moisture-proof Ny/PE film packaging with moisture absorbent (Ny/PE + MA), and modified atmosphere Ny/PE film packaging with oxygen absorbent (Ny/PE + OA). Film pouches were hermetically sealed using an electric impulse sealer (Tower Industry Co., TH-300, Seoul, Korea). All samples were stored at 25 ± 2 °C and 26–28% RH for 5 months with temperature abuse at 40 ± 3 °C and 2–3% RH for 2 weeks after 112 days of storage and periodically analyzed quality attributes of pepper powder.

Moisture content and water activity

The moisture content (MC) of red pepper powder samples was determined by measuring the weight loss of samples dried at 60 °C in a vacuum oven for 24 h (AOAC, 1995). Water activity (A_w) of the pepper powder sample was measured in triplicate at 20 ± 2 °C using an A_w meter (Novasina AG, MS1 set, Lachen, Switzerland) by equilibrating the samples against saturated salt solutions.

Color

The color of each red pepper powder sample was measured using a Chroma Meter (Konica-Minolta, CR-400, Osaka, Japan). A rectangular CIE-Lab system (L^*, a^*, and b^*) was used for color measurement, and the total color difference (ΔE^*) was calculated as follows:

$$\Delta E^* = \sqrt{\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}}$$

Six readings at least were made separately at transparent sample cases (PP Petri dishes of Φ50 mm) containing red pepper powder.

ASTA value

ASTA color value was determined by the ASTA 20.1 method (ASTA, 2004). Red pepper powder of 100 mg was quantitatively extracted with 50 mL acetone, and the mixed solution was stored at 0 °C for 16 h. An aliquot of the transparent extract was taken, and the absorbance of the solution at 460 nm was measured using a spectrophotometer (Jasco, V-550, Tokyo, Japan). ASTA color value was calculated as follows:

ASTA color value = (Abs_{460} of acetone extracts × 16.4 × I_f)/sample weight (g)

where I_f is a correction factor for the instrument (I_f = NIST A for glass filter at 460 nm/Lab A of glass filter at 460 nm), calculated from a standard solution of potassium dichromate, ammonium, and cobalt sulfate (Kim et al., 2006).

Ascorbic acid

Two g of pepper powder was mixed with 25 mL of metaphosphoric acid solution (10%, w/v) for 30 min and added with 75 mL of metaphosphoric acid solution (5%, w/v). After 2 h at room temperature, ascorbic acid was extracted by filtering with filter paper (No. 2, Whatman, Maidstone, UK). The filtrate was filtered again using a PVDF syringe filter (0.22 µm, Millipore Co., Billerica, MA, USA). For analysis of ascorbic acid, the extract was directly injected into an HPLC (Jasco, PU980 & UV975, Tokyo, Japan) system equipped with an XTerra™ RP_{18} column (5 µm, 4.6 × 150 mm, Waters Co., Milford, MA, USA) where column temperature was controlled at 40 °C. The injection volume was 20 µL, and the mobile phase was 0.05 N KH_2PO_4/MeOH (65:35, v/v) at a 0.8 mL/min flow rate. Eluents were monitored at 254 nm.

Capsaicinoids

Analysis of capsaicinoids was carried out according to the previously reported method (Lee et al., 2003). Red pepper powder of 4 g was vortex-mixed with 20 mL acetonitrile for 2 min. The extract of 1.0 mL was diluted with 9.0 mL of distilled water and passed into the C18 Sep-Pak (Waters Co.) conditioned with 5 mL of acetonitrile and 5 mL of MeOH. Absorbed capsaicinoids were eluted with 4 mL of acetonitrile and 1.0 mL of acetonitrile containing 1% acetic acid. Capsaicinoids were analyzed by an HPLC (Jasco) equipped with a Model PU 2089 pump and a Model UV 2075 Plus detector. The wavelength was set at 280 nm, and an XTerra™ MS C_{18} column (5 µm, 4.6 × 150 mm, Waters Co.) connected with a guard column (Waters Guard–Pak™, Millipore Co., USA) was used. The column temperature was kept at 35 °C, and the mobile phase was MeOH/water (70:30, v/v) at a flow rate of 1.0 mL/min. The total capsaicinoid content was determined as the sum of capsaicin and dihydrocapsaicin.

Free sugars

Two g of pepper powder was vortex-mixed with 40 mL of ethanol (80%, v/v) for 2 min. The supernatant was filtered using a PVDF syringe filter (0.45 µm, Millipore Co., USA). Free sugars of the extract were determined by an HPLC (Jasco, PU 2089, Tokyo, Japan) equipped with an RI detector (Jasco, RI 2031 Plus). A carbohydrate analysis column (10 µm, 3.9 × 300 mm, Waters Co.) was used and kept at 35 °C. The mobile phase was acetonitrile/water (87:13, v/v) at a 1.2 mL/min flow rate with an injection volume of 20 µL. The content of free sugars was assumed as a sum of glucose and fructose in samples.

Microorganisms

For microbiological examinations, 10 g of red pepper powder from the sample packages were aseptically removed and mixed with 100 mL of sterile physiological solution (0.85% NaCl) in an aseptic sampling bag (NASCO, Whirl Pak® B01195, Fort Atkinson, WI, USA). After gently shaking, aliquots of solution samples (1 mL) were serially diluted in 9 mL of 0.1% sterile peptone water (Difco Lab., Detroit, MI, USA) with portions plated in Petri dishes. Mesophilic aerobes were counted on plate count agar (Difco Lab.) media after incubation at 37 °C for 2 days. Microbial counts were represented as colony-forming units (CFU) per gram of the powder samples.

Statistical analysis

Storage experiments were carried out independently in duplicates. All the results were presented as the mean and standard deviation (SD) of multiple measurements ($n \geq 6$). Statistical differences in experimental data among packaging treatments were analyzed using the GLM procedure (SAS Institute Inc., ver. 9.3, Cary, NC, USA) at $p < 0.05$ with mean separation by LSD test.

Results and discussion

Effect on moisture content and water activity

The moisture content of red pepper powder changed significantly depending on packaging treatments during

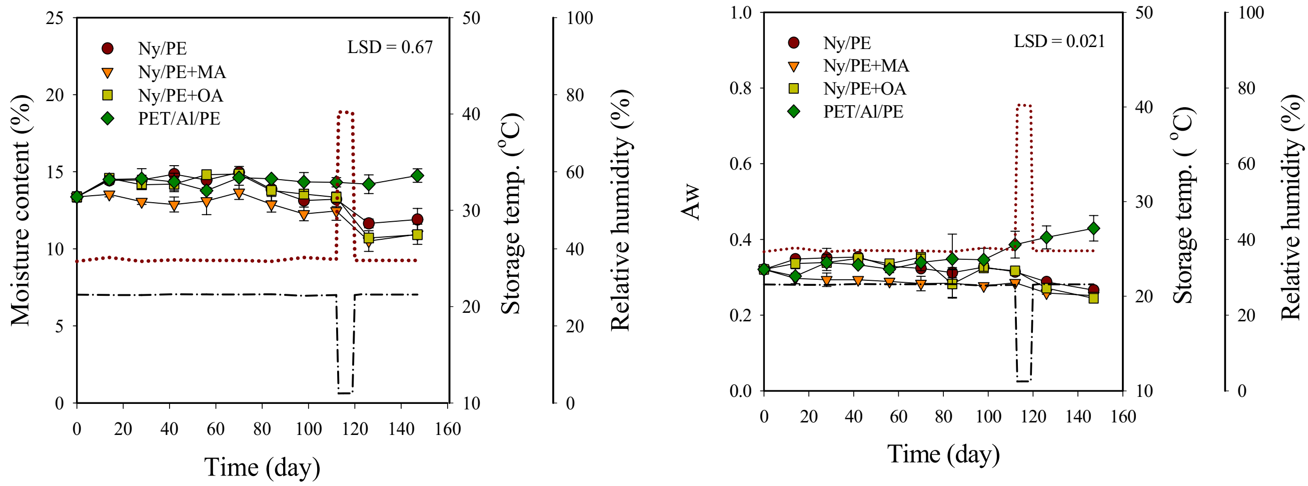

Fig. 1 Changes in the moisture content and water activity of red pepper powder with various packaging treatments during storage at 25 °C for 147 days with temperature abuse at 40 °C for 14 days (dotted line: storage temperature, dash-dotted line: relative humidity)

storage, showing different patterns after temperature abuse (Fig. 1). The initial MC values of all pepper powder samples, except the Ny/PE + MA treatment, increased slightly from 13.4 ± 0.3% to an average of 14.5 ± 0.2% after storage of 2 weeks. The increased MC was presumably caused by the moisture absorption of red pepper powder from the environment during the preparation process of the packaged samples. Red pepper powder in the Ny/PE + MA treatment showed the lowest MC content throughout the storage time due to the action of the inserted moisture absorber. After temperature abuse at 40 °C for 2 weeks, the MC in all the Ny/PE packages, regardless of absorbers, decreased by approximately 2–3% compared to the initial value. However, red pepper powder in the PET/Al/PE treatment maintained the early stage MC level of 14.4 ± 0.3% until the storage end. Since all pepper powder samples were exposed to very dry air conditions of 2–3% RH for 2 weeks in the course of temperature abuse, those in the Ny/PE packages could lose more moisture through film permeation than those in the PET/Al/PE package based on a significant difference in water vapor transmission rates of the packaging films used (Ny/PE: 4.5 ± 0.8 g/m^2·day and PET/Al/PE: < 0.3 g/m^2·day at 25 °C, 90% RH). On the contrary, red pepper powder may gain moisture in the Ny/PE packages if exposed to humid environments or high moisture conditions.

The water activity of red pepper powder was also significantly affected by packaging treatments (Fig. 1). At the beginning, the A_w value of 0.32 ± 0.01 maintained consistently in all the Ny/PE packages up to 112 days and then slightly decreased to 0.25–0.27, with being the lowest in the Ny/PE + MA treatment. Meanwhile, A_w in the PET/Al/PE package gradually increased after 112 days of storage to around 0.43 ± 0.03 at the storage end. The A_w values in this study were very similar to those reported in the literature (Ordóñez-Santos et al., 2014; Topuz et al., 2009). Water activity may change with time through the permeation process of water vapor across the packaging film (Ordóñez-Santos et al., 2014). The slight decreases in A_w indicate that the Ny/PE film pouches have allowed the exit of a small amount of water vapor in temperature abuse. Considering the data on the water vapor permeability of the packaging films used, it is logical that a slight migration of water from inside to outside the package has occurred. In the PET/Al/PE treatment, however, water has been partly desorbed from the pepper powder samples during temperature abuse, but it can hardly migrate outside the package, resulting in a notable increase of A_w. The monolayer MC, which measures the minimum MC covering hydrophilic sites on the red pepper powder, was reported to decrease from 0.122 to 0.091 g water/g solid with increasing temperature from 25 to 50 °C (Rhim and Hong, 2011). Generally, moisture content defines the amount of water in food samples, while water activity measures the excess water available to microorganisms. The overall effects of packaging treatment and temperature abuse on red pepper powder's moisture content and water activity during the entire storage period were similarly consistent.

Effect on color and ASTA

The apparent color of red pepper powder has featured a mix of redness and yellowness due to carotenoids (Rhim and Hong, 2011). These color components can usually be represented by CIE *L** (lightness), *a** (redness), and *b** (yellowness) color coordinates. The result of red pepper powder's *L**, *a**, and *b** values with different packaging treatments determined during storage are plotted in Fig. 2. Packaging treatments did not significantly influence the color of red pepper powder. All pepper powder samples' *L** and *b**

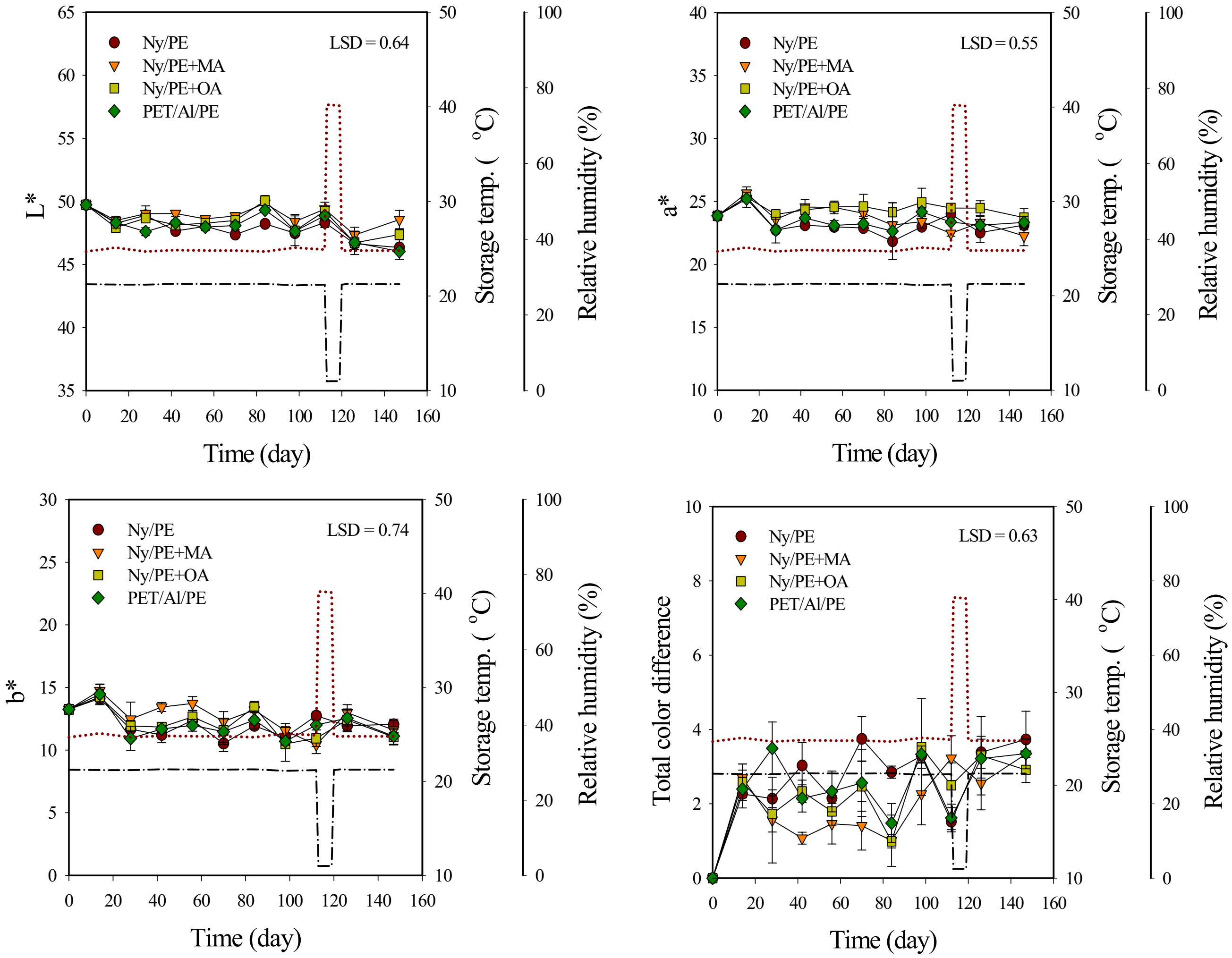

Fig. 2 Changes in the color values of red pepper powder with various packaging treatments during storage at 25 °C for 147 days with temperature abuse at 40 °C for 14 days (dotted line: storage temperature, dash-dotted line: relative humidity)

values fluctuated but slightly decreased during storage. The *L** and *b** values gradually decreased in the limited ranges from 49.7 ± 0.2 and 13.3 ± 0.4 to around 46.0–48.6 and 11.0–12.1, respectively.

Meanwhile, the *a** values with a random fluctuation were retained consistently within the range of 21.8–25.3 throughout the storage period. Although there was no significant difference among packaging treatments, it was notable that the Ny/PE+OA treatment kept *a** value relatively higher than the other treatments. Nonetheless, the total color difference (ΔE^*) in all analyzed pepper powder samples showed values less than 4.0 over the entire storage time. It is generally known that color difference values less than 5.0 cannot be easily detected by human eyes (Francis, 2005). Despite temperature abuse applied during storage in this study, as a consequence, no significant color changes of red pepper powder could be observed among packaging treatments. Storing red pepper powder at a low temperature below 25 °C and medium ranges of A_w is reportedly desirable to keep the color quality. However, the pepper powder remained red to an A_w of 0.43 at 40 °C (Rhim and Hong, 2011).

The ASTA value, which is generally evaluated as an oil-extracted color and a representative color quality index of red pepper or paprika, is directly related to the pigment content. The ASTA values of red pepper powder with various packaging treatments obtained during storage are depicted in Fig. 3. The measured ASTA color value of the initial pepper powder sample was 108.7 ± 2.7, which is in good agreement with those of dried red pepper (ASTA values of 107–118) (Kim et al., 2006; Rhim and Hong, 2011). The ASTA values were very stable to level off at the initial state, but they had a decreasing tendency after 84 days of storage in all pepper powder samples. At the end of storage, the reduction in the ASTA values for the pepper powder samples varied from 2.2 to 16.5%, depending on packaging treatments. However, a

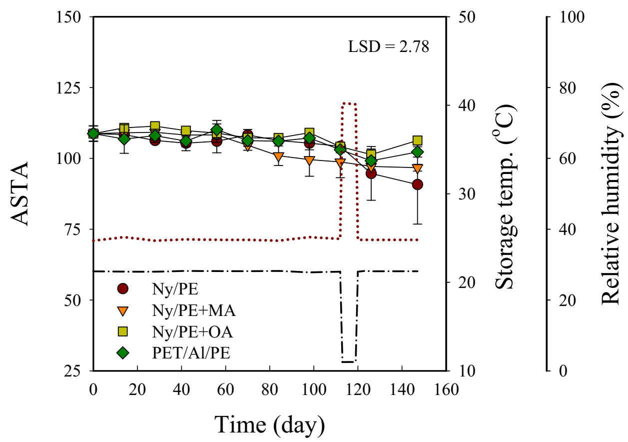

Fig. 3 Changes in the ASTA value of red pepper powder with various packaging treatments during storage at 25 °C for 147 days with temperature abuse at 40 °C for 14 days (dotted line: storage temperature, dash-dotted line: relative humidity)

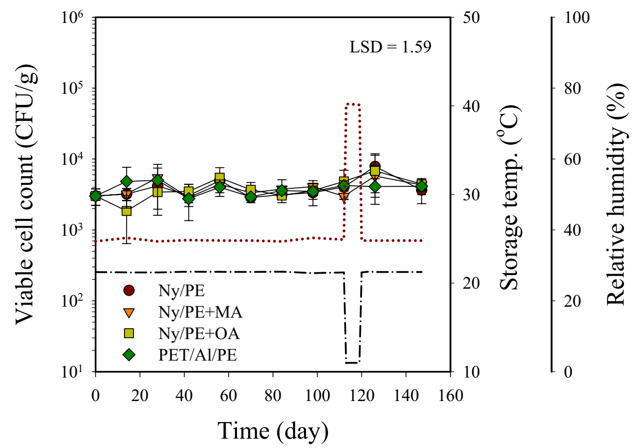

Fig. 4 Changes in the mesophilic aerobes of red pepper powder with various packaging treatments during storage at 25 °C for 147 days with temperature abuse at 40 °C for 14 days (dotted line: storage temperature, dash-dotted line: relative humidity)

significant difference in the ASTA values still could not be found among packaging treatments.

Interestingly, slightly higher ASTA values, similar to the result of *a** values above, were exhibited during storage in the Ny/PE+OA treatment compared with the other treatments, presumably due to the action of the oxygen scavenger inserted to prevent oxidation of carotenoids. The ASTA color value of red pepper is mainly attributed to the carotenoids such as capsanthin, capsorubin, and β-carotene (Kim et al., 2004). Generally, the degradation of color pigments in paprika is higher for the yellow carotenoids (zeaxanthin, ß-cryptoxanthin, and ß-carotene) than for the red carotenoids (mainly capsanthin and capsorubin). The linear relationship between carotenoid content and color values (ASTA, *L**, *a**, *b**, and C*) of paprika has also been demonstrated by Ordóñez-Santos et al. (2014).

Effect on microbiological and chemical quality parameters

Microbiological quality change of red pepper powder, assessed by viable cell counts of mesophilic aerobes with various packaging treatments during storage, was monitored in the food safety aspect (Fig. 4). The microbial population of the initial pepper powder sample in this study was 3.47 ± 0.09 log CFU/g, which is a little higher than that (2.33 log CFU/g) recorded by Yun et al. (2012) but much lower than that (ca. 6.05 log CFU/g) reported by Choi et al. (2018). The viable cell counts of mesophilic aerobes in all tested pepper powder samples tended to increase with no significant difference among packaging treatments slightly but kept stable at the level of approximately ~ 10^3 CFU/g throughout the storage period. Such microbial stability could be attributed to the pepper powder samples' very low water activity (0.25–0.43). It is well known that virtually no microorganism can grow at an A_w value smaller than 0.6. The general effect of lowering A_w below optimum is to increase the length of the lag phase of growth and decrease the growth rate and size of the final population. This effect may be expected to result from adverse influences of lowered water on all metabolic activities because all chemical reactions of cells require an aqueous environment (Jay, 1995).

Chemical quality parameters were also evaluated during storage, including capsaicinoids, ascorbic acid, and free sugar contents of red pepper powder with various packaging treatments. Overall, no significant changes in chemical parameters were observed before and after storage, although there were statistically significant but very small differences between packaging treatments (Table 1). The initial capsaicinoids, ascorbic acid, and free sugar contents in the pepper powder sample were 64.04 ± 4.04 mg/100 g, 908.79 ± 47.15 mg/100 g, and 13.83 ± 0.34 g/100 g, respectively. After the entire storage period of 147 days, the concentrations of capsaicinoids were kept very stable at the initial level, in the range of 62.30–65.90 mg/100 g, showing no significant difference between packaging treatments. The concentration of capsaicinoids, including capsaicin and dihydrocapsaicin, contributes mainly to the pungency level in hot peppers as an important factor in determining their commercial quality (Choi et al., 2023). In particular, capsaicin is the primary molecule responsible for hot peppers' heat and burning sensations (Iqbal et al., 2015; Kim et al., 2022). Typically, capsaicinoids in polyethylene-packed dried hot peppers or dehydrated paprika gradually decreased during storage (Lee et al., 2003; Topuz and Ozdemir, 2004), and the disappearance rate increased with storage temperature (Iqbal et al., 2015). In this study, however, no reduction of

Table 1 The capsaicinoids, ascorbic acid, and free sugar contents of red pepper powder with various packaging treatments during storage at 25 °C for 147 days with temperature abuse at 40 °C for 14 days

Storage time (days)	Packaging treatment	Parameter		
		Capsaicinoids (mg/100 g dry wt)	Ascorbic acid (mg/100 g dry wt)	Free sugar (g/100 g dry wt)
0		64.04 ± 4.04^{a}	908.79 ± 47.15^{a}	13.83 ± 0.34^{a}
147	Ny/PE	63.27 ± 1.40^{Aa}	882.37 ± 52.32^{ABa}	13.29 ± 0.23^{Bb}
	Ny/PE + MA	62.30 ± 3.18^{Aa}	860.69 ± 28.55^{Ba}	13.69 ± 0.22^{Aa}
	Ny/PE + OA	63.67 ± 0.46^{Aa}	910.08 ± 46.53^{Aa}	13.31 ± 0.29^{Bb}
	PET/Al/PE	65.90 ± 0.98^{Aa}	896.81 ± 33.46^{Aa}	13.53 ± 0.33^{ABa}

The values shown are the mean and standard deviation of six measurements. The mean followed by the same capital letter is not significantly different ($p > 0.05$, LSD test) among packaging treatments. The mean followed by the same lowercase letter is not significantly different ($p > 0.05$, LSD test) between the initial and final values (before and after storage of 147 days)

capsaicinoids observed in the pepper powder samples after storage could be partly attributed to their low water activity of 0.25–0.43 and the high barrier film packaging to oxygen and water vapor. Furthermore, the stability of capsaicinoids could be reportedly influenced by differences in biochemical factors (i.e., peroxidase activity) among hot pepper cultivars and the advancement of maturity and drying (Iqbal et al., 2015).

The ascorbic acid contents of the pepper powder samples after storage of 147 days were in the range of 860.69–910.08 mg/100 g and tended to slightly decrease in all the packages except the Ny/PE+OA treatment, probably due to the action of the oxygen scavenger inserted for inhibiting the oxidation of inherent ascorbic acid. Kim et al. (2006) also reported that the ascorbic acid contents in dry red pepper varied from 305 ± 39 to 1241 ± 215 mg/100 g, greatly relying on drying methods, and those in conventionally dried samples were not changed for 6 months regardless of storage temperature. They suggested that the maintenance of ascorbic acid contents in red pepper might be related to the formation of browning products by non-enzymatic reaction and caramelization during drying. Ascorbic acid is well known as an antioxidant and biologically-active compound and an important nutritional and functional constituent of hot pepper fruit (Iqbal et al., 2015). In general, the ascorbic acid contents of red peppers reduce dramatically during the drying process. The final contents of ascorbic acid can differ depending on their harvesting time (Kim et al., 2006). Moreover, ascorbic acid concentrations in dried hot peppers without high gas-barrier packaging or modified atmosphere packaging decrease significantly with increasing storage time and temperature (Iqbal et al., 2015).

After storage, the final free sugar contents of the pepper powder samples were 13.29–13.69 g/100 g and showed a slightly decreasing tendency in all the packaging treatments. There were statistically significant differences among packaging treatments, but those were too small to differentiate the packaging effect. Sugars and capsaicinoids primarily represent red pepper spices' characteristic sweet and hot taste. In general, heat treatments at high temperatures during the long drying process of red pepper can cause non-enzymatic browning reactions and caramelization, reducing the amount of sugars (Kim et al., 2006). The free sugar contents reportedly ranged from 4.34 to 19.95 g/100 g depending on the varieties of Korean red pepper, and the fructose content was higher than the glucose content (Huang et al., 2014). Korkmaz et al. (2020) also revealed that glucose contents decreased gradually due to the non-enzymatic browning reactions in Turkish red pepper spices packaged in polyethylene bags during one year of storage in the room condition.

Consequently, the quality attributes of red pepper powder in all packaging treatments, including color, microbial cell count, capsaicinoids, ascorbic acid, and free sugar contents in this study, remained similar to their initial levels without remarkable changes during storage. Such behavior of these quality parameters in the red pepper samples may be related to the consistent MC values ranging from 10.7 to 14.8%, which have been maintained close to the reported monolayer MC values of 9.1–12.2% (Rhim and Hong, 2011). Generally, the monolayer MC values are recognized as criteria for achieving safe storage with a minimum quality loss for a long time (Moreira et al., 2008).

In conclusion, overall quality changes of the pepper powder sample were not observed, although the water activity of the PET/Al/PE package slightly increased at the late storage stage. Synergic effects of the moisture and oxygen absorbers used were not also significantly evident in the storage stability of red pepper powder with 13–14% initial moisture contents, probably due to its very low water activity (< 0.45) and surrounding RH (< 30%) kept during storage. Therefore, experimental results suggested that packaging with a proper gas-barrier film such as the Ny/PE and PET/Al/PE could work efficiently to preserve a high quality of red pepper powder treated with optimized control of initial moisture contents during long term storage, regardless of the additional gas absorbers used and the temperature abuse condition.

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Declarations

Conflict of interest The authors declare no conflict of interest.

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