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Qualitative Performance and Consumer Acceptability of Starch Films for the Blueberry Modified Atmosphere Packaging Storage

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The sustainability of packaging is an important part of food system innovation and it can influence the purchase decision for the fresh produce. In this work, we evaluated the qualitative performance and the consumer acceptability of three starch films for the blueberry modified atmosphere packaging (MAP) storage under fluctuating temperatures. Fruits cv. Duke were monitored for up to 18 days (15 days at $1\pm1°C$ and 3 days at $20\pm1°C$). The respiration rate of the blueberries and the permeability of the films affect the initial atmospheric composition (0.2 kPa CO_2 and 21.2 kPa O_2) inside each package influencing the headspace gas composition and the quality parameters of the fruits. The F3 film has better controlled O_2 values inside the packages up until the end of storage (5.7 kPa) and it maintained the highest anthocyanin content (156.21 mg C_3G/100 g FW) and antioxidant capacity (22.18 Fe^{2+}/kg) of fruits at $20\pm1°C$.

INTRODUCTION

The blueberry is one of the most important soft fruits; it has become an increasingly popular crop that is available all year round in Italy whose total production in 2012 was approximately 1200 tonnes according to Faostat data [Faostat, 2012]. The nutraceutical properties of blueberries and their integrated and organic cropping systems influence their perceived status as wholesome and healthy fruits [Girgenti *et al*., 2013], and therefore the packaging should also contribute to this image. Half the blueberry production went towards exports, and the fresh packaged berries are the most important way to market these fruits. The fruit appearance, the flavor and the high nutritive value are keys to successfully gaining the consumer's acceptability [Díaz *et al*., 2011; Duarte *et al.,* 2009], and their maintenance during packing, storage and transport ensure that the berries display their maximum value and garner the highest market price at the time of sale [Bower, 2007]. Post-harvest loss in terms of value and consumer quality attributes can occur at any stage between harvest and consumption. The managing of the temperature with other technologies can manipulate the fresh produce respiration rate, together with the gas concentration, and/or film/package permeability (controlled atmosphere storage, modified atmosphere packaging, equilibrium modified atmosphere packaging, and vacuum packaging) having the greatest effects on the shelf life and marketability of the fruits [Paniagua *et al*., 2014]. The optimum conditions recommended for blueberry

storage are 0°C and 90% RH [Perkins-Veazie *et al*., 2004] and fruits, when held at or below 5°C, benefit from 10 to 15% CO_2 + 1 to 10% O_2 [Prange *et al*., 1995]. The recommended CO_2 values are 17–18% and an O_2 value $\leq$ 9% extend Coville blueberry shelf life. The optimum gas compositions were reported by Yam & Lee [1995] as 11–20% and 0–10%, respectively, for the CO_2 and the O_2. The blueberries cv. Duke changed in terms of flavor, firmness, and acid content if maintained at a CO_2 level greater than 12% [Alsmairat *et al*., 2011]. Packaging that adds extra benefits to a product can be an important preservation technique for retaining the post-harvest quality and extending the shelf life of blueberries [Junqueira-Gonçalves *et al*., 2013]. The types of packaging used for fresh horticultural produce handling include different materials such as wood crates, corrugated shipping boxes, polymeric film pouches, bags, baskets, crates, trays, paper sheets, and pouches to respond to specific needs [Bower, 2007]. The new packaging attributes are associated with a lower environmental impact and they must include a selection of more renewable materials enhancing the efficiency and energy consumption associated with sourcing, producing and converting packaging materials [Wikström *et al*., 2014]. They should also be a better alternative than a packaging system with a higher environmental impact and reduce food waste [Wikström *et al*., 2014]. The effect of bio-based packaging on the shelf life of blueberries and other types of fresh produce is reported in previous studies. Joo *et al.* [2011] comparing the shelf life of blackberries using closed packages made from oriented polylactic acid (OPLA) and petroleum based containers, showed how both packages were agree to the standards grade for the commercialization. PLA containers were used to in-

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crease the shelf life of blueberries at different storage temperatures [Almenar *et al.*, 2008] and the consumers generally were able to distinguish and positively evaluate the PLA packaging [Almenar *et al.*, 2010]. Cherry tomatoes and peaches were selected to develop and to optimize equilibrated modified atmosphere packaging (EMAP) using PLA films [Briassoulis *et al.*, 2013]. Among biopolymers, starch is one of the most studied for food packaging applications because of its availability, biodegradability and low cost, but its mechanical performance and hydrophilic characteristics represent a critical point for the use of this natural polymer. Researches on starch-based films have shown that such films could be suitable alternatives to conventional plastics for different food products [Peelman *et al.,* 2013; Peano *et al*., 2013; Briano *et al*., 2015]. The berries in growing conditions of Europe are manually harvested and they are directly picked into baskets with which they are transported from fields to a packing house; so the use of flexible films to wrap and to pack blueberries with or without modified atmosphere might be more advantageous than the use of other packaging such as clamshell in terms of product handling. Applications of biodegradable materials from starch corn to store highly perishable fruits such as blueberry under passive MAP are limited. This study aims to investigate the performance of films from starch corn applied for storage of blueberry fruits (cv. Duke) under fluctuating temperature such as in the supply chain and to manage passive modified atmosphere packaging (MAP), comparing the new films with that currently used at retail points. The most important qualitative traits and the nutraceutical components of stored berries will be considered with the most relevant criteria to consumers and preference to evaluate the acceptability of the new tested films.

MATERIALS AND METHODS

Sample preparation and storage conditions

Blueberry (*Vaccinium corymbosum* L.) samples cv. Duke were obtained from a commercial orchard of the Agrifrutta Soc. Coop. SRL (Piedmont, Italy). The fruits were hand-picked in PLA baskets at the end of July at commercial maturity. Samples were uniform in size and lacked any visual injuries or shrivelling. After the picking, the fruits were transported in less than an hour to the packing house (Peveragno, Cuneo, Italy) where the different packaging procedures were carried out (approximately 3 h after harvest). The films used for the packaging were: one commercial polypropylene macroperforated film (6-mm holes) (F1) that is actually used in Italian retail distribution (Trepack, Italy, 25 μm) and three non-commercial biodegradable and compostable films that were non-perforated (prototypes, Novamont, Italy) (F2 of 25 μm, F3 of 15 μm and F4 of 25 μm).

The starch film prototypes characterization has been largely studied in a previous work [Briano *et al.*, 2015]. In Table 1 the oxygen transmission rate (O_2TR) and the carbon dioxide transmission rate (CO_2TR) values are reported at 20±1°C and 1±1°C (temperatures of the storage trial). Each tray containing 0.125 kg of fruit (size 9.5 × 14 × 5 cm; consumer unit) was hermetically sealed with a Taurus 700 (Delphin, Italy) flow pack machine under ordinary atmospheric conditions (0.2 kPa CO_2 and 20.8 kPa O_2). The blueberries were stored at 1±1°C at 90–95% RH in a cold room for 15 days. After the cool storage, the fruits were removed and held in the laboratory for 3 additional days at 20±1°C to simulate the retail conditions.

Sampling procedures

Three randomly selected baskets/film (0.375 kg of blueberry fruits) were sampled for each time point and the F1 was used as the control. All physicochemical analyses, with the exception of the headspace gas composition, were performed for each sample at five time points as follows: at harvest (0); after 5, 10 and 15 days at a constant temperature of 1±1°C; at 24 h after the change in storage temperature at 16 days (20±1°C); and at the end of the storage period (18 days: 15 days at low temperature +3 days at high temperature). Sensory evaluations (consumer acceptance) were conducted after 15 and 18 days of storage.

Respiration rate

The rates of oxygen consumption (RO_2) and carbon dioxide production (RCO_2) for the blueberries were measured using a gas chromatograph (GC Varian 450, Italy) equipped with a capillary column (Molsieve 5A PLOT 30 μm × 30 m × 0.53 mm) and a TCD detector following the permeable system [Beaudry *et al.,* 1992]. The respiration rates in terms of O_2 and CO_2 at a given temperature were expressed as an average of three measurements (mmol kg^{-1}h^{-1}) according to the following equations : Eqs. (1)–(2), respectively:

$$RO_2 = \frac{\frac{PO_2 \times A}{l} \times (pO_2\ atm - pO_2\ pkg)}{M} \qquad (1)$$

$$RCO_2 = \frac{\frac{PCO_2 \times A}{l} \times (pCO_2\ pkg - pCO_2\ atm)}{M} \qquad (2)$$

where: P is the permeability coefficient (mmol cm cm^{-2} h^{-1} kPa^{-1}); A is the surface area (cm); l is the thickness of the film (cm); p_{atm} is the partial atmospheric pressure (kPa); p_{pkg} is the pressure inside the packaging (kPa), and M is the mass (kg).

Headspace gas composition

The headspace gas composition inside each package changed during storage because of the combined effect of the cv. Duke respiration, the films acted as a barrier to gases, and the temperature. Therefore, to measure the relative changes in the carbon dioxide and oxygen concentrations, we used a CO_2 and O_2 analyzer (CheckPoint II, PBI Dansensor, Italy). The changes in gas composition values were measured daily over the trial period and are expressed as v/v kPa. To avoid modifications in the headspace gas composition from gas sampling, the same air volume (with a free volume of 330 mL) was maintained in the packages during the trial period (because of a modification to the packages made by the supplier) because the analyzer introduced the same quantity of air that it removed for the analyses. To prevent gas leakage during the measurement, an adhesive single sep-

tum system (Septum white 15 mm diameter, Dansensor, Italy) was placed on the surface of the package. The results are expressed as an average of three replicates.

Qualitative fruits assessment

Weight loss

The weight (water) loss of each blueberry tray was measured by using an electronic balance (SE622, WVR, USA) with an accuracy of 0.01 g. The weight losses are reported as a percentage of the initial fruit weight of each package (Equation 3). The results are expressed as an average of three replicates.

$$\text{Weight loss (\%)} = \frac{W_O - W_t}{W_O} \tag{3}$$

where: W_o is the initial weight and W_t is the weight of the sample at time t.

Soluble solids content (SSC) and titratable acidity (TA)

A soluble solids content (SSC) analysis was conducted by using squeezed blueberries at 20°C. The SSC concentration was determined through the homogenization of fruits from each lot with an Atago Pal-1 pocket refractometer (Atago Co. Ltd., Japan), and it was expressed in units of °Brix at 20°C. The TA was measured by using an automatic titrator (Titritino 702, Metrohm, Swiss) and was determined potentiometrically by using 0.1 N NaOH to an end point of pH 8.1 in 5 mL of juice diluted in 50 mL of distilled water.

Total anthocyanin and phenolic contents and the antioxidant activity

To determine the main nutraceutical compounds a preliminary extraction of blueberries was performed. To this end, 25 mL of the extraction solution (500 mL of methanol, 23.8 mL of deionized water and 1.4 mL of 37% hydrochloric acid) were used for 10 g of blueberries of each sample. After 60 min in dark storage conditions at room temperature, a homogenized sample was obtained using the Ultra Turrax (T25, IKA WERKE, Staufen, Germany) at 3000 rpm for 15 min. Before the analysis the supernatant was stored at -20° C. The pH differential method of Cheng & Breen [1991] was the base for the evaluation of the total anthocyanin content. The method was based on the difference of absorbance of anthocyanins at 510 and 700 nm in a buffer solution at pH 1.0 and pH 4.5, respectively.

Data reported as milligrams of cyanidin-3-glucoside (C3G) equivalents per 100 g of fresh weight (FW) were calculated using the following equation:

$$A_{tot} = (A_{515} - A_{700}) \text{ pH } 1.0 - (A_{515} - A_{700}) \text{ pH } 4.5.$$

According with the method of Slinkard & Singleton [1977], the total pholyphenols content was evaluated with the Folin-Ciocalteu reagent with gallic acid as a standard. The absorbance was measured at 765 nm with a UV-Vis spectrophotometer 1600 (PC VWR International) and the data were reported as milligrams of gallic acid equivalents per 100 g of fresh weight (mg_{GAE}/100 FW).

The method of Pellegrini *et al*. [2003], with some modifications was used to analyze the antioxidant capacity of blueberries. The capacity of the reduction of the ferric 2,4,6-tripyridyl-s-triazine (TPTZ) to its ferrous form in the TPTZ-ferric chloride solution (FRAP reagent) was measured at 595 nm. The spectrophotometric results were expressed as mmol Fe^{2+} per 1 kg of fresh berries.

Sensory evaluations

A sensory evaluation was performed with fifteen trained panelists to assess the acceptability of blueberries packaged with the different starch corn films. Ten berries randomly selected for each sample were judged according with the main sensory descriptors (appearance, aroma, texture, flavor and overall acceptability). The 9-point hedonic scale (where 9= "like extremely," 8= "like very much", 7 = "like moderately", 6 = "like slightly" 5 = "neither like nor dislike", 4 = "dislike slightly", 3 = "dislike moderately," 2= "dislike very much" and 1 = "dislike extremely"), largely applied in the food and consumer research [Lim, 2011], was used to evaluate the fruits. The unacceptability of the fruits was under 3 score.

Statistical analysis

All statistics were performed using IBM-SPSS.22 for Windows [2015]. The data obtained were treated with two-way analysis of variance (ANOVA) and the means were separated using the Duncan test ($p \leq 0.05$).

RESULTS AND DISCUSSION

Respiration rate of blueberries and headspace gas composition of packages

The initial atmospheric gas composition (0.2 kPa CO_2 and 21.2 kPa O_2) changed in the packages with all the starch films, the exchange area through the film packages (550 cm²) was kept constant, so the evolution of the internal atmosphere inside the baskets was passively created by the respiration rate (RCO_2) of the cv. Duke berries (Figure 1) and the permeability of the films (Table 1) to O_2 and CO_2 [Beaudry *et al*., 1992], both of which were affected by the temperature. High respiration rates generally influence negatively the quality of the products promoting the consumption of organic acids. Among berries, blueberries generally show a low respiration rate. The catabolic activity is affected more by the storage temperature than the biodegradable films used and this implies that a severe temperature control is extremely necessary to store berries along the supply chain. In fact the RCO_2 values after 5 days of storage at 1 ± 1°C were of 0.45, 0.65 and 0.47 mmol kg⁻¹h⁻¹ respectively for the F2, F3 and F4 films and were similar to those reported by Harb & Streif [2004]. These values were maintained in a similar range for all the time the fruits were maintained under low temperature. With the change of the temperature the same packaged fruits increased their metabolism achieving at the end of storage time (18 days) respectively 2.75, 4.63 and 4.27 mmol kg⁻¹h⁻¹ of CO_2. The gas barrier of biodegradable films changes as the temperature increases [Beaudry *et al*., 1992]; at 20 ± 1°C the oxygen transmission rate (O_2) and the carbon dioxide transmission rate (CO_2) of all the biodegradable and compostable films (Table 1) increases more than 70% so, their barrier effects have been
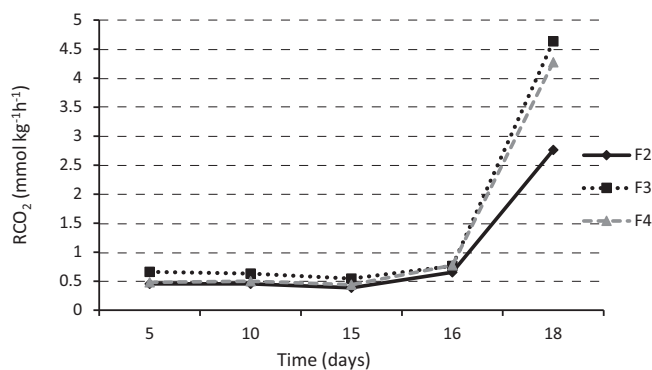
FIGURE 1. CO_2 respiration rate (RCO_2) of cv. Duke with the biodegradable and compostable films.

FIGURE 2. CO_2 headspace concentration (kPa) of cv. Duke fruits during storage.

TABLE 1. Values of the oxygen transmission rate (O_2TR) and carbon dioxide transmission rate (CO_2TR) of prototype films.

Film	Temperature (°C)	O_2TR (ASTMF2622–08) cm³/ m²/ d / bar)	CO_2TR (ASTMF2476–05) cm³/ m²/ d / bar)
F2	20	729	2544
	1	368	1435
F3	20	1197	4748
	1	437	1881
F4	20	865	3272
	1	377	1596

changed. The O_2 and CO_2 levels detected in the sample packages headspace during storage are reported in Figures 2 and 3, respectively. The atmosphere inside the packages with the F1 film did not change at any storage time because of the macro hole (6-mm-diameter). As expected, a decrease in the headspace O_2 and an increase in the headspace CO_2 over time was observed. Among all the biodegradable films, the F3 provides the lowest barrier effect and at $20\pm1°C$ the CO_2 concentration achieved the lowest values. At $20\pm1°C$, the CO_2 gas transmission rate was greater than those of O_2 and at the end of the storage period (18 days), 12.6 kPa, 17.2 kPa and 22.0 kPa CO_2 were achieved for the F3, F4 and F2 films, respectively, which corresponded to 13.3 kPa, 5.8 kPa and 2.8 kPa O_2. The detection of off-flavors attributed to fermentation in highbush blueberries that were kept respectively to high CO_2 and to low O_2 concentrations are well known [Krupa & Tomala, 2007]. Even if after 18 days the O_2 gas composition inside each package strongly decreased (especially for the F4 film), all the biodegradable and compostable films well controlled the oxygen transmission rate (O_2TR) permitting blueberries to receive enough O_2 to prevent fermentation inside packages.

Fruit quality assessment

Weight loss

Maintaining the net weights of berries upon delivery is a required condition for markets. As reported in the litera-
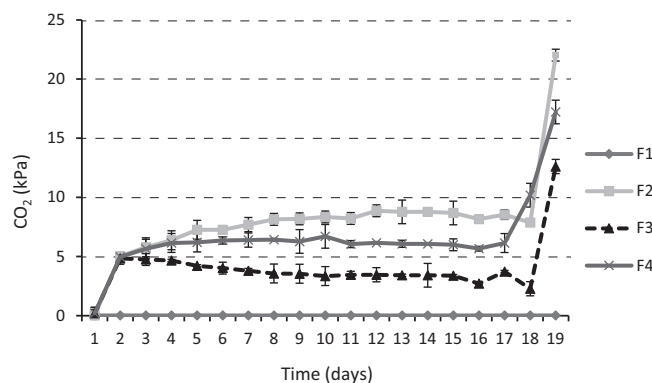
ture, weight losses of 5% lead to wilting and poor texture, and the taste is considered critical for blueberry marketability [Almenar *et al*., 2008]. Considering this criterion, from our findings (Table 2) all blueberries stored with the starch films (F2, F3 and F4) would be marketable for up to 18 days. At the low temperature ($1\pm1°C$), all films control weight loss well, likely because they were the only protection from mechanical damage in the case of the F1 film and they provided a protective atmosphere with the F2, F3 and F4 films. For each wrapping film, the effect of the high temperature ($20\pm1°C$) was more obvious in terms of blueberry weight loss than at $1\pm1°C$; the highest weight losses were observed for the control (5.30%). This trend is expected because as the temperature increases, the free energy of water molecules also increases and thus enhances the molecular movement, and the potential for exchange [Katul *et al*., 2012]. At the end of the storage time (18 days), the F3 film showed the lowest weight losses (2.48%). According to the literature [Bertuzzi *et al*., 2007], packaging films made from renewable resources (corn starch) such as those used in this study show a naturally high permeability to water vapor; in fact, water condensation did not develop inside the MAP samples and no fungal development was observed on the fruits (data not shown).

SSC and TA

Changes in the SSC and TA levels of Duke highbush blueberries during storage are summarized in Table 3. Kader [1999] proposed a value of 10 as a minimum SSC that is acceptable for blueberry flavor. In our study, the blueberries cv. Duke at harvest showed 11.1 °Brix and the SSC values stayed acceptable over the whole storage period. The SSC values obtained at $1\pm1°C$ and $20\pm1°C$ varied from 11.0–11.6°Brix to 9.8–11.5 °Brix, respectively. According to previous studies [Rosenfeld *et al*., 1999], the higher SSC values were found in all packages at the lower storage temperature. Blueberries packed in MAP were reported to have a constant SSC evolution during storage at $1\pm1°C$ and no statistically significant differences were observed up to 15 days of storage. The difference in the SSC between the different MAP packages was noticeable with the increased temperature. All films showed SSC declines thanks to the increase in the respiration rate of the blueberries although the CO_2 levels in MAP storage (F2, F3 and F4) can reduce the rate at which sugars
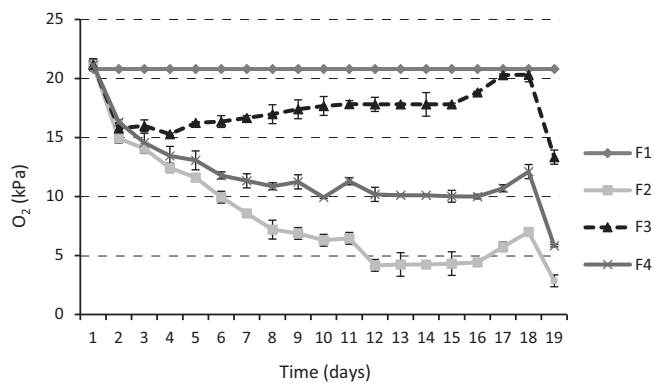
FIGURE 3. O_2 headspace concentration (kPa) of cv. Duke during storage.

are used when compared with the control treatment (F1). After 18 days of storage the F3 film showed the best performance to control the evolution of the SSC value (10.8 °Brix). The acidity of the fresh blueberries (0 days) was determined to be 9.24 meq/L. This value was at approximately the same level in fruits packed in MAP during 15 days of storage at a low temperature (1 ± 1°C) and no differences were observed among the different starch films. The TA of fruit used as a control (F1) instead had decreased already after 10 days of cold storage as a result of blueberry ripening, which continues by converting acid to sugar. As reported in previous studies [Almenar *et al.,* 2008], the TA values declined significantly with the change in temperature (16 days) but significantly higher TA values (7.27, 7.37 and 7.42 meq/L) were observed at the end of storage (18 days) with higher CO_2 (F2, F4 and F3, respectively).

Total anthocyanin and phenolic contents and antioxidant activity

The changes in nutraceutical compounds are shown in Table 4. Although the anthocyanin, phenolic contents and antioxidant activity of blueberry fruits have been previously reported, this is the first report on changes in cv. Duke after storage when using films for MAP made from starch corn. Blueberries are one of the richest sources of anthocyanins [Wu *et al*., 2006] and the absence of oxygen, a low pH and low processing/storage temperatures are external factors that favor the stability of anthocyanin pigments [Kalt *et al*., 1999]. According to previous studies [Prior *et al*., 2003], cv. Duke was confirmed as a valuable source of potentially healthy compounds; in fact, the total anthocyanin content at harvest was of 223.86 mg C_3G /100 g FW. Although many studies have been performed, the effects of the storage time and temperature on the behavior of the anthocyanin contents are not well known [Kalt *et al*., 1999; Routray & Orsat, 2011] and the CO_2-enriched atmospheric effects on their stability are also uncertain [Wang, 2007]. Our data show that for all films used, the degradation rate of anthocyanins increases as the temperature rises according to previous studies [Routray

TABLE 2. Effect of different packaging on weight loss of blueberry cv. Duke during the storage.

Films	Day 5*	Day 10	Day 15*	Day 16	Day 18
F1	1.07%±0.23	1.81%±0.22	2.52%±0.27	2.83%±0.30	5.30%±0.59
F2	1.05%±0.14	1.65%±0.19	2.30%±0.24	2.51%±0.20	4.20%±0.69
F3	0.46%±0.12	0.84%±0.10	1.21%±0.10	1.39%±0.11	2.38%±0.27
F4	0.84%±0.20	1.46%±0.27	2.01%±0.35	2.15%±0.29	3.79%±0.39

The data were expressed on means(%)±standard error. * 5,10, 15 days at 1 ± 1°C and 16,18 days at 20 ± 1°C.

TABLE 3. Evolution of soluble solid content (SSC) and titratable acidity of blueberry cv. Duke during the post-harvest.

Quality parameters	Films	Day 5*	Day 10	Day 15	Day 16	Day 18
			Harvest 11.1±0.1			
SSC (°Brix)	F1	11.4±0.10[bA]**	11.3±0.10[nsA]	11.0±0.15[bB]	10.9±0.10[bB]	9.80±0.06[cC]
	F2	11.5±0.10[abA]	11.4±0.10[nsAB]	11.3±0.10[aB]	11.0±0.10[bC]	10.5±0.06[bD]
	F3	11.5±0.10[abA]	11.4±0.10[nsAB]	11.2±0.12[aBC]	11.1±0.10[abC]	10.8±0.20[aD]
	F4	11.6±0.10[aA]	11.4±0.10[ns]	11.2±0.12[aA]	11.5±0.10[aA]	10.4±0.10[bB]
			Harvest 9.24±1.37			
TA (meq/L)	F1	9.35±0.5[nsA]	8.11±0.24[bB]	7.50±0.53[bBC]	6.74±0.83[bCD]	6.40±0.40[bD]
	F2	9.64±0.1[nsA]	9.69±0.37[aA]	9.48±0.24[aA]	7.77±0.32[abB]	7.27±0.08[aC]
	F3	9.38±0.3[nsA]	9.58±0.32[aA]	9.48±0.29[aA]	7.97±0.55[aB]	7.42±0.15[aB]
	F4	9.87±0.1[nsA]	9.48±0.35[aA]	9.51±0.38[aA]	7.29±0.17[abB]	7.37±0.30[aB]

* 5,10, 15 days at 1 ± 1°C and 16,18 days at 20 ± 1°C. **Values in the column followed by different lowercase letters and lines followed by different uppercase letters are significantly (p<0.05) different according to Duncan's test.

TABLE 4. Evolution of nutraceutical compounds of blueberry cv. Duke during the post-harvest.

Nutraceutical compounds	Films	Day 5*	Day 10	Day 15	Day 16	Day 18
			Harvest 223.86±18.28			
Total anthocyanins (mg_{C3G}/100 FW)	F1	266.71±32.71[ns**A***]	269.83±22.91[aA]	161.58±17.10[nsB]	146.26±14.69[nsB]	155.44±26.56[nsB]
	F2	210.19±22.70[nsA]	181.06±23.17[bcAB]	141.71±17.59[nsBC]	160.47±26.16[nsABC]	119.97±37.25[nsC]
	F3	255.41±86.44[nsA]	204.63±29.52[bAB]	181.00±28.16[nsAB]	123.59±37.48[nsB]	156.21±11.82[nsB]
	F4	213.03±39.64[nsA]	142.11±32.89[bB]	150.80±28.65[nsB]	120.49±28.01[nsB]	114.52±27.60[nsB]
			Harvest 491.54±19.01			
Total polyphenols (mg_{GAE}/100 FW)	F1	506.90±15.01[nsAB]	535.11±69.40[aA]	434.79±47.96[nsBC]	374.24±21.02[nsCD]	332.65±30.30[bD]
	F2	450.72±27.89[nsA]	425.01±31.22[bAB]	419.99±10.61[nsAB]	365.07±55.74[nsB]	422.80±59.62[aAB]
	F3	492.22±56.66[nsA]	483.16±18.46[abA]	387.23±25.06[nsB]	378.53±37.54[nsB]	368.19±52.92[aB]
	F4	495.56±44.46[nsA]	387.30±97.01[bB]	378.50±32.69[nsB]	365.40±24.96[nsB]	366.60±20.27[aB]
			Harvest 23.25±0.72			
Total Antioxidant Capacity (mmol Fe^{2+}/kg)	F1	22.37±0.27[nsNS]	21.36±1.60[bNS]	22.89±0.54[aNS]	22.81±1.63[aNS]	21.16±1.12[bNS]
	F2	22.80±0.50[nsA]	22.92±0.20[aA]	22.72±0.70[aA]	20.98±0.97[bB]	22.16±1.39[aAB]
	F3	23.65±1.50[nsNS]	22.22±1.00[aNS]	22.52±0.40[aNS]	22.20±0.60[aNS]	22.18±0.29[aNS]
	F4	23.60±0.82[nsA]	22.95±0.38[aAB]	21.79±0.37[bBC]	21.75±0.47[aBC]	21.51±1.22[aC]

*5,10, 15 days at 1±1°C and 16,18 days at 20±1°C. **ns=not significant. ***Values in the column followed by different lowercase letters and lines followed by different uppercase letters are significantly (p<0.05) different according to Duncan's test.

& Orsat, 2011]. All samples showed a decrease in the total anthocyanin content if compared with the values at harvest, as a consequence of decreases in the TA values and increases in weight loss during storage. After 15 days of storage at 1±1°C, anthocyanin decreases of 27.8%, 36.7%, 18.8% and 32.7% were observed for the F1, F2, F3 and F4 films, respectively, and at the end of the storage time (18 days), the fruits wrapped with the same films lost 30.5%, 46.3%, 30.5% and 48.9% of their initial anthocyanin values. Among all the starch films, the F3 maintained the highest anthocyanin content (181.00 and 156.21 mg C_3G /100 g FW, respectively) after 15 and 18 days with the highest O_2 kPa measured inside the packages [Kalt *et al.*, 1999] during the entire storage time.

The total phenolic content of the cv. Duke at harvest was 491.54 mg GAE/100 g FW, and it was within the range of values found in previous studies [Howard & Hager, 2007]. For all the packages, the change in the total phenolic content occurred more slowly at the lower temperature (1±1°C). Even when the berries were subjected to metabolic stress from the change in temperature (20±1°C), the F2, F3 and F4 films can help to maintain high nutritional values in fruits and no significant differences were found among the starch films (422.80, 368.19 and 366.60 mg GAE /100 g FW, respectively).

The total antioxidant capacity in blueberries cv. Duke was 23.25 Fe^{2+}/kg, which is correlated especially well with the anthocyanin and phenolic compound contents. These fruits may be considered as one of the highest antioxidant sources among fruits and vegetables [Vrhovsek *et al.*, 2012]. During the whole storage time, the antioxidant capacity of the blueberry fruits decreased in comparison with fresh

fruits according to previous studies [Remberg *et al.*, 2003] although they still maintained their value near harvest time. Among all the starch films, the F3 was the only one able to maintain a stable antioxidant capacity for the whole storage time ranging to 23.65 Fe^{2+}/kg (5 days) to 22.18 Fe^{2+}/kg (18 days).

Sensory evaluations

In general, sensory analysis is a good tool to evaluate the impact on consumer acceptability. Sensory evaluation was performed to see if CO_2 managed using the different films affected the blueberries quality. It is seen from Figure 4 that the effect of the temperature is more important than that of films used. All the mean scores of sensory attributes for the control (F1) and MAP samples (F2, F3 and F4) recorded a decrease in the shelf life storage (18 days) due the increase of the temperature. Differences in weight loss (Table 2) explained why the F3 film recorded the best consumer evaluations in term of appearance and texture while the highest balance between sugar and acid content influenced largely the flavor attribute. Generally blueberries wrapped with the F3 film showed the highest score both after 15 days (1±1°C) than after 18 days (20±1°C) of storage while the F1 film effects on the consumer acceptability were negative in terms of all descriptors used.

CONCLUSION

The data obtained in this study demonstrated the possible use of starch films for MAP in the post-harvest storage of blueberries. The use of these materials can increase
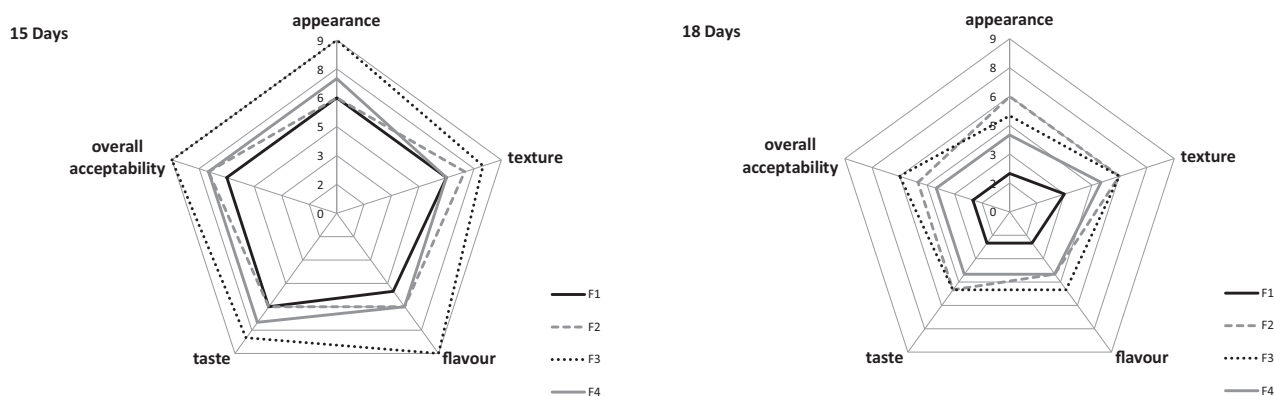
FIGURE 4. Radar chart for sensory evaluation of cv. Duke after 15 and 18 days of storage at $1\pm1°C$ and $20\pm1°C$.

the environmental sustainability of the food packaging sector. The knowledge of the behavior of the gas diffusivity of these new wrapping films at different temperature is very important to provide the evolution of gas inside the packages of fruits during the supply chain and the marketing especially when the storage temperature shifts and is outside of the cold range requested by berries. The MAP storage with the starch films helped to control changes in post-harvest physicochemical properties, such as the pH and TA. Generally, the F2, F3 and F4 films were also capable of maintaining the antioxidant and nutritional values of fruits after 15 days of storage when the berries were subject to metabolic stress from changes in temperature. The F3 film was more likely to maintain the most important qualitative and nutraceutical traits close to those at harvest because it showed more equilibrated film selectivity throughout the storage time. To improve and to validate the use of these films in the post-harvest supply chain of fruits, it could be interesting to test these materials on other fresh products with different physiology.

CONFLICT OF INTEREST

Authors declare no conflict of interest.

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