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Postharvest shelf life extension of blueberries using a biodegradable package

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Abstract

Small berries are commonly packaged and sold to consumers in vented petroleum-based clamshell containers. Biodegradable and compostable packages may be used as an alternative package to reduce waste generation and landfill disposal. In addition, the current clamshell container design does not allow the development of a modified atmosphere that could prolong berry shelf life. Thus, in this study, a non-ventilated biodegradable container was evaluated as a possible alternative to the containers normally used in commercial distribution of small berries. To determine the potential of biodegradable containers for small berries, highbush blueberries were packaged in polylactide (PLA) containers and stored at 10 °C for 18 days and at 23 °C for 9 days. Commercial vented clamshell containers were used as controls. Physicochemical and microbiological studies were carried out in order to compare the efficacy of both packages. Results showed that the PLA containers prolonged blueberry shelf life at different storage temperatures.

Keywords: Blueberries (*Vaccinium corymbosum* L., Elliott); Physicochemical parameters; Polylactide; Clamshell container

1. Introduction

Petroleum-based materials such as polyethylene terephthalate (PET) and polystyrene (PS) are commonly used in containers for fresh produce. For berries, PET and PS vented clamshell containers are widely used in retail and wholesale packaging. A comparison of both clamshell containers showed that PET containers have the highest values for global warming, ozone depletion, non renewable energy and so on (Madival, Auras, Singh, & Narayan, 2007). In 2003, approximately 500 million pounds of PET clamshell containers were produced and basically the same amount was deposited in landfills since the recycling rate is negligible. In an attempt to reduce this environmental impact, SmartCycle™, a PET derived from recycled bottles specifically for use in clamshell containers, was developed in 2006 (King & Green Blue, 2006). However, this product is in an early stage of development, and it is not made from 100% post-consumer recycled material.

Alternatively, polylactide (PLA) containers have properties for being used as substitute for commercial clamshell containers. PLA is biodegradable, recyclable, compostable, made 100% from renewable resources, approved by the Food and Drug Administration for contact with food, and have similar physical and mechanical properties to those of PET and oriented PS (Auras, Harte, & Selke, 2004; Auras, Singh, & Singh, 2005). In addition, its production consumes quantities of carbon dioxide and provides significant energy savings (Dorgan, Lehermeier, Palade, & Cicero, 2001) and containers made from PLA are economically competitive with the PET recycled clamshell containers. The effectiveness of PLA in prolonging fresh produce shelf life has been investigated in only a few studies. In all those, biodegradable containers have been shown to be as effective as the petroleum-based ones. Kantola and Helen (2001) evaluated the quality of tomatoes in different biodegradable packages, one of them being polylactide coated paperboard overlapped with a perforated Master-Bi® bag

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(based on starch). They found that tomato quality in biodegradable packages remained as good as the quality of tomatoes stored in low-density polyethylene (LDPE) bags for three weeks. Koide and Shi (2007) reported on the effects of PLA based biodegradable film packaging on the microbial and physicochemical quality of green peppers. No remarkable differences in colour, hardness, and ascorbic acid concentration were observed among PLA, LDPE and perforated LDPE after 1 week of storage at 10 °C. In addition, lower coliform bacteria counts were observed on the peppers in the biodegradable film packaging than in the LDPE film packaging. This may be because of the high water vapour transmission rate of PLA films compared to that of LDPE films. Rigid trays and packs manufactured from PLA resin are being used for apples, cherries and tomatoes.

In this study, blueberry fruit (*Vaccinium corymbosum*) was chosen as the produce to be packed in biodegradable and clamshell containers because of its constantly increasing production and economic importance. Blueberries are well known for their singular flavour and antioxidant properties. They contain a number of substances that are thought to have health benefits including fructose, fibre, vitamins and antioxidants (Ehlenfeldt, Meredith, & Ballington, 1994). In 2005, blueberry production totalled 466 million pounds in the US (Villata, 2006), as the leading producer in the world. These blueberries were shipped to domestic and export markets. Each year millions of non-degradable blueberry packages create a waste disposal problem to the detriment of the environment. In addition, the vented clamshells used nowadays to pack berries have large slots (openings) inherent in their design. Thus, they are incompatible with the technique of equilibrium modified atmosphere packaging (EMAP) which is an effective tool for prolonging fresh produce shelf life (Almenar, Hernández-Muñoz, Lagarón, Catalá, & Gavara, 2006a). EMAP creates an atmosphere inside the package by balancing between the product's respiration processes and the permeation of the gases involved in metabolic processes through the packaging material. This technology is known to reduce weight loss, retard softness, and maintain aroma of the fresh produce. The effectiveness of EMAP in prolonging berry shelf life has been widely shown (Almenar et al., 2007; Beaudry, 1993; Beaudry, Cameron, Shirazi, & Dostal-Lange, 1992). In general, berries have prolonged postharvest shelf life when exposed to levels of CO_2 above 15%. However, different results regarding the optimum concentrations of CO_2/O_2 to prolong blueberry shelf life have been reported. While several authors (Kim, Song, & Yam, 1995; Rosenfeld, Meberg, Haffner, & Sundell, 1999) claim between 15% and 18% CO_2 and $\leqslant$ 9% O_2 as the optimum amounts, Harb and Streif (2004) reported that 'Duke' blueberries react to increased CO_2 amounts (>12%) with loss of firmness and acidity content and a negative impact on flavour.

The purpose of this study was (1) to evaluate a biodegradable package that constitutes a suitable alternative to the petroleum-based clamshell containers for the fresh-pack market of small berries, and (2) to increase their shelf life in commercial distribution by using EMA generated in this non-vented biodegradable package. As a result, the marketing options for producers of blueberries, Saskatoon berries, cranberries, raspberries, blackberries and other berries will be increased and the polymeric waste in landfills could be reduced.

2. Materials and methods

2.1. Materials and fruit packaging

Highbush blueberries (*V. corymbosum* L., Elliott) provided by MBG (Michigan Blueberry Growers) Marketing (Gran Junction, MI) were transported to the School of Packaging in insulated ice coolers by car. Ice packs were placed in the bottom of the coolers and on top of the highest stacked clamshells containers containing blueberries. Fruits were selected based on their uniformity of size and colour. Rotten and damaged fruits were eliminated.

Approximately 100 g of blueberries were weighted using a common scale (Adventurer™ precision balance, OHAUS, NJ) and then placed inside non-vented PLA containers (Fig. 1a) (8 oz.) (VersaPack®, Wilkinson Industries Inc., Fort Calhoun, NE) which were snap-fitted. The same amount of fruit was placed inside commercial PET vented clamshell containers (1 pint) (Pactiv Corporation, Lake Forest, IL) (Fig. 1b) and then used as controls. After filling, the containers were divided into two groups. Some PLA and clamshell containers were stored at 10 °C and 66% RH in a conventional refrigerator (Roper, Whirlpool) for 18 days. The other group was kept at 23 °C using a temperature-controlled chamber (84% RH) for 9 days. Physicochemical and microbiological analyses were carried out on the blueberries every 3 days. At each sampling period, 4 packages (replications) of each type container and storage temperature were analyzed.

2.2. Physicochemical analyses

2.2.1. Headspace composition

The headspace composition of the PLA packages during storage was monitored using a 6600 headspace oxygen/car-

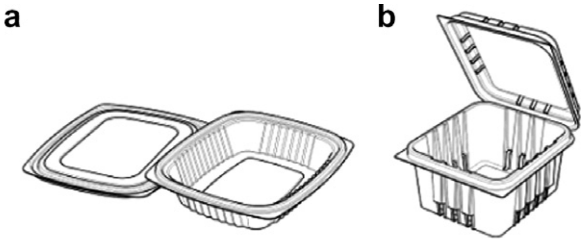

Fig. 1. Design of the containers used for packaging blueberries: (a) biodegradable non-vented container and (b) commercial petroleum-based vented clamshell container.

bon dioxide analyzer (Illinois Instruments, Johnsburg, IL). Just before being measured, packages were removed from storage and an adhesive septum (Illinois Instruments, Johnsburg, IL) was adhered to the lid surface. The headspace composition of the clamshells was measured and the result reported as air composition as expected.

2.2.2. Weight loss

The weight of each package of blueberries was measured on day 0 and on the sampling day using an Adventurer™ precision balance (OHAUS, Pine Brook, NJ). Values are reported as percent of weight loss per initial fruit weight.

2.2.3. Soluble solid content (SSC)

Approximately 50 g of blueberries were blended in a blender (Hamilton Beach, NC) for 30 s. Soluble solids in the juice were determined using a refractometer RHB-32ATC (Cole–Parmer Instruments, Vernon Hills, IL). The mixture was kept at approximately 0 °C to avoid enzyme degradation of the sample. Three measurements were taken on each sample and the results expressed as °Brix.

2.2.4. pH

The pH of the above mentioned blueberry mixture was measured using a PHB-212 pH meter (Omega Engineering Inc., Stamford, CT). Three measurements were taken on each sample and the results expressed as units of pH.

2.2.5. Titratable acidity (TA)

Four–five fruits (approximately 5 g) plus 50 ml of distilled water were blended using a commercial blender (Hamilton Beach, NC). The acidity, expressed as % of TA, was measured by titration with 0.1 N NaOH to an end point of pH 8.2 using a PHB-212 pH meter (Omega Engineering Inc., Stamford, CT) with a glass electrode according to Zheng, Wang, Wang, and Zheng (2003). Three measurements were taken of each sample.

2.2.6. Off-flavours and aroma

The main volatile compounds related to blueberry aroma plus a fermentative metabolite were monitored using a procedure optimized in a previous work (Almenar, Hernández-Muñoz, Lagarón, Catalá, & Gavara, 2006b). Levels of ethanol, hexanal, 2*E*-hexenal, 1-hexanol, 2-ethyl-1-hexanol, benzaldehyde, linalool and nonanal were recorded for blueberries packed in ventilated clamshells and in non-ventilated PLA containers stored for and 18 days at 10 °C. The compounds were identified by gas chromatography–mass spectrophotometry (GC–MS) and quantified by gas chromatography–flame ionization detection (GC–FID) using the procedure described below.

Amounts of 5 g of blueberry blend were placed in 20 mL vials, crimp-sealed, and frozen at −20 °C. For analysis, samples were thawed out at room temperature for 20 min and then heated at 75 °C for 20 min. The volatile compounds were extracted by solid phase micro-extraction (SPME) using a 65-μm DVB/CAR/PDMS SPME fibre (Supelco, PA). The fibre was exposed to the vial headspace for 20 min, and the trapped volatiles were desorbed (for 5 min) at the splitless injection port of a Hewlett–Packard 6890 series GC (Agilent Technology, Palo Alto, CA) equipped with a flame ionization detector (FID) and an HP-5 column (30 m × 0.32 mm × 0.25 μm, Hewlett–Packard, Palo Alto, CA). The oven temperature was set to 40 °C for 5 min and increased to 230 °C at 5 °C/min and then maintained for 10 min. The injector and detector temperatures were 220 and 230 °C, respectively. Compound identification was determined using a DSQ II™ GC–MS (Thermo Fisher Scientific, Barrington, IL) using the same column and chromatographic conditions as in FID–GC. Three vials were analyzed for each package. Calibration curves of the different volatile compounds were not plotted because this study was carried out to compare volatile levels between packages. Results are expressed in chromatographic area (c.a).

2.3. Microbiological analyses

Alternaria alternata development was visually estimated on each individual fruit immediately after opening the packages. Any blueberry with visible mould growth was considered to be decayed. The results were expressed as percentage of fruits infected by fungus.

2.4. Statistical analyses

One-way analysis of variance (ANOVA) was conducted to compare average values of the physicochemical and microbiological results using the Tukey test ($p \leqslant 0.05$) (MINITAB Statistical Software, Release 14 for Windows, State College, Pennsylvania (Minitab Inc. 2003)). Using this software, differences among packaging types and storage temperatures and their interactions could be determined.

3. Results and discussion

3.1. Headspace evolution

An equilibrium modified atmosphere was developed inside the PLA containers due to the respiratory activity of the enclosed blueberries and the permeability of the packaging material. Blueberries enclosed in the clamshell container did not reach this modified atmosphere because of its vents. Fig. 2 shows the evolution of CO_2 and O_2 inside the PLA containers for 9 and 18 days of storage at 23 and 10 °C, respectively. Steady-state conditions were reached after three days of storage time and then maintained at 10 °C. This behaviour was not observed at 23 °C probably because the storage time was not long enough. Oxygen levels in the PLA packages decreased as temperature increased, indicating that the respiratory activity of blueberries increased more rapidly than O_2 transmission rate through the container. Similar results were reported by Beaudry et al. (1992) for 'Bluecrop' blueberries packed in LDPE packages. Gas composition showed temperature

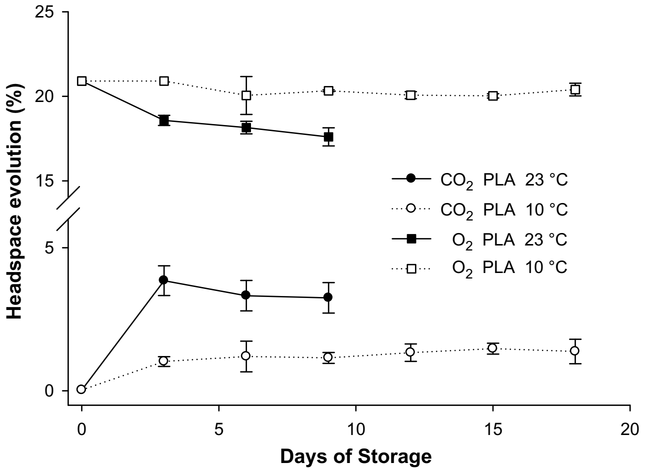

Fig. 2. Evolution of the headspace (% CO_2 and O_2) of the polylactide containers at 10 and 23 °C. Error bars indicate standard deviations of the means.

dependence. Rosenfeld et al. (1999) also reported the influence of storage temperature on chemical attributes of 'Bluecrop' blueberries as more important than others factors such as film type and the initial atmosphere modification. The temperature dependence for blueberries is not as strong as it is for other fruits. Equilibrium CO_2 levels inside the PLA containers increased from 1.4% to 3.25% when the temperature was increased from 10 to 23 °C. This small increase may be because of changes in blueberry respiration associated with ripening. The blueberry respiratory coefficient (RQ) was 1.33 at 10 °C. Although RQ is normally assumed to be equal to 1, RQ higher than 1 have been reported for blueberries because of their high citric acid and sugars content (Beaudry et al., 1992). CO_2/O_2 levels reached in the PLA containers were below/above those reported as effective for blueberry shelf life extension. However, they are closer than levels present in the air in the clamshell containers. According to Kim et al. (1995), CO_2 and O_2 levels for 'Coville' blueberries should be maintained at less than 17–18%, and 9%, respectively. CO_2 levels above 12% had an overall negative impact on flavour, firmness, and acid content of 'Duke' blueberries although higher levels were necessary to inhibit *Botrytis cinerea* (Harb & Streif, 2004).

Firmness is one of the quality parameters used to define freshness in horticultural crops. Firmness is related to gas composition. Decreased softness in fresh produce has been reported when exposed to high levels of CO_2. According to Harb and Streif (2004), 'Duke' blueberries stored in 6–12% CO_2 maintained their firmness at acceptable values. In the present study, 'Elliott' blueberries maintained their plumpness during 18 days storage (data not shown) even when exposed to levels of CO_2 less than 6% (Fig. 2). Blueberries packed in clamshells containers had became soft a few days after packaging (data not shown).

3.2. Weight loss

Important differences in weight loss were observed for blueberries in PLA and clamshell containers during storage at both temperatures (Fig. 3). Factors such as the vents in the clamshells and the water barrier properties of the PLA containers caused those differences. PLA and other biodegradable materials such as alginates have been reported to retard weight loss in produce (Koide & Shi, 2007; Tay & Perera, 2004). Fresh produce generally shows symptoms of freshness loss with 3–10% weight loss (Ben-Yehoshua, 1987). Ohta, Shiina, and Sasaki (2002) reported that a weight loss higher than 5% as a cause of reduction in retail value of vegetables and fruits. Taking this into account, blueberries that were packed in PLA containers and stored at 10 °C would still be marketable during 18 days storage (Fig. 3). Likewise, blueberries in commercial clamshells would be non marketable after 3 days of storage due to a weight loss of 5%. Miller, McDonald, and Cracker (1993) reported less than 1% weight loss in 'Sharblue' blueberries packaged in vented polystyrene cups after 3 weeks of storage at 1 °C. This may be due to a lower storage temperature. At room temperature, greater differences in blueberry weight loss were observed (4% vs. 48% for PLA and clamshell containers, respectively, after 9 days). Kim et al. (1995) reported a weight loss of 3.6% when 'Coville' blueberries were exposed to 2.9% CO_2 and 15 °C, which is close to the conditions in this study in PLA containers. Therefore, the effectiveness of PLA containers in retarding shriveling and loss of plumpness is dependent on temperature, the lower the temperature, the higher the effect of the PLA container.

3.3. SSC

Soluble solids are relatively high in blueberries (Bushway, Mc Gann, Cook, & Bushway, 1983). In this study, the SSC was 12.67 ± 0.12 °Brix, in agreement with previous values reported (Kim et al., 1995; Schotsmans, Molan, & MacKay, 2007). During storage, the SSC increased significantly in blueberries packed in clamshell containers (Table 1). SSC of 15.57 and 15.43 °Brix were reached after 18 and 9 days of storage at 10 and 23 °C, respectively. SSC increased because of the reduction in the water content in

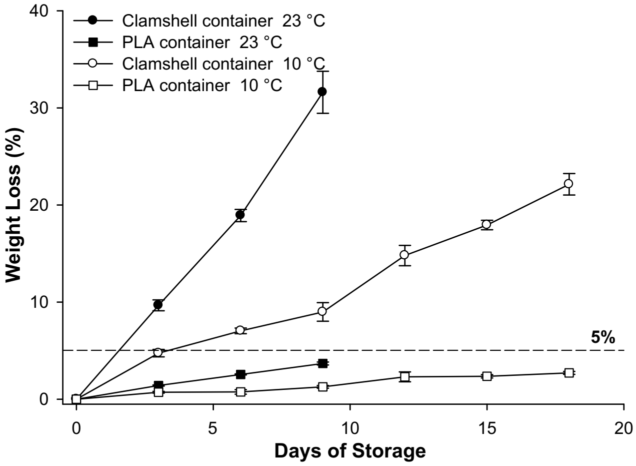

Fig. 3. Change in weight (%) of blueberries packaged in clamshells and polylactide containers and stored at 10 and 23 °C. Error bars indicate standard deviations of the means.

Table 1
Effect of the container (clamshell or polylactide) on the evolution of SSC (°Brix), pH and TA (%) of blueberries during 18 days of storage at 10 and 23 °C

Container	SSC (°Brix)		pH		TA (%)	
	10 °C	23 °C	10 °C	23 °C	10 °C	23 °C
Day 0						
C[a]	12.67 ± 0.10αa	12.67 ± 0.10Aa	3.15 ± 0.01αa	3.15 ± 0.01Aa	0.84 ± 0.00αa	0.84 ± 0.00Aa
P[b]	12.67 ± 0.10αa	12.67 ± 0.10Aa	3.15 ± 0.01αa	3.15 ± 0.01Aa	0.84 ± 0.00αa	0.84 ± 0.00Aa
Day 3						
C	13.20 ± 0.22αb	13.67 ± 0.00Ab	3.04 ± 0.02αb	3.19 ± 0.06Aa	1.06 ± 0.01αa	1.02 ± 0.00Ab
P	12.87 ± 0.16αab	12.30 ± 0.10Ba	3.13 ± 0.01βa	3.21 ± 0.02Aab	1.32 ± 0.00βb	0.92 ± 0.15Aa
Day 6						
C	13.77 ± 0.08αc	14.70 ± 0.08Ac	3.24 ± 0.01αc	3.30 ± 0.02Ab	0.93 ± 0.16αa	0.86 ± 0.05Aa
P	12.43 ± 0.23βac	11.97 ± 0.11Bb	3.13 ± 0.04βa	3.24 ± 0.02Bb	0.97 ± 0.18αab	0.76 ± 0.13Aab
Day 9						
C	13.97 ± 0.15αcd	15.43 ± 0.48Ad	3.07 ± 0.06αb	3.44 ± 0.02Ac	1.09 ± 0.19αa	0.98 ± 0.09Aab
P	12.33 ± 0.21βc	12.07 ± 0.13Bb	2.96 ± 0.02βb	3.40 ± 0.02Bc	0.70 ± 0.04αa	0.54 ± 0.09Bb
Day 12						
C	14.20 ± 0.02αd		3.06 ± 0.01αb		0.95 ± 0.06αa	
P	12.40 ± 0.13βc		3.07 ± 0.02βc		0.90 ± 0.03αa	
Day 15						
C	15.00 ± 0.25αe		3.21 ± 0.03αc		1.00 ± 0.00αa	
P	12.56 ± 0.16βac		3.17 ± 0.03βa		1.04 ± 0.06αab	
Day 18						
C	15.57 ± 0.08αf		3.20 ± 0.02αac		1.16 ± 0.10αa	
P	12.47 ± 0.10βac		3.11 ± 0.02βa		0.99 ± 0.20αab	

Different letters following the values indicate differences according to the Tukey test at $p \leqslant 0.05$: α and β indicate differences in SSC, pH or TA between containers stored at 10 °C; A and B indicate the same differences for storage at 23 °C; a, b, c, d, e and f indicate differences during storage period for each type of container and storage temperature.

[a] Clamshell container.

[b] Polylactide container.

the blueberries during storage (Fig. 3) and therefore the rise of SSC in the fruit. Because of the lack of slots in the PLA containers, this increase in SSC was not observed in the fruit packed in these containers. At 10 °C, the SSC was relatively constant during storage. However, SSC decreased by 5% when the containers were stored at 23 °C. This slight decline was because of the increase in the respiration rate of the fruit and therefore an enhanced consumption of soluble solids as respiration substrate. As mentioned earlier, the respiration rates of berries are directly related to storage temperature. Blueberries stored at 10 and 20 °C have respiration rates of 23–35 and 52–87 mg CO_2/kg h, respectively (http://usna.usda.gov/hb66/039blueberry.pdf). Mathooko (1996) suggested that enhancement of respiratory activity in fruits may result from an activation of enzymes at increasing temperature. Silva (1998) reported that low

CO_2 levels can reduce the rate at which sugars are utilized. Therefore, it can be speculated that a lesser amount of soluble solids was consumed because of the almost 4% CO_2 in the PLA containers (Fig. 2). Rosenfeld et al. (1999) also reported that the SSC is affected by temperature and headspace composition. The lower the temperature, the higher the SSC.

3.4. pH

Fresh blueberries had a pH value of 3.15 ± 0.06 (Table 1). This value was in agreement with the 3.20 ± 0.10 reported by Kim et al. (1995) for ‘Coville’ blueberries. pH was almost constant for 18 days of storage at 10 °C for both containers. At 23 °C, the pH of the blueberries increased significantly ($p \leqslant 0.05$) in both packages. An increase of almost 0.4 pH units was observed after 9 days of storage. However, Rosenfeld et al. (1999) reported the highest pH values at low temperature storage for ‘bluecrop’ blueberries. The package type did not affect the pH of blueberries as did temperature.

3.5. TA

Highbush blueberries are characterized by high citric and succinic acid contents, averaging 75% and 17%, respectively (Ehlenfeldt et al., 1994). Therefore, acidity results are expressed as a percentage of citric acid. Changes in TA levels of ‘Elliott’ highbush blueberries during storage are summarized in Table 1. The acidity of the fresh blueberries was determined to be $0.84 \pm 0.00\%$. This stayed at about the same level during 18 days of storage at 10 °C for both containers. No differences ($p \leqslant 0.05$) were observed through the end of storage. At 23 °C, blueberry acidity was affected by the container type. Acidity decreased ($p \leqslant 0.05$) in blueberries packed in PLA containers while it was constant in blueberries packed in clamshells. This is in agreement with Harb and Streif (2004) who reported an enhanced consumption of organic acids as respiration substrate because the respiratory rate of berries stored under increasing CO_2 values was significantly higher than that of air-stored fruits. Kim et al. (1995) reported higher TA with higher CO_2 levels for ‘Coville’ blueberries. Temperature also affected acidity for blueberries packed into PLA containers. Results showed decreased acidity with increased temperature storage. Rosenfeld et al. (1999) reported that TA in ‘Bluecrop’ blueberries increased with increased temperature storage for the same package.

3.6. Off-flavours and aroma

Blueberries are highly appreciated by consumers for their great taste and odour. This is the result of a complex multi-component relationship among many aromatic constituents. In order to identify these compounds in ‘Elliott’ blueberry fruit, its juice was analyzed using GC–MS. Ethanol, hexanal, 2*E*-hexenal, 1-hexanol, 2-ethyl-1-hexanol, benzaldehyde, linalool and nonanal were among those found. All in all, over 60 compounds were identified. This extensive of a profile has not been previously reported in the literature possibly because odour impact compounds depend on both specie and variety. For instance, 2*E*-hexenal, 2*E*-hexenol, linalool, geraniol, citrinellol, hydroxycitrinellol, farnesol and farnecyl acetate have been found in *Vaccinium myrtillus* L. (http://usna.usda.gov/hb66/023flavor.pdf). Nevertheless, Von Sydow and Anjou (1970) reported nonanal as the main flavour compound for this variety of berries. Hirvi and Honkanen (1983) identified benzyl alcohol as the majority volatile compound for different cultivars of blueberries. In addition, 1-hexanol, 3*Z*-hexen-1-ol, 2*E*-hexen-1-ol, 2-phenylethanol, linallol, α-terpineol, butanoic acid, hexanoic acid and phenol were also found. Fig. 4 compares the evolution of ethanol, hexanal, 2*E*-hexenal, 1-hexanol, 2-ethyl-1-hexanol, benzaldehyde, linalool and nonanal from blueberries packed into PLA containers against those from blueberries packed into clamshell containers for 18 days at 10 °C. Results at 23 °C are not reported because fungal growth developed and could have affected the blueberry aroma profile. Bacterial and fungal growth can affect fresh produce aroma as has been reported in the literature. As shown in Fig. 4, blueberry aroma profile was slightly affected by package type. Significant differences ($p \leqslant 0.05$) were observed for some volatiles. Overall, most of the volatiles increased during storage, the increase being larger for the blueberries packed in clamshell containers. Among them, linalool and nonanal, both related to lemon/orange odour, showed the most noticeable rise ($p \leqslant 0.05$). Berries from clamshell containers also showed higher hexanal and 2*E*-hexenal amounts for almost the entire storage period. These volatiles have been associated with the odour of cut-grass. Benzaldehyde and 2-ethyl-1-hexenol showed the same behaviour in storage for both containers. Regarding off-flavour development, ethanol increased slightly during storage. It was a little higher in blueberries packed in PLA containers (2.3 vs. 1.7 folds) which could be due to the increase in CO_2 levels in the packages (Fig. 2) since higher CO_2 levels have been related to higher ethanol levels (Almenar et al., 2006a). According to these results, different aroma profiles were developed for blueberries in PLA and clamshell containers and therefore, a sensorial evaluation is needed to compare the instrumental differences with consumer evaluation. Changes in grassy and fruity odours and/or a development of a rancid flavour (hexanal and nonanal coming from linoleic and linolenic) will be evaluated in the future.

3.7. Fungal decay

The postharvest shelf life of blueberries is also limited by fungal decay. According to Day, Skura, and Powrie (1990), the storage life of these fruits in the transport chain is restricted primarily by fungal spoilage. Fungi such as *Colletotrichum acutatum*, *A. alternata* and *B. cinerea* are the main culprits (Smith, Magee, & Gupton, 1996). In this study, berry decay was only caused by *A. alternata* and this was mainly located at the stem scar. Table 2 shows the incidence of decay (%) of blueberries packaged in the different containers (PLA and clamshell) and stored at 10 and 23 °C. Package type affected decay incidence after 15 days of storage at 10 °C. No differences ($p \leqslant 0.05$) were observed at 23 °C during storage. Berries packaged into clamshell containers showed lower fungal development than those into PLA containers (5% vs. 11%). This may be because the blueberries in the clamshell containers had loss more moisture which decreased fungal development after 12 days of storage. In addition, it is well known that high internal relative humidity atmospheres increase microbial growth and this was the case in the PLA containers. Temperature control was more effective than package type in decreasing fungal decay during storage (Table 2). Postharvest shelf life of blueberries packaged in either container and stored at 23 °C was not longer

Table 2

Effect of the container (clamshell or polylactide) type on the percentage of blueberries infected by *Alternaria alternata* after 9 and 18 days of storage at 23 and 10 °C, respectively

Day	% Infected blueberries			
	Clamshell		PLA	
	10 °C	23 °C	10 °C	23 °C
0	0.00 ± 0.00a	0.00 ± 0.00A	0.00 ± 0.00a	0.00 ± 0.00A
3	0.00 ± 0.00a	0.00 ± 0.00A	0.00 ± 0.00a	0.00 ± 0.00A
6	0.00 ± 0.00a	7.16 ± 2.99B	0.00 ± 0.00a	12.43 ± 2.13B
9	0.00 ± 0.00a	11.96 ± 5.49B	0.00 ± 0.00a	21.47 ± 1.86B
12	2.93 ± 1.86a		4.07 ± 1.73a	
15	3.94 ± 1.57a		7.96 ± 0.60b	
18	4.78 ± 1.43a		11.03 ± 1.80b	

Different letters following the values indicate differences in fungal growth at a determinate temperature according to the Tukey test at $p \leqslant 0.05$.

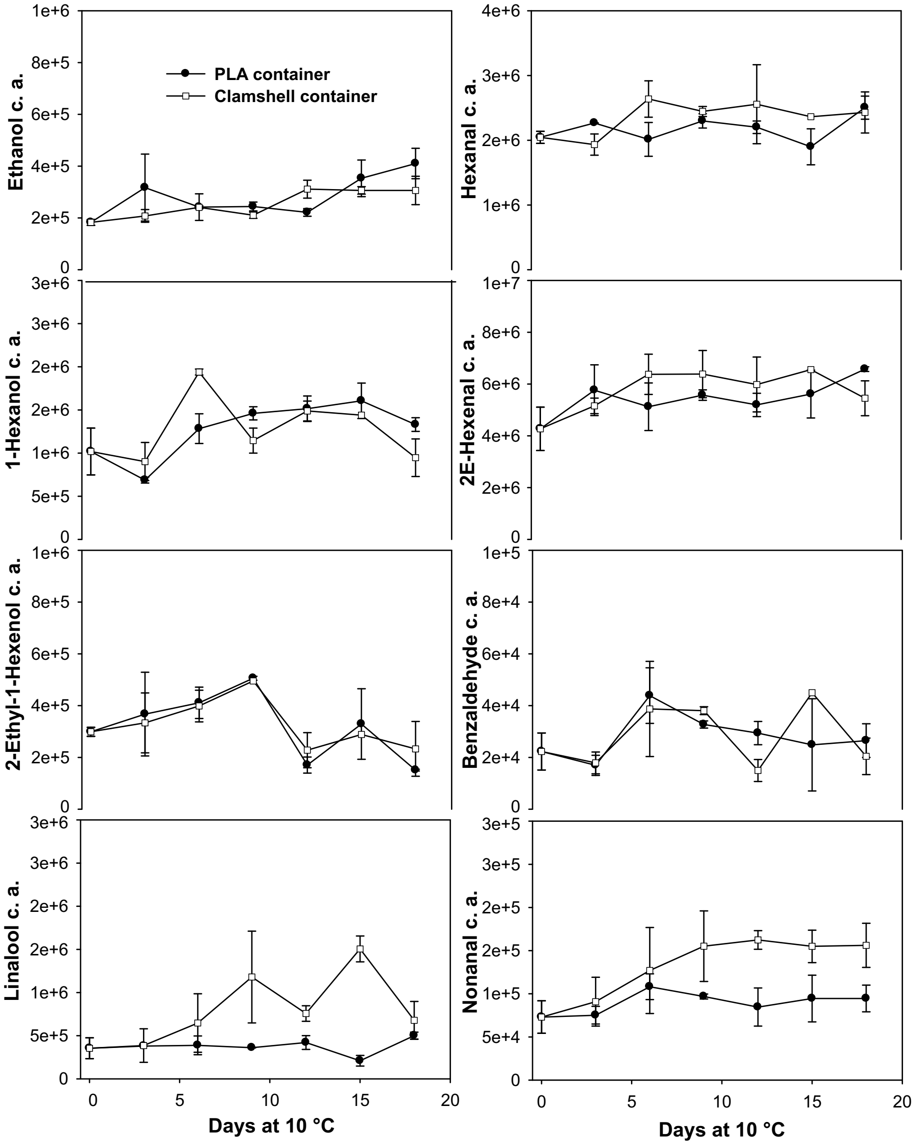

Fig. 4. Effect of the container (clamshell or polylactide) type on the blueberry aroma profile during storage at 10 or 23 °C. Error bars indicate standard deviations of the means.

than 9 days because of the presence of *A. alternata*. These berries were free of fungus for less than 6 days. An additional week of fungal free blueberries was at 10 °C.

CO_2 is an antifungal compound. Its effect is dependent on concentration, exposure time and application time following fruit harvest. According to our results, the CO_2 generated inside the PLA packages was not enough to prevent *A. alternata* growth at 10 °C. These results were expected since Harb and Streif (2004) reported that amounts higher than 6% CO_2 were needed to retard *B. cinerea* growth in blueberries stored near 0 °C.

In summary, PLA containers were shown to be viable packages for use in the commercial postharvest packaging of small berries because of their capability to enhance fruit shelf life as well as to reduce packaging waste. A sensory evaluation is needed to confirm flavour differences.

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