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Use of microperforated films and oxygen scavengers to maintain storage stability of fresh strawberries

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ABSTRACT

The effectiveness of 2 biaxially oriented polypropylene (BOPP) and 4 biaxially oriented polypropylene microperforated films (MP) of different transmission rates (7 and 9 holes) with and without oxygen scavengers, on storage stability of fresh strawberries were studied. Gas concentration in trays, pH, total soluble solids, surface color (L^* and a^*), electrical conductivity, sensory acceptance, texture profile and FT-NIR analyses were measured during storage at 4 °C. The microperforations and oxygen scavenger significantly affected the maintenance of an optimum gas composition within the package for increasing strawberry storage life and quality. The BOPP group had the greatest total soluble solids reduction from 9.72% to 7.25% and also highest pH changes (3.55–3.81) while MP groups showed the lowest pH change (3.55–3.72) at the end of storage. The MP fruit were firmer than the BOPP fruit, and L^* and a^* values were also better maintained. At the end of storage, the highest firmness values were obtained in the MP package with 616.35 gf for the 9-hole and 607.28 gf for the 7-hole films, whereas BOPP and BOPP + scavenger values were 421 gf and 448 gf, respectively. FT-NIR can be used for monitoring quality of strawberry nondestructively.

1. Introduction

Fresh strawberry fruit (*Fragaria* × *ananassa* Duch.) are very susceptible to mechanical injury, water loss, decay and physiological deterioration after harvest. Strawberries therefore require particular postharvest attention in order to prolong shelf-life (Cao et al., 2010; Aday and Caner, 2011; Aday et al., 2011). Strategies to extend the shelf-life of fresh fruit include modified atmosphere packaging (MAP), using low O_2 (1–5 kPa) and high CO_2 (5–10 kPa) concentrations, active packaging technologies including oxygen, carbon dioxide and ethylene scavengers, edible coatings and chemical sanitizers.

The key to successful MAP of fresh products is to use a packaging film of correct intermediary permeability where a desirable equilibrium modified atmosphere is established when the rate of O_2 and CO_2 transmission through the pack balances the product's respiration rate (Caner et al., 2008). The use of polymeric films having differential permeability rates for O_2 and CO_2 reduces moisture loss and restricts ventilation, resulting in the build up of CO_2 and a reduction of available O_2, creating a modified atmospheric condition. Control of atmosphere within equilibrium MAP is not precise, because product respiration rates, film permeability and external factors such as temperature affect the MAP conditions (Caner et al., 2008; Ramin and Khoshbakhat, 2008). Oxygen scavengers in the form of small sachets containing various iron-based powders, the most commercially important sub-category of active packaging, can be used alone or in combination with MAP. Oxygen scavengers are capable of reducing oxygen levels in the headspace of packages, and can be effective with respiring fruit and vegetables (Charles et al., 2003; Caner et al., 2008).

Microperforated films allow or foster the rapid development of adequate CO_2 and O_2 levels to extend produce shelf-life. The gas exchange rate of a microperforated film with a gas barrier base is controlled by the number and dimensions of the perforations. By altering the size and density of the micro hole, packaging films with specific flow rates can be adjusted for a specific product. The high respiration rate of a product such as fresh strawberries requires much greater permeability than that provided by unperforated films. The size of the perforations normally used in MAP is between 50 and 200 μm in diameter (Paul and Clarke, 2002; González-Buesa et al., 2009).

Microperforated films have been shown to successfully extend the shelf-life of strawberries. Sanz et al. (2002) showed that packages with perforation areas of 1.57, 3.14 and 4.71 mm^2 can be used to preserve strawberry quality for 10 d at 2 °C. Almenar et al. (2007) reported that microperforated films with one and three perforations maintained the chemical, physical and sensory qualities of strawberries. However, there is insufficient research published on

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monitoring the effect of microperforated films and oxygen scavengers on the quality of fresh strawberries.

The objectives of the present study were to evaluate the effect of 2 biaxially oriented polypropylene (BOPP) and 4 biaxially oriented polypropylene microperforated (MP) films of different transmission rates (7 and 9 holes) with and without oxygen scavengers, on air-packaged strawberry quality, and to follow quality parameters during storage.

2. Materials and methods

2.1. Materials and packaging conditions

Fresh 'Camarosa' strawberries (*Fragaria* × *ananassa*) were harvested from a local farm in Adapazarı, Turkey and transported to the laboratory. Fresh fruit were selected free from visual defects or damage and uniform size and color. Strawberries (180 g) were placed in trays (PVC/PE (220 × 175)) and sealed using microperforated biaxially oriented polypropylene (BOPP; obtained from KOROZO Packaging and Ltd. Sti) under atmospheric conditions. For each treatment, 16 trays were used for 5 weeks of storage. Oxygen permeability of the films was 8770 (90 μm BOPP with 7 holes) and 11,039 (90 μm BOPP with 9 holes) cm^3/m^2 d at 25 °C. Commercial oxygen scavenger sachets (ATCO-210) were supplied by Standa Industries (Caen, France). These sachets have an oxygen capacity of 210 mL O_2. All fruit were stored at 4 °C. Packaging treatments and abbreviations can be summarized as follows:

- Biaxially oriented polypropylene without oxygen scavenger (BOPP).
- Biaxially oriented polypropylene with oxygen scavenger (BOPP + Scv).
- Microperforated biaxially oriented polypropylene with 9 holes (BOPP9H).
- Microperforated biaxially oriented polypropylene with 9 holes and oxygen scavenger (BOPP9H + Scv).
- Microperforated biaxially oriented polypropylene with 7 holes (BOPP7H).
- Microperforated biaxially oriented polypropylene with 7 holes and oxygen scavenger (BOPP7H + Scv).

2.2. Gas composition inside the packages

An Oxybaby gas analyzer (HTK, Hamburg, Germany) was used for monitoring headspace composition of the packages before opening. Three replicates were used to determine the gas composition. The gas analyzer needle was inserted through an impermeable rubber seal attached on the outside of the film and the results are expressed as O_2 kPa and CO_2 kPa (Aday and Caner, 2011; Aday et al., 2011).

2.3. pH

After the fruit stems of were discarded, nine fresh strawberries in each package were cut into small pieces and homogenized with a blender and filtered through cheese cloth. The filtrate was used for measuring pH using a pH meter (Sartorius PP-50, Goettingen, Germany) (Aday and Caner, 2011).

2.4. Total soluble solids (TSS)

The filtrate was also used for measuring the TSS using an Atago Pal-1 pocket refractometer (Atago Co. Ltd, Tokyo, Japan) and expressed as % at 20 °C (Caner and Aday, 2009; Aday and Caner, 2011; Aday et al., 2011). A drop of juice was used to record the TSS and values were expressed as %.

2.5. Surface color

Fruit surface color was measured with a Minolta CR-400 portable Chromameter (Konica Minolta Sensing, Osaka, Japan). Nine strawberries were used to measure skin color, using the CIELAB color system (*L*, *a*, and *b*). Color was recorded using the CIE$L^*a^*b^*$ uniform color space (CIELab), where L^* indicates lightness, a^* indicates chromaticity on a green (−) to red (+) axis, and b^* chromaticity on a blue (−) to yellow (+) axis.

2.6. Texture profile analysis

A texture analyzer fitted with a 30 kg load cell and the 10 mm diameter cylinder plunger SMS-P/10 CYL Delrin probe was used. Texture profile analyses (TPA) were performed according to Caner et al. (2008) with a TA-XTPuls texture analyzer (Stable Micro Systems Ltd., UK) with the following parameters: pre-test speed 5.0 mm/s, test speed 1.0 mm/s and post-test speed 8.0 mm/s; penetration distance 4 mm and a rest period of 5 s between two cycles; trigger force 1.0 N. TPA measurements were made on nine strawberries in each package. Values for firmness, springiness, cohesiveness, adhesiveness, gumminess, resilience and chewiness were automatically calculated from the resulting force-time curve by the software (Caner et al., 2008; Aday and Caner, 2011; Aday et al., 2011).

2.7. Electrical conductivity

Electrical conductivity of strawberry juice was recorded with a PP 50 Sartorius (Sartorius PP-50, Goettingen, Germany) conductivity probe (ATC 4-band/c^{-1} cm^{-1}) (Aday et al., 2011).

2.8. FT-NIR spectrometry

The near infrared spectral specifications were measured using a Bruker Multi-purpose Analyser (MPA) FT-NIR spectrometer (Bruker Optic, Gmbh, Ettlingen Germany). The FT-NIR spectrometer includes InGaAs detectors, TE-InGaAs internal for reflectance and RT-IngaAs external for transmittance. The reflectance measurements were performed with 32 scans and between 780 and 2500 nm wavelengths. The transmittance measurements were scanned 64 times and covered 800–1725 nm wavelengths. The FT-NIR spectrometer includes a 20-Watt High Intensity Tungsten–Halogen NIR light to measured spectra of the strawberries. The spectral resolution was 8 cm^{-1} for transmittance and reflectance modes. OPUS software (Bruker Optik, GmbH, Ettlingen, Germany) was used for instrument control (Aday and Caner, 2010).

Reflectance measurements were acquired with a fiber optic probe (type IN 261). The probe contains a bifurcated optical configuration which sends near infrared light to the sample and the detector (TE-InGaAs) receives the reflected light from the sample. Detector and light source were placed at the head of the fiber optic probe. The probe was placed at a 90° angle to the strawberry samples to take spectra (Aday and Caner, 2010).

For transmittance, strawberries were placed horizontal to the transmittance area of the FT-NIR spectrometer. A light beam passes through the center of the strawberry and the detector (RT-InGaAs) senses the outgoing light from the strawberries. A neutral density (NG9) filter was used to take the spectra of strawberry samples in the transmittance mode (Aday and Caner, 2010).

2.9. Sensory evaluation of strawberries

A panel of ten trained judges evaluated fruit sensory profiles in the second week of storage. The attributes analyzed were global appearance, color, firmness, flavor and general acceptability. The samples were coded with three-digit numbers to verify objectivity. Ratings were based on a 9-point hedonic scale, where 9 = excellent and 1 = poor, unusable, according to Aday and Caner (2011).

2.10. Statistical analysis

The study was repeated three times and analyses were run in triplicate for each replicate. Statistical analysis was performed with SAS 9.1.3. Two-way ANOVA was used to analyze effect of different treatments on quality criteria of strawberries and one-way analysis of variance was used for analysis of the effect of microperforated films on the fruit sensory quality.

The following statistical model was used for two-way ANOVA:

$$Y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + e_{ijk}$$

where Y_{ijk}: random variable giving the response for observation t of the treatment at level i of α and level j of β, μ: general population mean, α_i: effect of storage periods (i = 1–5), β_j: effect of treatments (j = 1–7), $(\alpha\beta)_{ij}$: effect of storage by treatments interaction, e_{ijk}: independent random variables

Differences between means were determined with Tukey post hoc comparison tests. p-Values of 0.05 or less were considered significant. When interactions (time × treatment) were found not significant, overall value was used to determine differences for main effects of time or treatment. Data were expressed as mean ± standard deviation.

3. Results and discussion

3.1. O_2 and CO_2 headspace concentration

Permeability of the package to CO_2 and O_2 is the main factor used to obtain an adequate atmospheric composition. The gas concentrations of trays for all treatments during storage are compared in Fig. 1.

As a result of fruit respiration, the contents of O_2 decreased quickly during the first week of storage due to the effect of the oxygen scavengers for BOPP + Scv, BOPP9H + Scv, BOPP7H + Scv; CO_2 contents increased. Microperforated films with O_2 scavengers, had lower CO_2 accumulation in the first weeks of storage. Our results support previous findings in the literature which showed that O_2 consumption was directly related to CO_2 production (Almenar et al., 2007). After three weeks of storage, O_2 levels inside the packages ranged between 8% and 2%, while CO_2 contents were between 5% and 29% depending on the type of packaging. The levels of CO_2 increased quickly for BOPP and BOPP + Scv. In turn, the CO_2 contents in the first weeks with BOPP and BOPP + Scv trays increased to 10–18% and by the end of storage to 37–40%. In the first three weeks of storage, CO_2 accumulation was not as great for the microperforated packages compared with BOPP and BOPP + Scv. This result has a number of similarities with results of Sanz et al. (2002) who found that CO_2 accumulation and O_2 depletion were dependent on perforation surface. The high CO_2 concentrations will be due to high respiration rates of fresh strawberries. In addition, high concentrations of CO_2 can be responsible for growth of anaerobic microorganisms (Almenar et al., 2007). BOPP7H exhibited lower CO_2 accumulation than BOPP9H and this confirms previous findings in the literature that with an increase in number of holes, O_2 concentration increases and CO_2 decreases in the headspace (Pandey and Goswami, 2012). Accumulation of CO_2 was higher in the BOPP packages. It is possible that high barrier films enable faster CO_2 accumulation and O_2 consumption in the package (Lucera et al., 2011). Minor fluctuations in O_2 consumption and CO_2 accumulation were observed in the headspace for all groups. It is possible that progressive deposition of water vapor on the inner surface of films affected the gas permeability of the films (Rai et al., 2009).

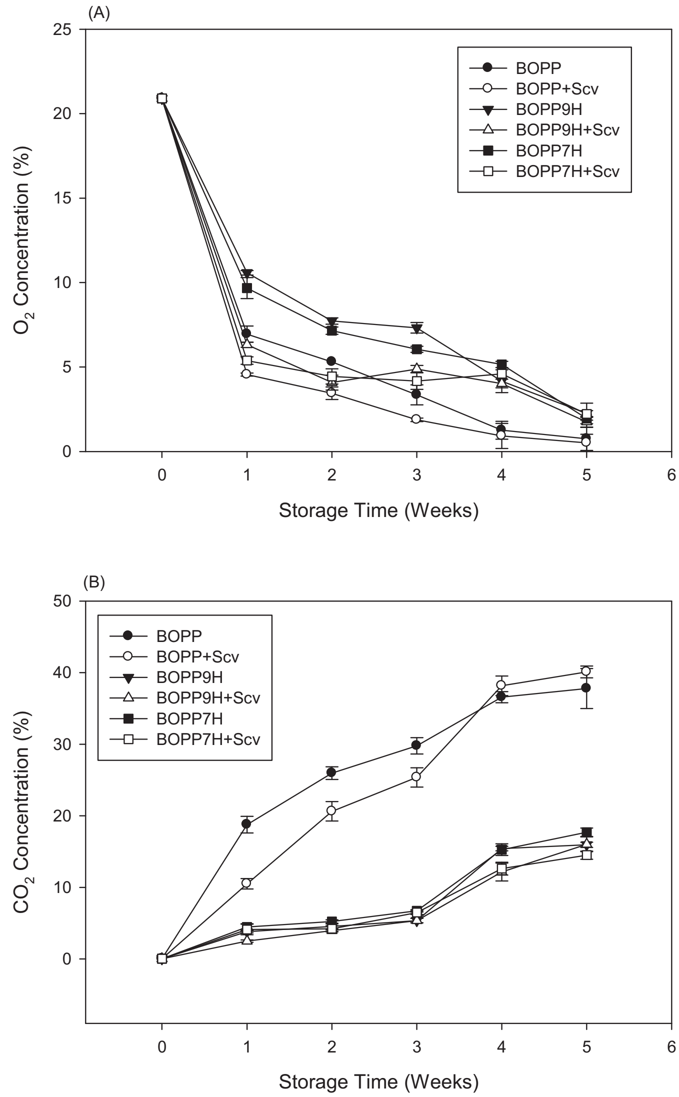

Fig. 1. Effect of different packaging conditions (biaxially oriented polypropylene without oxygen scavenger (BOPP), biaxially oriented polypropylene with oxygen scavenger (BOPP + Scv), microperforated biaxially oriented polypropylene with 9 hole (BOPP9H), microperforated biaxially oriented polypropylene with 9 hole and oxygen scavenger (BOPP9H + Scv), microperforated biaxially oriented polypropylene with 7 hole (BOPP7H), microperforated biaxially oriented polypropylene with 7 hole and oxygen scavenger (BOPP7H + Scv)) on headspace gas composition ((A)O_2 and (B)CO_2) of strawberries during storage. Vertical bars denote standard deviation of three replicates.

After four weeks of storage, microperforated packages seemed to be best for the desired gas contents with level of 15–20% for CO_2 and 5–10% for O_2 (Sanz et al., 1999). After the first three weeks, BOPP9H and BOPP7H treatments resulted in higher concentrations of oxygen than those of BOPP and BOPP + Scv. Low O_2 concentrations in the BOPP and BOPP + Scv packages may cause breakdown of tissue, off-flavor development and growth of anaerobic microorganisms (Almenar et al., 2007). Microperforated treatments had similar O_2 and CO_2 levels and have a beneficial effect in slowing

Table 1
Effect of different packaging conditions (biaxially oriented polypropylene without oxygen scavenger (BOPP), biaxially oriented polypropylene with oxygen scavenger (BOPP + Scv), microperforated biaxially oriented polypropylene with 9 hole (BOPP9H), microperforated biaxially oriented polypropylene with 9 hole and oxygen scavenger (BOPP9H + Scv), microperforated biaxially oriented polypropylene with 7 hole (BOPP7H), microperforated biaxially oriented polypropylene with 7 hole and oxygen scavenger (BOPP7H + Scv)) on pH values of strawberries during storage.

Treatments	0 W	1 W	2 W	3 W	4 W	5 W
BOPP	3.55 ± 0.05 D,a	3.59 ± 0.03 D,a	3.67 ± 0.02 C,a	3.72 ± 0.07 B,C,a	3.77 ± 0.03 A,B,a	3.81 ± 0.03 A,a
BOPP + Scv	3.55 ± 0.05 D,a	3.54 ± 0.02 D,a,b	3.62 ± 0.02 C,a,b	3.69 ± 0.04 B,C,b	3.72 ± 0.05 A,B,a,b	3.75 ± 0.07 A,b
BOPP9H	3.55 ± 0.05 B,a	3.55 ± 0.03 B,a,b	3.63 ± 0.01 A,a,b	3.66 ± 0.02 A,b,c	3.68 ± 0.05 A,b,c	3.65 ± 0.07 A,b,c
BOPP9H + Scv	3.55 ± 0.05 C,D,a	3.53 ± 0.02 C,b	3.55 ± 0.01 C,D,c	3.60 ± 0.03 B,D,c	3.64 ± 0.04 A,B,c	3.69 ± 0.05 A,c
BOPP7H	3.55 ± 0.05 B,a	3.51 ± 0.03 B,b	3.64 ± 0.01 A,a	3.65 ± 0.03 A,b,c	3.70 ± 0.01 A,b,c	3.67 ± 0.06 A,c
BOPP7H + Scv	3.55 ± 0.05 D,E,a	3.50 ± 0.02 E,b	3.58 ± 0.02 C,D,b,c	3.62 ± 0.04 B,C,c	3.68 ± 0.06 A,B,b,c	3.72 ± 0.03 A,b,c

Data are means ± SD of three replicates.
a–c means in the same column with different letters are significantly different ($p \le 0.05$).
A–E means in the same row with different letters are significantly different ($p \le 0.05$) (mean seperation was performed by Tukey test).

Table 2
Effect of different packaging conditions (biaxially oriented polypropylene without oxygen scavenger (BOPP), biaxially oriented polypropylene with oxygen scavenger (BOPP + Scv), microperforated biaxially oriented polypropylene with 9 hole (BOPP9H), microperforated biaxially oriented polypropylene with 9 hole and oxygen scavenger (BOPP9H + Scv), microperforated biaxially oriented polypropylene with 7 hole (BOPP7H), microperforated biaxially oriented polypropylene with 7 hole and oxygen scavenger (BOPP7H + Scv)) on total soluble solid (%) values of strawberries during storage.

Treatments	0 W	1 W	2 W	3 W	4 W	5 W
BOPP	9.72 ± 0.23 A,a	8.88 ± 0.24 B,a	8.34 ± 0.33 C,b	8.04 ± 0.30 C,b	7.33 ± 0.53 D,c	7.25 ± 0.38 D,b
BOPP + Scv	9.72 ± 0.23 A,a	8.98 ± 0.27 B,a	8.46 ± 0.31 C,b	8.26 ± 0.36 C,D,a,b	8.00 ± 0.42 D,b	7.48 ± 0.14 E,b
BOPP9H	9.72 ± 0.23 A,a	8.97 ± 0.19 B,a	8.63 ± 0.16 B,C,a,b	8.53 ± 0.21 C,a	8.27 ± 0.14 C,a,b	8.18 ± 0.14 C,a
BOPP9H + Scv	9.72 ± 0.23 A,a	9.12 ± 0.24 B,a	8.97 ± 0.25 B,a	8.54 ± 0.23 C,a	8.54 ± 0.18 C,a	8.03 ± 0.18 D,a
BOPP7H	9.72 ± 0.23 A,a	8.89 ± 0.24 B,a	8.70 ± 0.28 B,C,a,b	8.49 ± 0.35 C,a	8.37 ± 0.20 C,a,b	7.60 ± 0.14 D,a,b
BOPP7H + Scv	9.72 ± 0.23 A,a	9.26 ± 0.18 A,a	8.83 ± 0.22 B,a	8.49 ± 0.12 B,C,a	8.18 ± 0.16 C,D,a,b	7.74 ± 0.11 D,a,b

Data are means ± SD of three replicates.
a–c means in the same column with different letters are significantly different ($p \le 0.05$).
A–E means in the same row with different letters are significantly different ($p \le 0.05$) (mean seperation was performed by Tukey test).

down the accumulation of CO_2 and maintaining an equilibrium state inside the package. The most suitable material for equilibrium modified atmosphere in the package could be microperforated packages with and without absorbers, providing a gas composition of 4–5% O_2, 10–15 CO_2%. These levels generally are suitable to prevent off-flavor development and reduce *B. cinerea* populations due to the fungistatic effect of CO_2 (García-Gimeno et al., 2002; Almenar et al., 2007).

3.2. pH

Table 1 shows pH values of each strawberry batch during storage and the initial pH value was 3.55. pH values of all the groups increased significantly with storage time. This trend was similar to the results of Han et al. (2004) who found that pH increases with fruit senescence. In our work, pH values were affected by microperforated films and scavengers in comparison with BOPP during three weeks of storage. The lower pH was observed with the microperforated treatments that keep O_2/CO_2 in balance due to slowing respiratory rates when compared with BOPP and BOPP + Scv, since a slower increase in pH was observed. These results correlate fairly well with Sanz et al. (1999) who found that microperforated packages preserved citric acid contents of strawberries better than nonperforated packages. Higher CO_2 concentrations inside the nonperforated packages can lead to higher rates of solubilization of CO_2 which results in high formation of HCO_3^- (Holcroft and Kader, 1999; Harker et al., 2000). As a result of this process, pH values can be increased more by nonperforated films. pH of the BOPP treatment was 3.67 in the second week of storage, while fruit in the BOPP7H treatment reached this value in five weeks. It is possible that microperforated films release more CO_2 than the nonperforated films. In our work, pH increase trended with the increase of CO_2 inside the packages. Our results are consistent with those obtained by Almenar et al. (2007) who showed that high CO_2 contents in packages resulted in higher pH values.

3.3. Total soluble solids

TSS of strawberries decreased in all treatments (Table 2). This reduction might be due to respiration, including breakdown of starch to sugar (Cliff et al., 2010). For the first week of storage, TSS contents were not significantly different between different package conditions. This finding is consistent with research of Soliva-Fortuny and Martiñ-Belloso (2003) which showed that TSS was independent of atmospheric conditions. After two weeks of storage, statistical differences were found between packages. All treatments significantly reduced the loss of TSS at the end of the fourth week compared with BOPP. Yet, BOPP and BOPP + Scv treatments had the lowest values among microperforated treatments during storage. This finding seems to be in accordance with García et al. (1998) who showed that perforated films have higher TSS contents than nonperforated polypropylene with 'Oso Grande' strawberries. At the end of storage (5 weeks), fruit in the BOPP9H and BOPP9H + Scv treatments had soluble solids contents that were equal with those of the BOPP treatment, which was 8.04% in the 3rd week. It is possible that low TSS values of nonperforated films are due to the effect of less oxygen and more carbon dioxide in the packages, reflecting a high respiration rate (Del-Valle et al., 2009). Another possible explanation is that high CO_2 concentrations inside nonperforated packages triggered hydrolysis and glycolysis reactions, resulting in consumption of sugars (Bodelón et al., 2010). However, microperforated films and O_2 scavengers decreased the levels of CO_2 inside packages, and delayed carbohydrate metabolism (Aday et al., 2011). The TSS results showed that microperforated groups were clearly effective in maintaining soluble solid contents, and BOPP9H was the most effective treatment. Microperforated films will have reduced respiration rates of strawberries, thus reducing the loss of TSS.

3.4. Color

Color is the most obvious quality parameter for consumers (Del-Valle et al., 2005). Even when harvested fully red,

Table 3
Effect of different packaging conditions (biaxially oriented polypropylene without oxygen scavenger (BOPP), biaxially oriented polypropylene with oxygen scavenger (BOPP + Scv), microperforated biaxially oriented polypropylene with 9 hole (BOPP9H), microperforated biaxially oriented polypropylene with 9 hole and oxygen scavenger (BOPP9H + Scv), microperforated biaxially oriented polypropylene with 7 hole (BOPP7H), microperforated biaxially oriented polypropylene with 7 hole and oxygen scavenger (BOPP7H + Scv)) on L^* values of strawberries during storage.

Treatments	0 W	1 W	2 W	3 W	4 W	5 W
BOPP	37.46 ± 3.36	31.51 ± 3.37	29.99 ± 2.42	28.91 ± 2.85	28.45 ± 2.48	27.98 ± 2.24
BOPP + Scv	37.46 ± 3.36	30.20 ± 2.82	30.54 ± 2.66	29.74 ± 1.63	29.12 ± 1.17	28.24 ± 1.17
BOPP9H	37.46 ± 3.36	29.66 ± 2.90	30.40 ± 1.65	29.47 ± 2.73	30.20 ± 1.94	29.58 ± 1.89
BOPP9H + Scv	37.46 ± 3.36	29.20 ± 2.32	30.71 ± 1.49	30.19 ± 1.61	29.59 ± 1.97	30.01 ± 1.28
BOPP7H	37.46 ± 3.36	29.94 ± 2.36	30.21 ± 1.54	29.53 ± 1.67	29.54 ± 1.50	28.91 ± 2.84
BOPP7H + Scv	37.46 ± 3.36	29.72 ± 4.30	30.79 ± 3.43	29.75 ± 2.31	30.23 ± 1.08	29.82 ± 1.59
Overall	37.46 ± 3.36 A	30.03 ± 3.10 B	30.46 ± 2.35 B	29.64 ± 2.06 B	29.59 ± 1.75 B	29.21 ± 1.88 B

Data are means ± SD of three replicates.
A–E means in the same row with different letters are significantly different ($p \leq 0.05$) (mean seperation was performed by Tukey test).

Table 4
Effect of different packaging conditions (biaxially oriented polypropylene without oxygen scavenger (BOPP), biaxially oriented polypropylene with oxygen scavenger (BOPP + Scv), microperforated biaxially oriented polypropylene with 9 hole (BOPP9H), microperforated biaxially oriented polypropylene with 9 hole and oxygen scavenger (BOPP9H + Scv), microperforated biaxially oriented polypropylene with 7 hole (BOPP7H), microperforated biaxially oriented polypropylene with 7 hole and oxygen scavenger (BOPP7H + Scv)) on a^* values of strawberries during storage.

Treatments	0 W	1 W	2 W	3 W	4 W	5 W
BOPP	33.40 ± 2.83 A,a	39.93 ± 3.26 B,a	30.51 ± 1.35 A,C,a	27.51 ± 2.54 C,D,b	25.56 ± 2.60 D,b	24.76 ± 3.09 D,b
BOPP + Scv	33.40 ± 2.83 A,a	37.38 ± 3.18 B,a,b	30.94 ± 2.41 A,C,a	29.89 ± 1.64 A,C,a,b	28.93 ± 2.77 C,a,b	28.33 ± 1.55 C,a,b
BOPP9H	33.40 ± 2.83 A,a	35.50 ± 2.59 A,a,b	31.36 ± 2.65 B,C,a	30.21 ± 2.29 B,C,a,b	29.79 ± 1.76 B,C,a	28.55 ± 2.23 C,a,b
BOPP9H + Scv	33.40 ± 2.83 A,a	33.11 ± 2.11 B,a,b	32.62 ± 2.07 A,a	31.43 ± 2.02 A,a	31.00 ± 2.16 A,a	29.88 ± 1.10 A,a
BOPP7H	33.40 ± 2.83 A,a	35.21 ± 2.43 A,b	33.53 ± 1.93 A,a	31.12 ± 2.48 A,a	30.73 ± 1.84 A,a	29.68 ± 2.25 A,a
BOPP7H + Scv	33.40 ± 2.83 A,a	36.63 ± 3.04 A,b	33.40 ± 3.54 A,a	31.15 ± 1.95 A,a	30.89 ± 1.69 A,a	29.90 ± 2.59 A,a

Data are means ± SD of three replicates.
a–c means in the same column with different letters are significantly different ($p \leq 0.05$).
A–E means in the same row with different letters are significantly different ($p \leq 0.05$) (mean seperation was performed by Tukey test).

strawberries continue to slowly change color and darken during storage (Sacks and Shaw, 1993). During storage, no significant differences between packaging conditions were found in terms of L^* and a^* values (Tables 3 and 4). This finding is consistent with work by Sanz et al. (2002) who found that strawberry color values did not change significantly between nonperforated and different microperforated films during 21 d of storage. In addition to this work, Ngcobo et al. (2012) showed that no significant difference was found in terms of L^*, Hue and C^* values between nonperforated and different microperforated films during 7–14 d storage of table grapes. In this study, all treatments resulted in a decrease in L^* values which then remained stable after one week of storage. The results are similar to those of Caner et al. (2008) and Almenar et al. (2007) who found that strawberries become darker with storage.A similar change was found for a^* values which increased over the first week then decreased during the last four weeks (Table 4). This trend could be attributed to a slow ripening process followed by senescence (Sanz et al., 2002). A statistically significant difference was found among the packaging conditions except at the second week of the storage. This result may be explained by the fact that different CO_2 and O_2 contents in the packages can affect anthocyanin synthesis or degradation (Sanz et al., 1999). The biggest changes of a^* values occurred with BOPP treatments, where a sharp decline occurred after the 3rd week. Our results are in agreement with Almenar et al. (2007) who showed that nonperforated samples had the lowest anthocyanin contents compared with microperforated samples. As a result, the color was better maintained in all microperforated groups.

3.5. Texture profile analysis (TPA)

Texture profile analysis (TPA) provides critical indices of the overall physiological conditions of fruit. During storage, the TPA parameters, including firmness, springiness, gumminess and chewiness, decreased whereas adhesiveness increased.

Firmness decreased as a function of storage time, from 895 gf to 633–421 gf (Fig. 2a). There was a faster rate of decrease in firmness for BOPP and BOPP + Scv throughout storage. At the 5th week, firmness values of BOPP9H (616.35 gf) and BOPP7H (607.28 gf) were similar to the 3rd week values of BOPP (534.02 gf) and BOPP + Scv (618.05 gf). It is possible that microperforated films maintained cell wall strength, cell–cell adhesion, cell packing and turgor of cells with retardation of senescence processes, resulting in high firmness values (Cia et al., 2006; Almenar et al., 2007). Another possible explanation is that microperforated treatments preserved firmness values more through lower respiration rates influenced by gas composition inside the packaging (Toivonen, 1997). Our results are in agreement with García et al. (1998) who found that perforated polypropylene samples had higher firmness values than polypropylene samples in 'Oso Grande' strawberries.

Adhesiveness is associated with surface characteristics of samples (Aday and Caner, 2011). BOPP treatments had the highest adhesiveness values compared with other treatments (Fig. 2b). Solubilization and depolymerization of cell walls may be associated with the highest values of BOPP (Yang et al., 2007). Springiness (elasticity), the ratio of the height the sample springs back after the first compression, was higher in the BOPP treatments during storage (Fig. 2c). The lower hardness value of strawberries seems to affect the springiness values. Cohesiveness, non-recoverable deformations of the first and second chews, increased during storage with all treatments (Fig. 2d). No significant differences were found in terms of cohesiveness among the microperforated samples.

Gumminess is associated with the energy required in disintegrating a solid product to a state ready for swallowing. Gumminess values decreased with storage time in all treatments. During storage, the values changed from 365 g to 173.65 (BOPP), 181.03 (BOPP + Scv), 228.58 (BOPP9H), 190.12 (BOPP9H + Scv), 222.77 (BOPP7H) and 175.97 (BOPP7H + Scv (Fig. 2e). Hydrolysis of starch causes the lower values of gumminess (Aday et al., 2011). Chewiness is the energy required to chew a solid food product to

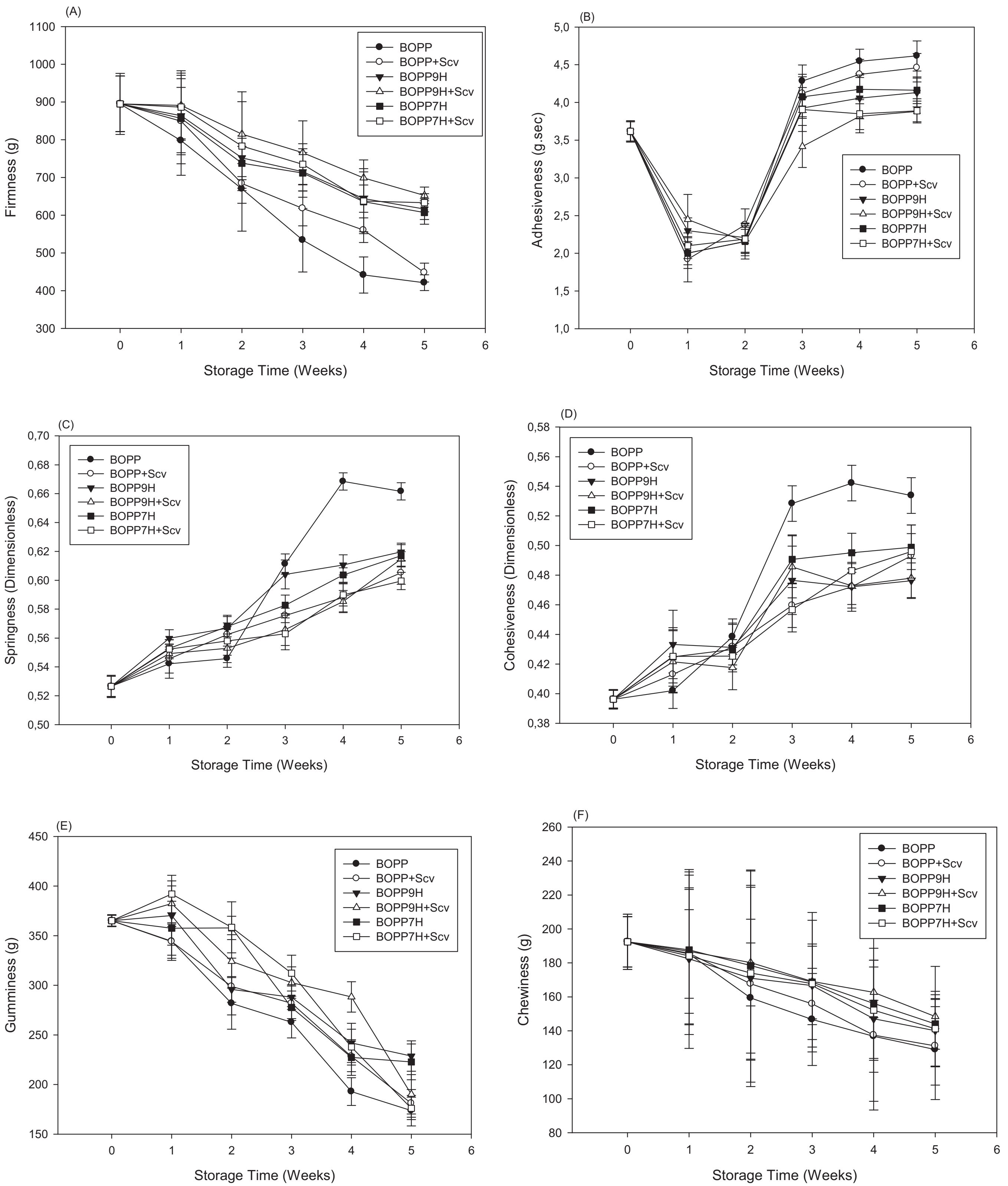

Fig. 2. Texture parameter ((a) firmness, (b) adhesiveness, (c) springness, (d) cohesiveness, (e) gumminess, (f) chewiness, and (g) resilience) changes of strawberries in different packaging conditions (biaxially oriented polypropylene without oxygen scavenger (BOPP), biaxially oriented polypropylene with oxygen scavenger (BOPP + Scv), microperforated biaxially oriented polypropylene with 9 hole (BOPP9H), microperforated biaxially oriented polypropylene with 9 hole and oxygen scavenger (BOPP9H + Scv), microperforated biaxially oriented polypropylene with 7 hole (BOPP7H), microperforated biaxially oriented polypropylene with 7 hole and oxygen scavenger (BOPP7H + Scv)) during storage. Vertical bars denote standard deviation of three replicates.

Table 5
Effect of different packaging conditions (biaxially oriented polypropylene without oxygen scavenger (BOPP), biaxially oriented polypropylene with oxygen scavenger (BOPP + Scv), microperforated biaxially oriented polypropylene with 9 hole (BOPP9H), microperforated biaxially oriented polypropylene with 9 hole and oxygen scavenger (BOPP9H + Scv), microperforated biaxially oriented polypropylene with 7 hole (BOPP7H), microperforated biaxially oriented polypropylene with 7 hole and oxygen scavenger (BOPP7H + Scv)) on electrical conductivity (μs/cm) values of strawberries during storage.

Treatments	0 W	1 W	2 W	3 W	4 W
BOPP	1.389 ± 0.004 D,a	1.566 ± 0.003 B,a	1.732 ± 0.031 A,a	1.776 ± 0.033 A,a	1.441 ± 0.037 C,a
BOPP + Scv	1.389 ± 0.004 C,a	1.554 ± 0.023 B,a,b	1.724 ± 0.031 A,a	1.747 ± 0.068 A,a	1.400 ± 0.0379 C,b
BOPP9H	1.389 ± 0.004 C,a	1.518 ± 0.024 B,c	1.720 ± 0.025 A,a	1.733 ± 0.032 A,a	1.391 ± 0.042 C,b
BOPP9H + Scv	1.389 ± 0.004 C,a	1.558 ± 0.005 B,a,b,c	1.726 ± 0.041 A,a	1.733 ± 0.006 A,a	1.400 ± 0.028 C,b
BOPP7H	1.389 ± 0.004 C,a	1.547 ± 0.010 B,a,b,c	1.711 ± 0.007 A,a	1.728 ± 0.043 A,a	1.402 ± 0.031 C,a,b
BOPP7H + Scv	1.389 ± 0.004 C,a	1.521 ± 0.041 B,b,c	1.693 ± 0.018 A,a	1.737 ± 0.030 A,a	1.411 ± 0.027 C,a,b

Data are means ± SD of three replicates.
a–c means in the same column with different letters are significantly different ($p \leq 0.05$).
A–E means in the same row with different letters are significantly different ($p \leq 0.05$) (mean seperation was performed by Tukey test).

the point required for swallowing it. Chewiness was higher in microperforated groups than BOPP and BOPP + Scv. During storage, chewiness values of fresh strawberries decreased due to fruit softening (Fig. 2f). These results showed that strawberries packaged with microperforated films have better textural values during storage compared with those in nonperforated films.

3.6. Electrical conductivity

Electrical conductivity can be used as indirect indicator of membrane stability during senescence of tissue (Xing et al., 2011). Electrical conductivity significantly increased during storage for all treatments (Table 5). No significant differences in electrical conductivity were found between BOPP and other treatments at weeks 2 and 3. For the first and fourth week of storage, BOPP had the highest electrical conductivity values related with high membrane damage. High levels of CO_2 accumulation inside the BOPP package may lead to cell disorganization (Martínez-Sánchez et al., 2011). Another possible explanation might be that loss of cell turgor and decrease in firmness, which was highest with BOPP, resulted in an increase in electrical conductivity (Zhou et al., 2011). Our results agree with those of Allende et al. (2004) who found that high CO_2 contents can trigger an increase in electrical conductivity in baby spinach. In addition to this work, De Reuck et al. (2010) showed that electrical conductivity increased in nonperforated films compared with microperforated films, perhaps associated with the decompartmentalization of enzymes and substrates and subsequent high enzyme–substrate interactions and accelerated anthocyanin degradation, which can be seen with the lowest a^* values in the BOPP packages.

3.7. FT-NIR evaluation

Near Infra-Red (NIR) spectroscopy, can be used to determine the quality of fresh fruit using their microstructure associated with sugars (C—H), acids and moisture (O—H) (Louw and Theron, 2010). NIR spectra of the fresh strawberries are shown in Figs. 3 and 4. The CH vibration region of 1650–1850 nm is the region of CH_3 and CH_2 groups. The spectral region at 980 nm and 2200–2300 nm shows the light absorption of available sugars because of the strong C—O vibration band voltage (Nicolaï et al., 2007; Aday et al., 2011). The absorption peak at 1800 nm, organic acid—COOH, is related to the C=O bond (Nicolaï et al., 2007).

As expected, BOPP treatments had the lowest absorption peaks at 980 nm in the 3rd week, but other packages delayed carbohydrate mechanism and had bigger absorption peaks than the BOPP treatments (Fig. 3). Carbohydrate absorption bands are associated with firmness affected changes of pectin, cellulose and

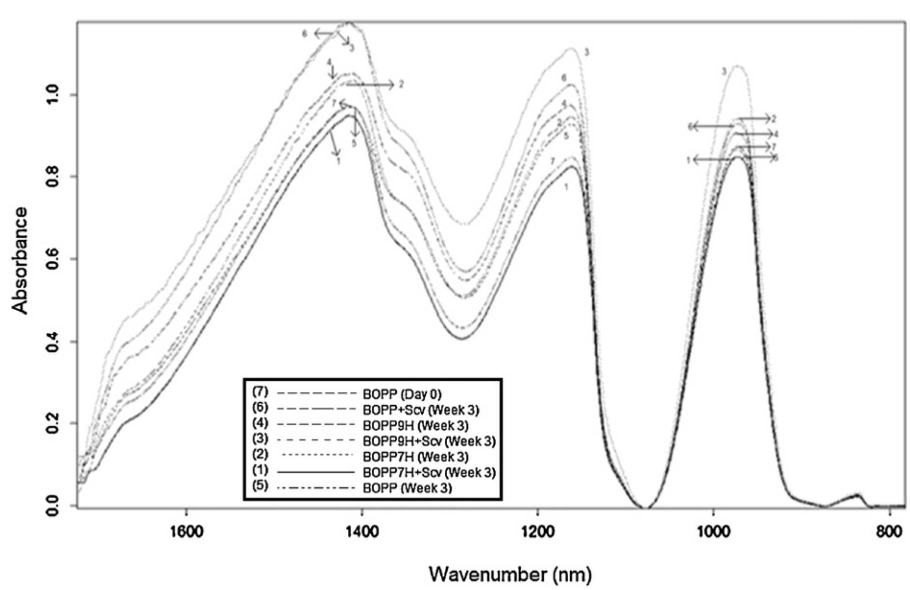

Fig. 3. Average relative absorbance spectra of strawberries storared in different packaging conditions (biaxially oriented polypropylene without oxygen scavenger (BOPP), biaxially oriented polypropylene with oxygen scavenger (BOPP + Scv), microperforated biaxially oriented polypropylene with 9 hole (BOPP9H), microperforated biaxially oriented polypropylene with 9 hole and oxygen scavenger (BOPP9H + Scv), microperforated biaxially oriented polypropylene with 7 hole (BOPP7H), microperforated biaxially oriented polypropylene with 7 hole and oxygen scavenger (BOPP7H + Scv)) obtained in transmission modes at the beginning and end of storage.

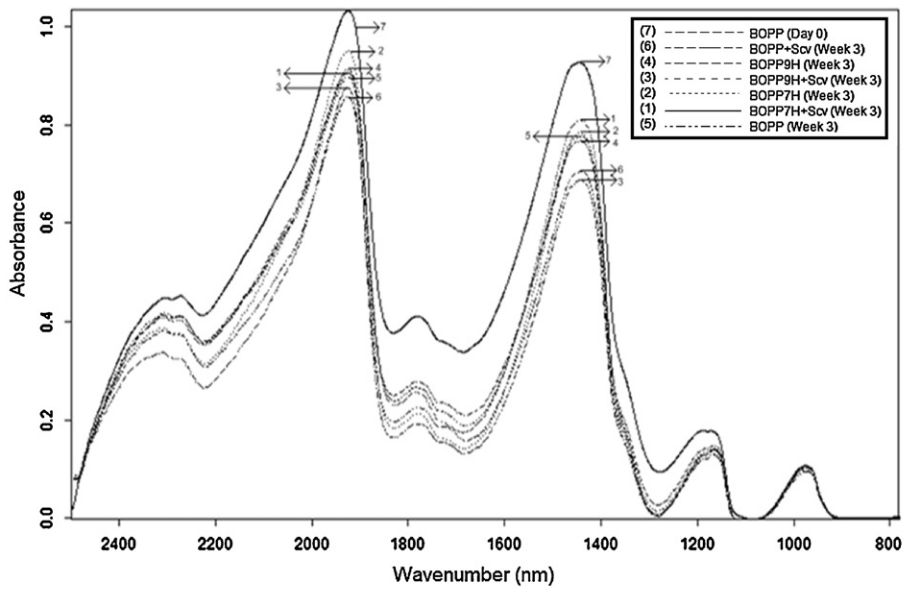

Fig. 4. Average relative absorbance spectra of strawberries stored in different packaging conditions (biaxially oriented polypropylene without oxygen scavenger (BOPP), biaxially oriented polypropylene with oxygen scavenger (BOPP + Scv), microperforated biaxially oriented polypropylene with 9 hole (BOPP9H), microperforated biaxially oriented polypropylene with 9 hole and oxygen scavenger (BOPP9H + Scv), microperforated biaxially oriented polypropylene with 7 hole (BOPP7H), microperforated biaxially oriented polypropylene with 7 hole and oxygen scavenger (BOPP7H + Scv)) obtained in reflectance modes at the beginning and end of storage.

Table 6
Effect of different packaging conditions (biaxially oriented polypropylene without oxygen scavenger (BOPP), biaxially oriented polypropylene with oxygen scavenger (BOPP + Scv), microperforated biaxially oriented polypropylene with 9 hole (BOPP9H), microperforated biaxially oriented polypropylene with 9 hole and oxygen scavenger (BOPP9H + Scv), microperforated biaxially oriented polypropylene with 7 hole (BOPP7H), microperforated biaxially oriented polypropylene with 7 hole and oxygen scavenger (BOPP7H + Scv)) on sensorial attributes of strawberries during storage.

Treatments	Appearence	Color	Firmness	Flavor	General acceptability
BOPP	6.28 ± 1.14 B,C	5.92 ± 1.05 B	7.25 ± 0.41 A	6.16 ± 1.16 A	6.33 ± 0.51 B,C
BOPP + Scv	8.00 ± 0.65 A	7.92 ± 0.83 A	7.31 ± 0.84 A	6.00 ± 0.75 A	7.64 ± 0.69 A
BOPP9H	6.00 ± 0.64 C	5.68 ± 0.75 B	5.87 ± 0.69 C	6.58 ± 0.49 A	6.12 ± 0.69 B,C
BOPP9H + Scv	6.41 ± 0.66 B,C	6.14 ± 0.85 B	6.71 ± 0.48 A,B	6.21 ± 0.90 A	6.33 ± 0.40 B,C
BOPP7H	5.58 ± 0.88 C	6.06 ± 0.77 B	6.12 ± 0.83 B,C	6.18 ± 1.22 A	5.87 ± 0.79 C
BOPP7H + Scv	7.00 ± 0.79 B	7.21 ± 0.63 A	7.10 ± 0.22 A	6.25 ± 0.78 A	6.78 ± 0.48 B

Data are means ± SD of three replicates.
A–E means in the same row with different letters are significantly different ($p \leq 0.05$) (mean seperation was performed by Tukey test).

hemicelluloses due to enzymatic breakdown (Aday et al., 2011). Sharp absorption bands at 1190 and 1406 nm nm are related to water loss (Hans, 2003; Aday et al., 2011).

Absorption bands of water molecules (OH bonds) in NIR reflectance can be observed at 760, 970 and 1450 nm (Aday et al., 2011). Strong water absorption bands were observed at 970 nm, 1197 nm, 1450 nm (OH water vibration) and 1900 nm (OH vibration and OH deformation). BOPP at day 0 had higher absorbance peaks at 970 nm and 1197 (OH of water vibration) than those of the other treatments at the end of storage (Fig. 4). During storage, it is clear that the absorbance peak was decreased especially with the BOPP treatments.Strawberry absorption spectra are very similar to the spectra of fruit such as plums or apples (Bobelyn et al., 2010; Louw and Theron, 2010). NIR spectra can be useful to determine quality attributes and estimate damage.

3.8. Sensory analysis

Results of sensory analysis, which was done in the second week, are presented in Table 6. BOPP + Scv resulted in higher scores than the other treatments for appearance. BOPP + Scv and BOPP7H + Scv samples had similar scores for color attributes but had higher preferences compared with other treatments. No significant effect of treatment on flavor was found. General acceptability was affected by different treatments and BOPP + Scv was rated as the best for this attribute.

4. Conclusions

This study has demonstrated the central importance of microperforated films and oxygen scavengers in food packaging. The findings of this study suggest that microperforated films with 7 and 9 holes (90 μm) produce an internal atmosphere of 15 kPa CO_2/5 kPa O_2 at 4 °C. The empirical findings, including results on pH, total soluble solids, electrical conductivity, color, texture profiles and sensory analysis enhanced our understanding of microperforated films to maintain quality of strawberries during distribution and storage chains. In addition to this, oxygen scavengers need to be placed in retail trays when microperforated films are used. The results of this research support the idea that microperforated films and oxygen scavengers can be used to meet the needs of industry. Shelf-life of fresh stawberries can be prolonged to beyond 4 weeks, increasing the marketing possibilities. In particular this study showed the potential of FT-NIR spectroscopy as a nondestructive rapid measurement technique to determine quality changes of fresh strawberries during storage. In future investigations it might be possible to use different carbon dioxide scavengers in microperforated packages to extend shelf-life.

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