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Packaging and storage condition affect the physicochemical properties of red raspberries (*Rubus idaeus* L., cv. Erika)

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Abstract

Packaging material and the storage temperature on red raspberries (Rubus idaeus L.) were studied in this paper. Raspberries were stored following their harvesting in different conditions: in the fridge at 1 °C and in the freezer at −20 °C, using different packaging materials: two Nanoactive films, Nanoactive A (NA) and Nanoactive B (NB), a biaxially oriented polyethylene terephthalate (PET) film and some other fruits were stored without any film (WF). Biometrics, color, titratable acidity, soluble solid content and moisture, were determined during storage. A loss of weight (24.87%) was found during storage at room temperature from 5.02 g to 4.02 g in two days. During the freezer storage was found a significant average higher Solid Soluble Content (9.44 °Brix) in PET, a significant higher Titratable acidity (2.08%) in WF, and no significant differences between different packaging for Moisture content. The O_2 and CO_2 concentrations were measured daily in the refrigerated fruits and the O_2 concentration on the 7th day was 5.0% (NA), 19.8% (NB) and 17.1 (PET). CO_2 percentage increased significantly during storage in the NA package from 9.6 (1st day) to 20.3 (14th day), whereas an inverse trend was found in the NB package from 4.4 (1st day) to 1.0 (4th day).

Keywords:

Syndiotactic polystyrene

Polyethylene terephthalate

Post-harvest

Raspberry

Rubus

Shelf life

Small fruits

Nanoporous crystalline phases

1. Introduction

Red raspberry (Rubus ideaus L.) is a shrub which is widely cultivated in all temperate regions of the world. Fruit is soft and it is consumed as fresh, frozen, purée, juice and dried. Red raspberry fruit has a very short shelf life due both to the high respiration rate and to the absence of peel or rind and as a consequence raspberry rapidly loses water and weight.

For this reason fresh consumption of refrigerated fruits should be within 2–3 days after manual picking. The visual aspect of quality includes freshness, color and absence of decay or physiological disorders, plays a key role in primary selection by the consumer. From this point of view the use of a packaging is often desirable. Over the last two decades, nanotechnologies have revolutionized the material industry, leading to high performance improvements (Cushen, Kerry, Morris, Cruz-Romero, & Cummins, 2012), in particular the food packaging industry, the role of nanotechnologies has been very important in improving overall packaging performance (mechanical, barrier) leading to functional, intelligent, and active packaging (Yam, Takhistov, & Miltz, 2005). Among the active functions, one of the most important is antimicrobial (Appendinia & Hotchkissb, 2002; Durango, Soares, & Andrade, 2006). Other important active functions are oxygen scavenger, that is the capture of the oxygen that penetrates the outer environment, as well as ethylene scavenger, that is the capture of the ethylene produced by the degradation of the fruit. The company NanoActive Film s.r.l. has patented active packaging (Albunia et al., 2012), multilayer films based on the common polypropylene (PP) and including a core layer of nanoporous syndiotactic polystyrene (s-PS). Syndiotactic polystyrene (s-PS) is a robust (D'Aniello, Rizzo, & Guerra, 2005), cheap and commercially available thermoplastic material essential within the polymeric framework (Schellenberg, 2009, pp. 17–29). Host-guest co-crystalline phases are obtained by solvent procedure and, after suitable solvent-extraction procedures, nanoporous crystalline phases named: δ (De Rosa, Guerra, Petraccone, & Pirozzi, 1997), ε (Petraccone, Ruiz de Ballesteros, Tarallo, Rizzo, & Guerra, 2008), disordered (Rizzo, Iannello, Albunia, Acocella & Guerra, 2014) or triclinic (Acocella, Rizzo, Daniel, Tarallo, & Guerra, 2015) can be easily achieved.

The ability of polymeric nanoporous phases to absorb low-molecular-mass molecules in their crystalline cavities leading to stable host/guest co-crystalline phases is well-described in the literature (Albunia, Rizzo, & Guerra, 2013; Guerra, Daniel, Rizzo, & Tarallo, 2012; Musto, Rizzo, & Guerra, 2005; Pilla et al., 2009). Co-crystalline phases, can be formed with gaseous molecules at room temperature, such as carbon dioxide (Annunziata, Albunia, Venditto, Mensitieri, & Guerra, 2006), ethylene (Albunia, Minucci, & Guerra, 2008) as well as with liquid guest molecules as carvacrol, a relevant natural antimicrobial molecule (Albunia, Rizzo, Iannello, Rufolo, & Guerra, 2014.

Recent studies based on active packaging films containing s-PS nanoporous-crystalline layer have shown that these innovative materials are able to prolong the shelf-life of non-climacteric fruits, such as oranges (Sicari, Dorato, Giuffrè, Rizzo, & Albunia, 2017).

A study on oxygen and carbon dioxide concentrations in the environment of packaged non-climacteric fruits as well as in s-PS nanoporous-crystalline layers has been also recently combined in order to understand the transport phenomena in active s-PS packaging films that control O_2 and CO_2 concentrations in the fruit environment, which are determinant in fruit and vegetable preservation (Rizzo et al., 2018).

The aim of this study was to highlight the best packaging material for the red raspberries, between the polyethylene terephthalate (PET) film and two Nanoactive films (NA) and (NB). The physicochemical evolution of raspberry during storage was also compared between refrigerated and frozen fruits, with and without film. This is the first paper where raspberry (cv. Erika) and PET, NA and NB films are related.

2. Materials and methods

2.1. Vegetable material

The red raspberries (cv. Erika) were cultivated in a greenhouse in the Reggio Calabria Province (Southern Italy) which is characterized by a typical Mediterranean climate, warm to hot, dry summers and mild to cool, wet winters. Fruits were randomly, manually and carefully picked at 7 a.m. on May 27, 2015 at the white stage of color, i.e. when they showed a faint pink color.

2.2. Films

Three-layer films (PP/sPS/PP) with overall thickness of nearly 50 μm made in lab-scale and composed by isotactic polypropylene (PP) and syndiotactic polystyrene (sPS) in the ratio 80:20 (PP/sPS/PP) were prepared.

Films were co-extruded by blown process: after extrusion, the core layer of syndiotactic polystyrene is amorphous (NB film) only after a patented treatment (Albunia et al., 2012) the s-PS film core layer is transformed in the disordered nanoporous crystalline phase (NA film) (Rizzo, Iannello, Albunia, Acocella & Guerra, 2014).

The s-PS used in this study to prepare Nanoactive film was manufactured by Dow Chemical Company under the trademark Questra 101.

The 13C nuclear magnetic resonance characterization showed that the content of syndiotactic triads was over 98%. The weight-average molar mass obtained by gel permeation chromatography (GPC) in trichlorobenzene at 135 °C was found to be Mw=3.2×105 with the dispersity index, Mw/Mn=3.9.

PET film ≈12 μm thick: Biaxially oriented polyethylene terephthalate film presents the following characteristics: low permeability to water and O_2, high resistance to acid and basic compounds, high permeability to alcohols and oils, high aptitude for food packaging use.

2.3. Packaging

After picking, the fruits were placed in disposable PET containers (90 g each) and immediately brought to the laboratory by a refrigerated vehicle. Packaging utilized three different flexible films NA, NB and PET with a thickness of ≈50, 50 and 12 μm respectively. The sealing was performed in the lab using a Multivac Vacuum apparatus (Tecno Pack). After sealing, a silicone rubber disc (15mm diameter; 2mm thickness) was applied on the film of each package. At this point, raspberries were put in the fridge at 1 °C. Some other samples were put in the fridge in PET pans and at the same temperature (1 °C) but without film (WF) and they were used as a control, other non-film protected fruits were left at room temperature (RT). Daily three PET containers for each packaging method were taken and analyses were conducted in duplicate on each packaging. The O_2 and CO_2 concentrations were also taken daily before starting the analysis. A complete set of fruits packaged with NA, NB, PET and WF were put in the freezer at −20 °C after harvesting, these samples were analysed monthly for 11 months.

2.4. Titratable acidity (TA)

The value of total titratable acidity is expressed in percentage terms (AOAC 942.15, 2005). A 10 g aliquot of mashed raspberries was mixed with 100 mL of deionized water. Then, the sample was titrated with a 0.1 N NaOH solution until a pH 8.1. The results were expressed as % of anhydrous citric acid.

2.5. Soluble solid content (SSC)

The °Brix is the percentage of total soluble solids calculated in a system previously calibrated with a sucrose solution at known concentration. The determination was performed at 20 °C in the refractive index value which rises to the value of Brix degrees by means of the tabular data, via refractometer ATAGO model DR -A1.

2.6. Moisture content

Twenty grams of the fruit were weighed into a ceramic container and placed in the oven at 102 °C, until constant weight. The moisture was determined by the following formula: $[(Fw - Dw)/Fw] \times 100$,

where Dw: dry weight; Fw: fresh weight.

2.7. Color

This analysis was performed using a colorimeter (Konica Minolta, model CM-A177) measuring L*, a* and b*. When a color is expressed in CIELAB, L* defines lightness, a* denotes the red/green value and b* the yellow/blue value. Color determination was conducted on the external side of each fruit.

2.8. Oxygen and carbon dioxide detection

A PBI Dansensor (Ringsted, Denmark) model Check Point was used to quantify O_2 and CO_2 percentages in the atmosphere of the package.

2.9. Statistical analysis

Results are the mean ± SD of six replicates (2 analyses x each of three PET containers, for each packaging method). Excel software (Office 2010) was used to calculate the means and the standard deviation.

Statistical analyses were performed using SPSS software for Windows (SPSS Inc., Elgin, IL, U.S.A.) 22.0 Version and Tukey test to determine any significant difference among all treatments at $P < 0.05$.

3. Results and discussion

In the following interpretation of the results, the fruits stored at room temperature without film were not taken into consideration, since they have shown a strong fungal activity the day after the harvest and from the quality point of view, there is no interest in discussing the findings in these fruits.

3.1. Biometrics

Biometrics have a direct effect on the consumer's choice, fruits which are too small or too large are usually rejected. All biometrics of raspberries varied during storage. Fruits stored at room temperature showed a significant decrease in length from 2.64 to 2.41 cm, the fruit diameter decreased from 1.97 to 1.81 cm whilst weight varied from 5.02 g at the fruit picking to 4.02 g after two days (Table 1). In Table 2 the results of red raspberries stored in the fridge are listed. NA allowed the longest storage (14 days) followed by PET, whereas NB showed the worst performance in terms of duration. At day 7, a significant difference was found and the fruits packaged with the three films showed the highest values when compared with fruits stored without film in which 2.27 cm (length), 1.79 cm (diameter) and 3.86 g (weight) were the lowest values. This means that film protection has reduced the loss of water. These results confirm the moisture content data (Table 6) in which the packaged fruits showed a higher weight if compared with fruits WF. The same trend was found from day 8 to day 10, also when only NA and PET can be compared with WF in this period. On the 12th day of storage, only PET and NA can be compared and NA showed the best performances.

3.2. Color

It has been demonstrated that berries harvested at early stages of color development (white stage) can become red during storage similarly to commercially ripe fruit (Kalt, Prange, & Lidster, 1993). This indicates that these fruits harvested at certain stages of maturity can synthesize pigment during storage under favorable conditions that are temperature dependent (Wang, Chen, & Wang, 2009). It is common for raspberry fruit to become darker and bluer after storage (Robbins & Moore, 1990). However, raspberries with a lighter red color and less blue color, such as fruit from controlled atmosphere storage (Haffner,Rosenfeld, Skrede, & Wang, 2002), are considered to be more attractive to consumers.

3.2.1. Lightness (L*)

Lightness ranges between 0 (black) and 100 (white). In the present study, for the fruits stored in the fridge, the highest L* value (40.47) was observed when the fruits were packaged with PET on the 10th day, and the lowest (26.38) was observed in the fruits WFF on the 8th day of storage (Table 4).

For fruits stored in the freezer, the highest L* value (46.86) was found in the NA film on the 9th month of storage and the lowest (30.89) in the PET film on the 3rd month of storage. In the refrigerated fruits, the L* values showed an initial decrease and a subsequent increase; this trend was mainly pronounced for the WF and PET packaged fruits whereas it was less evident for NA and NB packaged fruits. There was highly significant difference in L* ($P < 0.01$) during both refrigeration and freezing storage methods, when the fruits were packed in the NA, while, this parameter was not significantly different when the fruits were packed with the NB film. Considering the fruits packaged with PET film and the fruits stored WF, L* was significantly different during storage in the fridge ($P < 0.01$ and $P < 0.05$) but it was not significantly different during the storage in the freezer (Tables 4 and 5). If L* is considered daily and films are compared amongst themselves during storage in the fridge, no significant difference was found until day 4, where L* was significantly influenced by the type of packaging from day 5 (Table 4). In the frozen fruits, significant differences were only found between films in the 4th and the 9th months (Table 5). The lightness decreased from day 0 -at harvest- (Table 3), when the fruits were stored in the fridge (Table 4). When red raspberries were frozen, L* increased slightly except in the fruits packaged with PET. The color trend based on the storage period in the fridge and the freezer showed that the lowest peak of L* was observed on the 5th and the 8th day of storage in the fridge for both NA and PET; on the 3rd day for NB and the 8th day for fruits WF. The highest peak was observed during the 4th and the 6th day for PET and NA respectively (Table 4). Then a decrease was again observed. When the fruits were frozen, a slight decrease of L* was observed until the 4th month for NA, NB and WF, then it increased until the 9th month for NA and the 7th month for NB and WF (Table 5). The results of the two-way ANOVA analysis are reported in Table 9. L* was not influenced by the packaging variable when the fruits were stored in the fridge. Packaging, storage duration and their combination did not influence L* in frozen fruits. Storage duration and its interaction with packaging produced a significant ($P < 0.05$) and a high significant effect ($P < 0.01$) respectively in the refrigerated fruits.

Peano, Girgenti, Palma, Fontanella, and Giuggioli (2013) in fruits picked at the end of July at red ripe stage of maturity and used as a control (Himbo Top cv, grown in North Italy), found 27.09 as L* value and a decrease to 25.38 during the four days of experimentation, i.e. a L* value always lower when compared to the data obtained in our work. Maro, Pio, Guedes, Abreu, and Moura (2014) used the same instrument that we used for measurements and in four red raspberry cultivars studied in Brasil consistently found L* values lower than in our work.

3.2.2. Red/green coordinate (a*)

This parameter indicates the green-red coordinate. The highest a* value (31.36) was found in the refrigerated fruits packaged with NB on the 7th day of storage and the lowest (9.89) was found in the fruits packaged with PET on the 6th day of storage. In the frozen fruits, the highest value (34.14) was observed in the fruits without film in the 9th month of storage and the lowest (17.36) was found in the PET film in the 7th month of storage. In comparison to the a* value at harvest

16.93, there was an increase in red color, except for some storage days in the fridge, in the fruits without film (days 2, 4, 9 and 10), NA film (days 4 and 6) and PET film (days 4, 6, 9 and 10), (Table 4). There was a highly significant difference between days for the fruits stored in the fridge, $P < 0.01$ for NA, NB and PET; a significant difference ($P < 0.05$) was found in the fruits stored WF (Table 4). In the frozen fruits, a* showed a significant difference between months ($P < 0.05$) for the fruits packed in the NA, and a high significant difference ($P < 0.01$) for the fruits packaged in the NB, PET and WF (Table 5).

There was highly significant influence in the a* parameter regarding the packaging method when the fruits were stored in the fridge ($P < 0.01$) and significantly influenced ($P < 0.05$) when the fruits

were stored in the freezer (Table 9). Storage duration and its interaction with packaging, has a highly significant influence on the a* value.

3.2.3. Yellow/blue coordinate (b*)

The b* parameter indicates the blue-yellow coordinate. There was a highly significant difference ($P < 0.01$) during storage in the fridge in all the tested packaging (Table 4); the same significance was found in the frozen fruits packaged WF and with NB, whereas significant ($P < 0.05$) and no significant differences were found in the frozen fruits packaged with NA and PET respectively (Table 5). The highest b* value was found in the refrigerated fruits packaged in the NB film 12.69

on the 5th day of storage, the lowest value (2.52) was observed in the fruits stored WF in the fridge on the 9th day of storage (Table 4). Significant differences were found between packaging methods for fruits stored in the fridge with the exception of day 8, whereas significant differences were found for frozen fruits in the 5th month (only for NB) and in the 10th months.

The b* values increased from day 0. a* and b* demonstrated the same trend in increasing their value with fluctuations from the 4th to the 7th day of storage. The lowest b* value was observed on the 9th day in fruit without film; on the 4h day for NA, on the 1st day for NB and on the 6th day for

PET. The a* and b* values of fruits stored in the freezer followed a decrease trend until the 7th month when the values increased until the 9th month.

3.3. Soluble solid content

For some Author, the flavor is derived from the interactive taste and aroma of many chemical constituents. SSC and TA contribute to fruit flavor. High sugars and high acids are required for good berry flavour (Kader, 1991).

The SSC showed no significant differences during refrigerated storage (Table 6). If the three films are compared, raspberries in NA always showed the lowest value until the 10th day. In the frozen storage, fruits packaged with NB and PET showed no significant differences over 11 months whereas SSC was significantly different in WF fruits ($P < 0.05$) with a highly significant difference ($P < 0.01$) in NA packaged fruits. A decrease in values was observed in frozen fruits from 10.87 at harvest to the lowest 6.47 which was observed in the fruits packaged in NA in the 11th month of storage. There was a significant ($P < 0.05$) and a highly significant ($P < 0.01$) influence in SSC in packaging when fruits were respectively frozen or refrigerated (Table 9). The storage duration effect was not significant in both refrigeration and freezing. The combined variables produced no significant differences for refrigerated fruits and highly significant differences ($P < 0.01$) in the frozen fruits (Table 9). All these values are in accordance with the non-climateric characteristic of red raspberry, in which SSC has a slight variation after picking. Ali, Svensson, Alsanius, and Olsson (2011), in red raspberries cv Polka, produced in Sweden in September–October, and stored for 9 days at 2 °C WF, found a lower SSC with respect to our results, varying from 7.46% (at harvest) to 6.50% (9th day). Maro et al. (2014) studied raspberries picked at the physiological maturity stage, of 4 raspberry cultivars each one grown in two Brazilian mountain locations (918–1628 m above sea-level) and found a SSC ranging from 6.60% to 10.40%, noting that in this case, 7 out of the 8 samples showed (at harvest) a lower SSC with respect to our results, even if our red raspberries were picked at an earlier stage of ripening.

3.4. Titratable acidity

In fruit juices, citric acid, malic acid and tartaric acid are quantitatively predominant, depending on the fruit. The TA increased following harvest (1.44) in both refrigerated and frozen raspberries. Significant differences were found in fruits WF and highly significant differences were found when NA, NB and PET were used (Table 6). No significant difference was found during freezing for the four types of packaging compared (Table 7). The highest value was observed in the PET packaged fruits stored in the fridge (2.72%) on the 9th day of storage, and the lowest was observed in the fruits stored WF in the freezer (1.59%) in the 7th month of storage. There was a highly significantly difference in TA ($P < 0.01$) during storage in the fridge, in the NA, NB, PET and WF (Table 6), but it was not influenced by storage in the freezer (Table 7). Two-way ANOVA analysis showed that TA was not influenced by either the storage period or the packaging method either in refrigerated or in frozen fruits, but there was a highly significant influence by the interaction of packaging per day ($P < 0.01$) and packaging per month ($P < 0.05$), (Table 9). Mölder, Moor, Tõnutare, and Põldma (2011), after storage of the fruit at 1 °C from Glen Ample cv, found a TA varying from 2.36% in the unwrapped fruits to 2.27% in fruits wrapped with polypropylene and to 2.2% in fruits wrapped with oriented polypropylene. These findings are higher than those we found on the 4th day in our experiment in fruits refrigerated and packaged WF, with NA and with NB, whereas they are similar to our results for fruits packaged with PET.

3.5. Moisture

The highest moisture contents were observed in the PET packaged fruits stored in the freezer (90.58% in the 9th month of storage) and in the NA packaged raspberries (90.35% in the 10th month of storage), (Table 7); the lowest moisture content was observed in the fruits stored in the fridge WF (83.88% on the 10th and last day of storage), (Table 6).

The storage period in the fridge did not influence the moisture content when the fruits were packaged in NA ($P > 0.05$), whereas significant differences were found in PET packaged fruits ($P < 0.05$) and high significant differences in NB packaged fruits ($P < 0.01$), (Table 6). In the fruits packaged WF a high significant decrease in moisture content was found during storage; from 87.40% to 83.88% (Table 6), which was due to the aerobic respiration of fruits, a biological

process which produces CO2, energy and aqueous vapor which is dispersed in the atmosphere, in this case the absence of the protective film increased the loss of water.

In the frozen fruits, no significant differences were found in the NA and NB packaged raspberries during 11 months of storage. Over many months no significant difference was found in the moisture content between NA and NB stored fruits (Table 7). Frozen fruits in PET packaging showed significant differences ($P < 0.05$) and highly significant differences ($P < 0.01$) were found in WF frozen fruits (Table 7). Two-way ANOVA analysis demonstrated that packaging and the interaction packaging per day, produced a highly significant influence in the moisture content ($P < 0.01$), whereas no significant influence was found by analyzing the storage duration effect (Table 9); the exact contrary was found in frozen raspberries (Table 9).

3.6. O_2 and CO_2

The initial O_2 and CO_2 content was measured immediately after the sealing of the films. The O2 was 20.90% and the CO2 was 0.03% of the detected atmosphere (Table 3). After one day of storage, the respiration of fruits caused a rapid variation of these values and O_2 decreased to 9.1% (NA), 17.3% (NB) 16.3% (PET), whereas CO_2 increased to 9.6% (NA), 4.4% (NB) and 5.9% (PET). As expected, the more or less pronounced barrier effect of each film strongly reduced the gas exchange with the external atmosphere from day 1 and different effects were shown in each type of packaging in relation to the wrapping film (Table 8). When raspberries are stored in a modified or controlled atmosphere they are relatively tolerant to high CO_2. The recommended controlled atmosphere storage conditions for raspberry fruit are 15–20% CO_2 and 5–10% O_2 (Kader, 2001, pp. 29–70). By comparing the two prototype films that were studied, NA showed the best O2 and CO2 concentrations: 5.81% for O2 and 15.58% for CO2, which explains the longer shelf life of the fruits when they were wrapped in this film. The gas concentrations observed in the NB wrapping (17.31% for O2 and 4.56% for CO2) and in PET wrapping (16.72% for O2 and 5.91% for CO2) were outside of the recommended range (Table 9). CO2 increased significantly during storage in the NA package, whereas an inverse trend was found in the NB package, this could be due to the differences in diffusivities of O2 and CO2 in amorphous and nanoporous-crystalline phases of s-PS that could be relevant in gas concentrations in fruit packaging (Rizzo, Cozzolino, et al., 2018). Within PET packaging no significant differences were found for either O2 and CO2 contents, this was probably due to the barrier effect of PET. The lowest value observed or the O2 (1.0%) was in the NA, on the 11th day of storage and the highest value was observed in the NB, on the 7th day of storage. Alternatively, the lowest CO2 value was observed in the NB 1.0% on the 7th day of storage and the highest value was observed in the NA, but on the 13th day of storage. The O2 concentration was not influenced by the storage period in the fridge, the same was true for CO2 measured in NA and PET packaging (Table 8).

The two-way ANOVA analysis showed that the films used in this experiment had a highly significant influence on both the O2 and the CO2 concentrations ($P < 0.01$), no significant effect was caused by the days of storage ($P > 0.05$) and a significant effect was found in the film interaction per day, $P < 0.05$ (Table 9).

Wang (2003) in the head space of polystyrene sap-on lid containers where raspberries cv Heritage were stored for 10 days at 10 °C, found a constant O2 concentration (19.36–20.32%) and a tendency for CO2 to increase from 0.55% to 1.89%.

4. Conclusions

Red raspberries without refrigeration show a very short shelf-life, maximum one day. The fruits preserved with Nanoactive A have shown the highest shelf-life (14 days) and maintained valuable physical-chemical characteristics. When the fruits were stored in the fridge, the packaging method (with or without wrapping film) had an impact on fruit biometrics, a*, b*, moisture, O_2 and CO_2. When the red raspberries were frozen, the packaging method influenced a* and soluble solid content. Meanwhile, the storage period in the fridge did not influence the soluble solid content, the titratable acidity, the moisture content, or the O_2 and CO_2 concentrations. When the red raspberries were frozen, a*, b* and moisture content, were highly influenced by the storage period. Nanoactive films have shown good performances, in particular the fruits stored in the fridge and preserved with Nanoactive A have shown the highest shelf-life (14 days) and maintained valuable physical-chemical characteristics during storage for: length (2.42 cm), diameter (2.22 cm), weight (4.30 g), lightness (30.05), red/green coordinate (27.87) and yellow/blue coordinate (11.98), titratable acidity (2.35% as citric acid). Studies inside packages show that for three-layer active film, exhibiting a nanoporous-crystalline s-PS core layer (NA), O_2 and CO_2 concentrations markedly decrease and increase, respectively, with packaging time. In the same conditions, for reference films (not activated three layer films (NB) or PET films), smaller variations with packaging time of O_2 and CO_2 concentrations are observed. This behaviour is due to a higher barrier to O_2 and CO_2 diffusion, offered by the activated nanoporous-crystalline phase of s-PS layer (NA). Moreover it is worth to underline that increase of CO_2 concentration inside fruit package can have also a remarkable positive effect in slowing down the development of molds, due to well-known anti-microbial properties of carbon dioxide.

Conflicts of interest

The authors have no conflicts of interest to declare.

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Appendix A. Supplementary data

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Table 1

Effect of storage period on raspberries (cv. Erika). at harvest (0 day) and left at room temperature without film, on length, diameter and weight.

Day	Length (cm)	Diameter (cm)	Weight (g)
0	2.64 ± 0.25^{b}	1.97 ± 0.29^{a}	5.02 ± 1.07^{b}
1	2.60 ± 0.21^{b}	1.88 ± 0.11^{a}	4.69 ± 0.62^{ab}
2	2.41 ± 0.24^{a}	1.91 ± 0.29^{a}	4.02 ± 0.79^{a}

The results are the mean of three replicates ± Standard Deviation.

The letters represent the significant difference vertically at $P < 0.05$.

Table 2

Effect of storage period on the length, diameter and weight parameters in red raspberries (cv. Erika), stored at 1 °C in the fridge.

Day	Length (cm)				Diameter (cm)				Weight (g)			
	WF	NA	NB	PET	WF	NA	NB	PET	WF	NA	NB	PET
1	2.54 ± 0.32^{dA}	2.49 ± 0.27^{cdA}	2.59 ± 0.24^{dA}	2.53 ± 0.28^{eA}	1.92 ± 0.22^{dAB}	1.87 ± 0.15^{cdeAB}	1.81 ± 0.16^{abcA}	1.96 ± 0.13^{cAB}	4.62 ± 0.86^{dA}	4.45 ± 0.85^{aA}	4.85 ± 0.79^{bA}	4.98 ± 0.92^{cA}
2	2.32 ± 0.34^{bcA}	2.48 ± 0.23^{cdAB}	2.52 ± 0.24^{dB}	2.54 ± 0.28^{eB}	1.78 ± 0.15^{bcA}	1.85 ± 0.21^{bcdA}	1.80 ± 0.13^{abA}	2.01 ± 0.32^{cdB}	4.05 ± 0.95^{abcA}	4.39 ± 0.72^{aAB}	4.56 ± 0.77^{abcAB}	4.77 ± 0.92^{bcB}
3	2.42 ± 0.25^{cdA}	2.55 ± 0.24^{cdA}	2.43 ± 0.28^{bcdA}	2.45 ± 0.27^{cdeA}	1.77 ± 0.16^{bcA}	1.82 ± 0.15^{bcdA}	1.75 ± 0.12^{aA}	1.80 ± 0.15^{bA}	4.23 ± 0.98^{bcdA}	4.68 ± 0.84^{abA}	4.33 ± 0.85^{abcA}	4.28 ± 0.80^{abA}
4	2.36 ± 0.14^{cAB}	2.42 ± 0.19^{bcdAB}	2.33 ± 0.21^{abcA}	2.48 ± 0.18^{deB}	1.78 ± 0.18^{bcA}	1.82 ± 0.15^{bcdA}	1.88 ± 0.14^{bcdAB}	1.95 ± 0.14^{cB}	4.55 ± 0.62^{cdAB}	4.86 ± 0.50^{abB}	4.17 ± 0.63^{abA}	4.57 ± 0.60^{bcAB}
5	2.37 ± 0.21^{cAB}	2.46 ± 0.21^{cdB}	2.25 ± 0.17^{aA}	2.35 ± 0.28^{bcdAB}	1.85 ± 0.13^{cdA}	1.98 ± 0.16^{eB}	1.91 ± 0.20^{cdAB}	1.93 ± 0.14^{cAB}	4.24 ± 0.71^{bcdAB}	4.60 ± 0.63^{abB}	4.10 ± 0.65^{aA}	4.40 ± 0.79^{abAB}
6	1.99 ± 0.18^{aA}	2.29 ± 0.17^{bB}	2.27 ± 0.23^{abB}	2.06 ± 0.25^{aA}	1.61 ± 0.18^{aA}	1.91 ± 0.13^{deC}	1.81 ± 0.10^{abcB}	1.66 ± 0.11^{aA}	3.81 ± 0.66^{abA}	4.64 ± 0.80^{abB}	4.52 ± 0.72^{abcB}	4.03 ± 0.59^{aA}
7	2.27 ± 0.16^{bcA}	2.48 ± 0.20^{cdB}	2.47 ± 0.28^{cdB}	2.55 ± 0.21^{eB}	1.79 ± 0.10^{bcA}	2.07 ± 0.10^{fgC}	1.94 ± 0.16^{dB}	2.10 ± 0.16^{deC}	3.86 ± 0.51^{abA}	4.60 ± 0.58^{abB}	4.70 ± 0.82^{bcAB}	5.07 ± 0.73^{cC}
8	2.15 ± 0.24^{bA}	2.45 ± 0.16^{cdB}		2.48 ± 0.18^{deB}	1.72 ± 0.13^{bA}	1.75 ± 0.18^{abA}		1.74 ± 0.10^{abA}	3.86 ± 0.63^{abA}	5.08 ± 0.55^{bC}		4.54 ± 0.63^{abB}
9	2.26 ± 0.17^{bcA}	2.39 ± 0.23^{bcA}		2.29 ± 0.22^{bcA}	1.61 ± 0.10^{aA}	1.69 ± 0.14^{aB}		1.68 ± 0.10^{aAB}	3.96 ± 0.59^{abA}	4.82 ± 0.79^{abB}		4.70 ± 0.59^{bcB}
10	2.28 ± 0.22bcA	2.44 ± 0.25^{bcdB}		2.47 ± 0.19^{deB}	1.93 ± 0.16^{dA}	2.16 ± 0.19^{ghB}		2.21 ± 0.17^{eB}	3.58 ± 0.65^{aA}	4.41 ± 0.48^{aB}		4.39 ± 0.69^{abB}
11		2.43 ± 0.19^{bcd}		2.27 ± 0.18^{b}		1.68 ± 0.12^{a}		1.74 ± 0.16^{ab}		4.35 ± 0.63^{a}		4.80 ± 0.66^{bc}
12		2.08 ± 0.30^{a}		1.94 ± 0.30^{a}		1.78 ± 0.21^{abc}		1.69 ± 0.22^{ab}		4.63 ± 0.90^{ab}		4.30 ± 0.80^{ab}
13		2.57 ± 0.27^{d}				2.33 ± 0.20^{i}				4.34 ± 0.73^{ab}		
14		2.42 ± 0.20^{bcd}				2.22 ± 0.13^{h}				4.30 ± 0.79^{ab}		
Mean	2.30 ± 0.15^{A}	2.42 ± 0.12^{B}	2.41 ± 0.13^{B}	2.37 ± 0.20^{AB}	1.78 ± 0.11^{A}	1.92 ± 0.20$^{(2)}$	1.84 ± .07^{B}	1.87 ± 0.18^{C}	4.08 ± 0.33^{A}	4.64 ± 0.21^{AB}	4.46 ± 0.28^{AB}	4.57 ± 0.31^{AB}
Sig.	**	**	**	**	**	**	**	**	**	n.s.	*	**

The results are the mean of six replicates ± Standard Deviation. ** ($P < 0.01$); * ($P < 0.05$); n.s. (not significant). The lowercase letters represent the significant difference vertically at $P < 0.05$. The capital letters represent the significant difference horizontally at $P < 0.05$ between the three films and the fruits without film for each day of analysis

Table 3

Physical parameters in red raspberries (cv. Erika), the day of the harvest and O2 and CO2 composition in the headspace of the packaging.

Day	L*	a*	b*	SSC (°Brix)	TA (% citric acid)	Moisture (%)	O_2 (%)	CO_2 (%)
0	38.38 ± 3.576	16.93 ± 0.63	6.86 ± 1.34	10.87 ± 0.84	1.44 ± 0.13	86.77 ± 0.51	20.90 ± 0.00	0.03 ± 0.00

The results are the mean of six replicates ± Standard Deviation.

Table 4

Effect of storage period in the fridge at 1 °C on the color parameter in red raspberries (cv. Erika).

Day	L*				a*				b*			
	WF	NA	NB	PET	WF	NA	NB	PET	WF	NA	NB	PET
1	36.09 ± 3.51 ^{cdA}	38.91 ± 3.41 ^{dA}	36.44 ± 3.44 ^{aA}	34.50 ± 2.98 ^{abcdA}	19.56 ± 0.09 ^{dA}	20.87 ± 2.97 ^{abcA}	19.30 ± 1.91 ^{aA}	20.66 ± 4.22 ^{cdA}	6.25 ± 0.52 ^{abAB}	7.52 ± 1.45 ^{abcdAB}	6.43 ± 0.57 ^{aAB}	8.19 ± 2.48 ^{bcdB}
2	36.50 ± 3.82 ^{cdA}	33.45 ± 4.22 ^{abcdA}	34.55 ± 4.65 ^{aA}	36.33 ± 5.27 ^{cdA}	11.69 ± 1.28 ^{aA}	22.48 ± 4.28 ^{bcdB}	23.35 ± 5.82 ^{abB}	18.72 ± 3.15 ^{bcAB}	4.07 ± 1.09 ^{aAB}	9.48 ± 1.33 ^{cdeB}	8.25 ± 1.90 ^{aB}	6.78 ± 1.07 ^{abcBC}
3	36.60 ± 5.43 ^{cdA}	31.22 ± 3.42 ^{abcA}	32.10 ± 0.66 ^{aA}	30.28 ± 2.82 ^{abcA}	18.39 ± 7.21 ^{abA}	26.61 ± 1.89 ^{cdA}	27.45 ± 2.90 ^{bcA}	21.87 ± 2.30 ^{cdA}	8.17 ± 3.08 ^{bcA}	11.21 ± 1.44 ^{e}	9.62 ± 1.06 ^{abA}	8.75 ± 0.96 ^{bcdA}
4	36.40 ± 2.32 ^{cdA}	37.04 ± 1.42 ^{cdA}	37.51 ± 2.43 ^{aA}	35.89 ± 4.43 ^{cdA}	11.81 ± 2.12 ^{aA}	14.17 ± 1.11 ^{aA}	20.50 ± 1.80 ^{abB}	14.82 ± 2.55 ^{abcA}	3.46 ± 0.53 ^{aA}	4.57 ± 0.34 ^{aA}	8.61 ± 0.83 ^{aB}	4.86 ± 1.10 ^{abA}
5	36.13 ± 5.39 ^{cdB}	28.30 ± 0.87 ^{aA}	37.15 ± 1.77 ^{aB}	26.86 ± 1.49 ^{aA}	14.13 ± 3.27 ^{aA}	23.74 ± 3.60cd ^{B}	30.82 ± 0.66 ^{cC}	22.35 ± 1.09 ^{cdB}	4.90 ± 1.97 ^{abA}	10.25 ± 2.21 ^{cdeBC}	12.69 ± 0.81 ^{bC}	8.36 ± 1.21 ^{bcdAB}
6	27.78 ± 1.20 ^{abA}	37.00 ± 2.61 ^{cdBC}	32.55 ± 2.40 ^{aAB}	38.71 ± 1.93 ^{dC}	17.25 ± 2.24 ^{abC}	14.94 ± 3.75 ^{abAB}	22.23 ± 3.31 ^{abC}	9.89 ± 1.34 ^{aA}	5.18 ± 1.09 ^{abAB}	5.41 ± 1.71 ^{abAB}	8.17 ± 1.31 ^{aC}	3.65 ± 0.80 ^{aA}
7	29.87 ± 2.31 ^{abcAB}	31.55 ± 1.66 ^{abcAB}	34.53 ± 1.46 ^{aB}	28.54 ± 3.63 ^{abA}	15.20 ± 4.56 ^{aA}	26.15 ± 0.81 ^{cdB}	31.36 ± 2.11 ^{cB}	28.61 ± 1.99 ^{dB}	5.30 ± 1.39 ^{abA}	10.91 ± 0.52 ^{deB}	12.41 ± 2.35 ^{bB}	11.26 ± 1.66 ^{dB}
8	26.38 ± 0.84 ^{aA}	28.79 ± 1.26 ^{aA}		27.90 ± 4.48 ^{abA}	25.49 ± 2.67 ^{bA}	23.47 ± 5.89 ^{cdA}		19.15 ± 4.21 ^{bcA}	9.41 ± 1.70 ^{cA}	8.65 ± 2.38 ^{bcdeA}		6.56 ± 2.49 ^{abcA}
9	39.37 ± 1.12 ^{dA}	34.36 ± 3.38 ^{abcdA}		35.06 ± 4.02 ^{bcdA}	10.83 ± 2.31 ^{aA}	25.15 ± 5.39 ^{cdB}		15.33 ± 3.88 ^{abcAB}	2.52 ± 0.83 ^{aA}	8.03 ± 2.15 ^{bcdeB}		4.98 ± 1.54 ^{abAB}
10	34.60 ± 3.99 ^{bcdA}	36.44 ± 0.42 ^{bcdA}		40.47 ± 1.65 ^{dA}	14.78 ± 1.76 ^{abB}	22.58 ± 4.75b ^{cdB}		13.11 ± 3.07 ^{abA}	5.10 ± 1.39 ^{abA}	8.05 ± 1.01 ^{abcdeB}		3.87 ± 0.39 ^{aA}
11		35.28 ± 2.37 ^{bcd}		30.40 ± 1.65 ^{abc}		25.10 ± 0.13 ^{cd}		22.88 ± 5.96 ^{cd}		10.31 ± 0.48 ^{cde}		8.56 ± 3.41 ^{bcd}
12		34.73 ± 3.34 ^{abcd}		29.90 ± 2.75 ^{abc}		21.40 ± 2.53 ^{bcd}		27.73 ± 5.05 ^{d}		8.04 ± 1.54 ^{bcde}		10.30 ± 1.81 ^{cd}
13		34.20 ± 4.40 ^{abcd}				18.37 ± 1.43 ^{abc}				6.65 ± 1.23 ^{abc}		
14		30.05 ± 0.39 ^{ab}				27.87 ± 4.02 ^{d}				11.98 ± 3.45 ^{e}		
Mean	33.97 ± 4.35 ^{A}	33.67 ± 3.26 ^{A}	34.97 ± 2.15 ^{A}	32.90 ± 4.49 ^{A}	15.91 ± 4.45 ^{AB}	22.35 ± 4.14 ^{DE}	25.00 ± 4.89 ^{E}	19.59 ± 5.64 ^{CD}	5.43 ± 2.07 ^{AB}	8.65 ± 2.19 ^{CD}	9.45 ± 2.31 ^{D}	7.18 ± 2.47 ^{BC}
Sig.	*	**	n.s.	**	*	**	**	**	**	**	**	**

The results are the mean of six replicates ± Standard Deviation. The lowercase letters represent the significant difference vertically at $P < 0.05$. The capital letters represent the significant difference horizontally at $P < 0.05$ between the three films and the fruits without film for each day of analysis.

Table 5

Effect of storage period in the freezer at −20 °C on the color parameter in red raspberries (cv. Erika).

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Months	L*				a*				b*			
	WF	NA	NB	PET	WF	NA	NB	PET	WF	NA	NB	PET
1	37.59 ± 1.30^{aA}	39.02 ± 1.88^{bcdA}	39.87 ± 1.35^{aA}	35.21 ± 3.87^{abA}	29.63 ± 1.06^{bcdA}	30.55 ± 0.81^{abcA}	26.84 ± 5.65^{bA}	27.27 ± 3.20^{bcA}	10.55 ± 0.66^{bcA}	10.41 ± 0.63^{cA}	9.55 ± 2.51^{cA}	10.41 ± 1.97^{abA}
2	37.99 ± 3.01^{aA}	38.22 ± 1.01^{abcA}	40.48 ± 1.56^{aA}	37.14 ± 1.03^{abA}	29.49 ± 1.21^{bcdA}	31.54 ± 0.75^{bcA}	30.07 ± 1.91^{bA}	30.26 ± 1.99^{cA}	9.84 ± 0.98^{cdeA}	10.72 ± 0.55^{cA}	9.82 ± 1.47^{cA}	11.37 ± 0.26^{bA}
3	37.29 ± 2.45^{aB}	36.58 ± 1.36^{abcB}	37.85 ± 2.81^{aB}	30.89 ± 1.97^{aA}	27.58 ± 4.62^{abcA}	27.45 ± 1.94^{bcA}	27.10 ± 2.66^{bA}	26.88 ± 1.12^{bcA}	9.80 ± 1.78^{cdeA}	9.39 ± 0.11^{cA}	8.05 ± 1.57^{bcA}	9.45 ± 0.45^{abA}
4	35.41 ± 0.95^{aAB}	33.53 ± 2.14^{aA}	37.03 ± 0.66^{aAB}	39.73 ± 2.96^{bB}	28.22 ± 1.91^{bcA}	28.53 ± 0.27^{abcA}	31.02 ± 1.32^{bA}	30.54 ± 4.69^{cA}	9.77 ± 1.27^{cdeA}	10.07 ± 0.39^{cA}	9.04 ± 1.05^{cA}	10.87 ± 2.49^{abA}
5	36.33 ± 1.90^{aA}	38.18 ± 2.43^{abcA}	38.60 ± 3.16^{aA}	35.15 ± 0.82^{abA}	27.84 ± 1.24^{abcA}	32.25 ± 0.95^{cB}	27.32 ± 1.01^{bA}	24.80 ± 1.80^{abcA}	8.73 ± 0.23^{bcdA}	10.92 ± 0.53^{cB}	7.78 ± 1.00^{bcA}	7.80 ± 1.27^{abA}
6	40.14 ± 3.04^{aA}	40.08 ± 1.30^{abcA}	40.45 ± 1.24^{aA}	36.50 ± 3.64^{abA}	24.01 ± 3.53^{abAB}	28.72 ± 1.73^{abcB}	24.94 ± 1.07^{bB}	20.73 ± 1.67^{abA}	7.08 ± 1.66^{abcA}	8.29 ± 0.42^{abcA}	7.39 ± 1.38^{bcA}	7.37 ± 1.54^{abA}
7	41.50 ± 1.47^{aA}	43.40 ± 3.76^{cdA}	44.25 ± 4.42^{aA}	37.89 ± 3.64^{abA}	22.32 ± 1.93^{aAB}	25.60 ± 3.55^{abB}	18.83 ± 4.38^{aAB}	17.36 ± 0.16^{aA}	5.99 ± 1.20^{aA}	7.25 ± 0.59^{aA}	5.31 ± 0.91^{aA}	6.40 ± 1.66^{aA}
8	38.27 ± 4.26^{aA}	41.79 ± 2.66^{cdA}	37.92 ± 2.62^{aA}	37.40 ± 4.29^{abA}	24.27 ± 2.61^{abAB}	25.68 ± 4.60^{abAB}	29.71 ± 1.74^{bB}	20.72 ± 4.33^{abA}	6.93 ± 1.37^{abA}	7.47 ± 1.34^{abA}	9.21 ± 1.20^{cA}	6.57 ± 2.61^{abA}
9	35.71 ± 3.68^{aA}	46.86 ± 2.79^{dB}	39.18 ± 4.64^{aAB}	36.63 ± 3.20^{abA}	34.14 ± 0.75^{dB}	25.02 ± 4.50^{aA}	27.30 ± 4.33^{bAB}	32.04 ± 2.63^{cAB}	12.41 ± 0.61^{eA}	9.94 ± 1.26^{bcA}	9.90 ± 1.13^{cA}	11.26 ± 1.51^{bA}
10	39.71 ± 2.47^{aA}	33.94 ± 2.81^{abA}	38.17 ± 5.64^{aA}	38.23 ± 2.93^{abA}	25.62 ± 3.28^{abcAB}	32.11 ± 1.58^{cB}	20.36 ± 2.74^{aA}	22.27 ± 6.03^{abA}	8.21 ± 1.40^{abcdAB}	11.24 ± 1.74^{cB}	5.79 ± 0.98^{abA}	7.60 ± 2.84^{abAB}
11	36.15 ± 3.35^{aA}	34.12 ± 0.44^{abA}	36.79 ± 3.91^{aA}	38.53 ± 4.70^{abA}	31.34 ± 1.90^{cdA}	31.95 ± 2.80^{cA}	30.93 ± 2.46^{bA}	26.63 ± 4.56^{bcA}	10.21 ± 0.35^{deA}	10.43 ± 2.47^{cA}	10.77 ± 0.68^{cA}	8.90 ± 3.14^{abA}
Mean	37.83 ± 1.96^{AB}	38.70 ± 4.19^{AB}	39.14 ± 2.11^{B}	36.66 ± 2.35^{A}	27.68 ± 3.47^{BC}	29.04 ± 2.81^{C}	26.76 ± 4.04^{AB}	25.41 ± 4.69^{A}	9.05 ± 1.88^{AB}	9.65 ± 1.39^{B}	8.42 ± 1.74^{A}	8.91 ± 1.87^{AB}
Sig.	n.s.	**	n.s.	n.s.	**	*	**	**	**	*	**	n.s.

The results are the mean of six replicates ± Standard Deviation. The lowercase letters represent the significant difference vertically at P < 0.05. The capital letters represent the significant difference horizontally at P < 0.05 between the three films and the fruits without film for each month of analysis

Table 6

Effect of storage period in the fridge at 1 °C on the soluble solid contents (SSC), titratable acidity (TA) and the moisture parameters in red raspberries (cv. Erika).

Day	Soluble Solid Content (°Brix)				Titratable Acidity (% citric acid)				Moisture (%)			
	WF	NA	NB	PET	WF	NA	NB	PET	WF	NA	NB	PET
1	10.50 ± 0.00^{abA}	10.05 ± 1.85^{bA}	9.30 ± 0.60^{aA}	9.25 ± 0.15^{aA}	2.15 ± 0.10^{abB}	1.80 ± 0.03^{aA}	1.82 ± 0.04^{aAB}	1.93 ± 0.04^{abC}	87.40 ± 0.56^{dA}	87.92 ± 0.27^{bA}	87.38 ± 0.24^{aA}	87.71 ± 0.05^{bcdA}
2	9.83 ± 1.15^{aA}	9.20 ± 0.08^{abA}	9.57 ± 0.09^{aA}	9.00 ± 0.73^{aA}	1.86 ± 0.22^{aAB}	1.71 ± 0.10^{aA}	2.04 ± 0.09^{bAB}	2.04 ± 0.15^{aAB}	86.16 ± 0.60^{cdA}	87.49 ± 0.07^{abB}	86.93 ± 0.84^{cdeAB}	87.43 ± 0.48^{abcB}
3	9.63 ± 0.46^{aA}	8.13 ± 1.44^{aA}	9.43 ± 0.33^{aA}	8.77 ± 1.42^{aA}	2.52 ± 0.22^{B}	1.92 ± 0.16^{abcdA}	2.04 ± 0.15^{bA}	2.12 ± 0.19^{abAB}	85.73 ± 0.41^{bcB}	87.44 ± 0.42^{abC}	84.71 ± 0.34^{aA}	87.19 ± 0.44^{abC}
4	9.57 ± 0.66^{aA}	9.23 ± 0.34^{abA}	10.13 ± 1.00^{aA}	9.37 ± 0.61^{aA}	2.05 ± 0.09^{abB}	1.85 ± 0.11^{abA}	2.05 ± 0.04^{bB}	2.36 ± 0.05^{bcC}	86.23 ± 0.29^{cdA}	87.12 ± 0.64^{abA}	86.39 ± 0.29^{bcdA}	86.95 ± 0.18^{aA}
5	10.53 ± 0.82^{abA}	9.77 ± 0.33^{abA}	9.03 ± 0.83^{aA}	9.30 ± 1.28^{aA}	2.16 ± 0.22^{abA}	1.99 ± 0.06^{bcdA}	2.13 ± 0.07^{bcA}	2.51 ± 0.12^{cdB}	85.37 ± 0.28^{abcA}	87.39 ± 0.64^{abB}	85.31 ± 0.59^{abA}	88.09 ± 0.22^{cdB}
6	10.27 ± 0.74^{abB}	7.93 ± 0.74^{aA}	9.50 ± 0.16^{aB}	9.67 ± 0.12^{aB}	1.99 ± 0.09^{abAB}	1.86 ± 0.07^{abcA}	2.30 ± 0.07^{cC}	2.13 ± 0.05^{abB}	84.93 ± 0.30^{abcA}	87.89 ± 0.53^{abB}	87.21 ± 0.59^{deB}	87.46 ± 0.45^{abcB}
7	11.50 ± 1.10^{abA}	8.43 ± 0.95^{abA}	8.23 ± 2.42^{aA}	8.90 ± 0.50^{aA}	2.32 ± 0.09^{bA}	2.09 ± 0.13^{cdeA}	2.09 ± 0.11^{bA}	2.36 ± 0.14^{bcA}	84.72 ± 0.67^{abcA}	87.85 ± 0.57^{abC}	86.04 ± 0.21^{bcB}	87.14 ± 0.60^{abBC}
8	12.07 ± 1.45^{bB}	8.83 ± 0.61^{abA}		8.70 ± 0.24^{aA}	1.99 ± 0.19^{abA}	2.43 ± 0.03^{gB}		2.15 ± 0.04^{abA}	85.17 ± 0.44^{abcA}	87.38 ± 0.59^{abB}		88.25 ± 0.24^{dB}
9	11.50 ± 0.43^{abB}	9.33 ± 0.98^{abA}		9.80 ± 0.54^{aA}	1.99 ± 0.07^{abA}	2.32 ± 0.07^{fgB}		2.72 ± 0.19^{dC}	84.49 ± 1.31^{abA}	86.77 ± 0.54^{aB}		87.98 ± 0.09^{cdB}
10	10.90 ± 0.37^{abB}	8.83 ± 0.39^{abA}		8.77 ± 0.41^{aA}	2.04 ± 0.12^{abA}	2.29 ± 0.02^{efgB}		1.96 ± 0.03^{aA}	83.88 ± 1.26^{aA}	87.25 ± 0.75^{abB}		87.69 ± 0.30^{abcdB}
11		9.07 ± 0.96^{ab}		8.13 ± 2.00^{a}		2.14 ± 0.14^{def}		2.06 ± 0.02^{a}		88.10 ± 0.26^{b}		87.60 ± 0.07^{abcd}
12		8.53 ± 0.50^{ab}		8.37 ± 0.09^{a}		2.22 ± 0.16^{efg}		2.53 ± 0.14^{cd}		87.67 ± 0.20^{ab}		87.67 ± 0.19^{abcd}
13		9.70 ± 0.36^{ab}				1.99 ± 0.08^{bcd}				87.14 ± 0.28^{ab}		
14		9.53 ± 0.66^{ab}				2.35 ± 0.10^{fg}				87.09 ± 0.30^{ab}		
Mean	10.63 ± 0.85^{C}	9.04 ± 0.63^{A}	9.31 ± 0.58^{AB}	9.00 ± 0.50^{A}	2.11 ± 0.19^{AB}	2.07 ± 0.23^{A}	2.07 ± 0.14^{A}	2.24 ± 0.25^{B}	85.41 ± 1.01^{A}	87.54 ± 0.41^{C}	86.28 ± 1.00^{B}	87.60 ± 0.39^{C}
Sig.	n.s.	n.s.	n.s.	n.s.	*	**	**	**	**	n.s.	**	*

Table 7

Effect of storage period in the freezer at −20 °C on the soluble solid contents (SSC), titratable acidity (TA) and the moisture parameters in red raspberries (cv. Erika).

Month	Soluble Solid Content (°Brix)				Titratable Acidity (% citric acid)				Moisture (%)			
	WF	NA	NB	PET	WF	NA	NB	PET	WF	NA	NB	PET
1	8.40 ± 0.50^{abA}	8.93 ± 0.87^{bcdA}	7.90 ± 0.50^{aA}	8.87 ± 0.58^{abA}	2.21 ± 0.17^{bA}	2.00 ± 0.07^{abcA}	2.01 ± 0.20^{aA}	1.97 ± 0.11^{abA}	85.62 ± 0.58^{abA}	85.96 ± 0.18^{aAB}	86.12 ± 0.32^{aAB}	86.62 ± 0.24^{aB}
2	7.93 ± 1.10^{aA}	9.30 ± 0.64^{dA}	7.57 ± 0.26^{aA}	9.27 ± 0.88^{bA}	2.09 ± 0.02^{abB}	1.77 ± 0.07^{aA}	2.02 ± 0.05^{aB}	2.05 ± 0.12^{abB}	86.85 ± 0.35^{cdA}	86.12 ± 0.24^{aA}	86.93 ± 0.38^{aA}	86.13 ± 0.62^{aA}
3	8.00 ± 0.37^{aA}	8.53 ± 0.09^{bcdAB}	8.27 ± 0.76^{abA}	9.60 ± 0.43^{abB}	2.16 ± 0.42^{bA}	2.15 ± 0.08^{bA}	1.93 ± 0.13^{aA}	1.78 ± 0.13^{aA}	86.34 ± 0.67^{bcA}	85.46 ± 0.85^{aA}	86.81 ± 0.34^{aA}	86.07 ± 0.35^{aA}
4	9.73 ± 0.05^{bcB}	9.20 ± 0.24^{cdAB}	8.63 ± 0.53^{abA}	9.87 ± 0.05^{bB}	2.49 ± 0.40^{B}	1.96 ± 0.04^{abcA}	2.04 ± 0.03^{aAB}	2.04 ± 0.17^{abAB}	86.79 ± 0.40^{cdA}	86.42 ± 0.53^{aA}	87.40 ± 0.23^{aA}	86.11 ± 0.11^{aA}
5	8.73 ± 0.42^{abcAB}	9.20 ± 0.36^{cdB}	8.07 ± 0.54^{abA}	9.20 ± 0.16^{bB}	2.02 ± 0.16^{abA}	1.90 ± 0.11^{abA}	1.94 ± 0.07^{aA}	2.01 ± 0.08^{abA}	87.23 ± 0.35^{cdB}	86.77 ± 0.23^{abAB}	86.64 ± 0.12^{aAB}	86.43 ± 0.33^{aA}
6	8.68 ± 0.94^{abcA}	8.30 ± 0.61^{bcdA}	9.28 ± 0.29^{abA}	8.50 ± 0.75^{aA}	2.02 ± 0.24^{abB}	1.88 ± 0.09^{abAB}	1.82 ± 0.10^{aAB}	1.80 ± 0.06^{aA}	87.28 ± 0.32^{abAB}	87.37 ± 0.24^{aB}	86.67 ± 0.30^{aA}	86.71 ± 0.08^{aAB}
7	8.67 ± 0.25^{abcA}	7.57 ± 0.26^{abA}	9.60 ± 0.86^{bA}	9.53 ± 1.46^{bA}	1.59 ± 0.15^{aA}	2.02 ± 0.12^{abcB}	1.86 ± 0.03^{aB}	1.97 ± 0.11^{abB}	87.56 ± 0.72^{dA}	87.56 ± 0.36^{abA}	87.65 ± 0.14^{aA}	87.05 ± 0.19^{aA}
8	9.87 ± 0.58^{cAB}	9.27 ± 0.58^{dAB}	8.93 ± 0.24^{abA}	10.17 ± 0.26^{bB}	2.00 ± 0.02^{abcAB}	2.19 ± 0.02^{bB}	1.87 ± 0.19^{aA}	1.87 ± 0.06^{abA}	85.01 ± 0.55^{aA}	85.35 ± 0.07^{aA}	85.66 ± 13.37^{aA}	85.26 ± 0.13^{aA}
9	9.60 ± 0.14^{bcA}	9.77 ± 1.02^{dA}	8.87 ± 1.16^{abA}	9.13 ± 0.37^{bA}	1.89 ± 0.21^{abA}	2.06 ± 0.07^{abcA}	2.03 ± 0.04^{aA}	1.93 ± 0.13^{abA}	87.73 ± 0.21^{dA}	87.99 ± 0.04^{abA}	87.93 ± 0.35^{aA}	90.58 ± 3.83^{bA}
10	9.63 ± 0.45^{bcA}	7.63 ± 1.23^{abcA}	7.73 ± 1.03^{aA}	9.57 ± 0.92^{abA}	2.39 ± 0.13^{bA}	2.25 ± 0.39^{aA}	2.00 ± 0.08^{aA}	2.09 ± 0.09^{bA}	86.36 ± 0.19^{bcA}	90.35 ± 5.10^{bA}	87.78 ± 0.67^{aA}	87.14 ± 0.23^{aA}
11	9.67 ± 0.71^{bcC}	6.47 ± 0.71^{aA}	8.27 ± 0.41^{abB}	10.10 ± 0.36^{abC}	2.01 ± 0.22^{abcA}	1.93 ± 0.01^{abcA}	1.99 ± 0.16^{aA}	2.07 ± 0.14^{bA}	86.88 ± 0.41^{cdA}	86.44 ± 0.18^{aA}	86.44 ± 0.58^{aA}	86.42 ± 0.15^{aA}
Mean	8.99 ± 0.73$_{B}$	8.56 ± 0.99$_{A}$	8.46 ± 0.65$_{A}$	9.44 ± 0.51$_{C}$	2.08 ± 0.24$_{B}$	2.01 ± 0.14$_{AB}$	1.96 ± 0.08$_{A}$	1.96 ± 0.11$_{A}$	86.70 ± 0.82$_{A}$	86.89 ± 1.42$_{A}$	86.00 ± 3.48$_{A}$	86.78 ± 1.37$_{A}$
Sig.	*	**	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	**	n.s.	n.s.	*

Table 8

Effect of storage period, from the fruits stored in the different films, on O2 and CO2 concentrations in red raspberries (cv. Erika), stored at 1 °C in the fridge

Day	O_2 (%)			CO_2 (%)		
	NA	NB	PET	NA	NB	PET
1	9.1 ± 0.9^{abA}	17.3 ± 2.0^{aB}	16.3 ± 1.6^{abB}	9.6 ± 0.6^{aB}	4.4 ± 2.0^{abA}	5.9 ± 1.7^{abcA}
2	7.7 ± 1.8^{abA}	17.7 ± 1.2^{aB}	16.8 ± 1.0^{abB}	11.7 ± 1.2^{abB}	4.8 ± 1.8^{abA}	5.3 ± 1.4^{abcA}
3	12.3 ± 4.4^{bA}	14.2 ± 6.9^{aA}	17.5 ± 1.2^{abA}	9.3 ± 3.8^{aA}	7.9 ± 5.9^{bA}	4.4 ± 1.7^{abA}
4	9.3 ± 8.5^{abA}	14.3 ± 4.3^{aA}	17.9 ± 0.6^{bA}	12.1 ± 7.5^{abA}	8.5 ± 4.5^{bA}	3.8 ± 0.8^{aA}
5	6.7 ± 8.8^{abA}	15.7 ± 3.1^{aA}	17.2 ± 1.1^{abA}	13.0 ± 7.1^{abA}	7.9 ± 4.4^{bA}	4.9 ± 1.6^{abA}
6	1.5 ± 0.8^{aA}	19.4 ± 0.3^{aC}	17.4 ± 1.1^{abB}	18.0 ± 2.9^{abB}	1.2 ± 1.0^{aA}	4.8 ± 1.6^{abA}
7	5.0 ± 3.9^{abA}	19.8 ± 0.3^{aB}	17.1 ± 1.6^{abB}	15.6 ± 2.7^{abB}	1.0 ± 0.6^{aA}	5.2 ± 2.4^{abcA}
8	9.8 ± 4.0^{abA}		16.8 ± 0.1^{aA}	12.7 ± 3.4^{abA}		5.6 ± 3.4^{abcA}
9	7.2 ± 2.3^{abA}		15.3 ± 9.8^{abA}	14.4 ± 12.2^{abA}		8.0 ± 1.2^{bcA}
10	2.0 ± 1.0^{aA}		15.9 ± 2.5^{abB}	20.8 ± 3.4^{bB}		7.5 ± 1.8^{bcA}
11	1.0 ± 1.2^{aA}		16.6 ± 0.5^{abB}	19.8 ± 3.6^{bB}		6.5 ± 1.6^{abcA}
12	2.4 ± 0.9^{aA}		16.7 ± 1.3^{abB}	19.8 ± 0.7^{bB}		6.4 ± 0.7^{abcA}
13	2.6 ± 0.3^{ab}			21.0 ± 7.1^{b}		
14	4.8 ± 0.28^{ab}			20.3 ± 0.91^{b}		
Mean	5.81 ± 3.58	17.31 ± 2.35	16.72 ± 0.76	15.58 ± 4.29	4.56 ± 3.32	5.91 ± 1.43
Sig.	n.s.	n.s.	n.s.	n.s.	*	n.s.

Table 9

Variance analyses on the different parameters, taking into consideration film effect, day or month effect and the interaction. ** (P< 0.01); * (P<0.05); n.s. (not significant).

Parameter	Refrigerated fruits			Frozen fruits		
	Film	Days	Film*Days	Film	Months	Film*Months
Length (cm)	**	**	**			
Diameter (cm)	**	**	**			
Weight (g)	**	*	**			
L*	n.s.	*	**	n.s.	n.s.	n.s.
a*	**	**	**	*	**	**
b*	**	**	**	n.s.	**	n.s.
SSC (°Brix)	**	n.s.	n.s.	*	n.s.	**
Titratable Acidity (% citric acid)	n.s.	n.s.	**	n.s.	n.s.	*
Moisture (%)	**	n.s.	**	n.s.	**	n.s.
O_2 (%)	**	n.s.	*			
CO_2 (%)	**	n.s.	*			