The effect of modified atmosphere storage on the postharvest quality of the raspberry 'Polka'

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Abstract. The aim of the experiment was to determine the effect of a passive modified atmosphere package (MAP) (30 µm LDPE bag (Estiko, Estonia), the Xtend® raspberry bag (Stepac, Israel) and an active MAP (30 µm LDPE bag, flushed with a gas mixture containing 10% O_2 and 15% CO_2) on the postharvest quality of the raspberry 'Polka'. Raspberries stored in macroperforated punnets (normal atmosphere – NA) served as the control. The raspberries were initially stored for 3 days at 1.6°C, then a half of the bags were moved into simulated retail conditions (6ºC) and a half remained at 1.6°C for another 24 hours.
The raspberry weight, O_2 and CO_2 content of the packages were measured daily. The fruit dry matter (DM) and soluble solids content (SSC), titratable acidity (TA), ascorbic acid content (AAC), and total anthocyanins (ACY) were determined at harvest and the total antioxidant activity (TAA) and rotting (weight of rotten berries) were determined after storage. Neither the active nor passive MAP suppressed rotting significantly. The raspberries stored at 1.6°C, had the best quality in passively modified LDPE bags, since the fruit had higher SSC and TA and lower ACY content compared to the control. After the simulated retail conditions, the Xtend® bags turned out to be the most suitable, since the fruit had the lowest ACY content (the fruit did not become too dark), but the highest TAA.

Key words: *Rubus idaeus*, soluble solids, titratable acids, ascorbic acid, anthocyanins, total antioxidant activity.

INTRODUCTION

Growing primocane raspberry cultivars is a good opportunity for berry growers in Estonia and other Nordic countries to prolong the fresh raspberry season. Also, pesticide need is reduced in primocane raspberries, since the oviposition period of the dominant pest, the raspberry beetle (*Byturus tomentosus* De Geer), does not coincide with the flowering period of the primocane cultivars (Vetek & Penzes, 2008). Also, frost damage during the winter does not affect the yield of primocane raspberries as much as it does summer fruiting raspberry cultivars.

The main risk in Estonia for cultivating primocane raspberry is the cold climate, since early autumn frosts and low temperatures in September may hinder raspberry ripening. The Polish primocane raspberry 'Polka' has been introduced as a self-supporting, semi vigorous, early autumn bearing, and high yielding cultivar (Danek, 2002). The first commercial plantations with the raspberry ‘Polka’ have been established in Estonia. Besides the local market, Finland is the main destination for Estonian berries and the producers are looking for cultivars, which would stand long distance transportation. Danek (2002) has stated that the fresh fruit of ‘Polka’ are firm and cohesive with tight skin. This statement makes it possible to hypothesize that this cultivar could have good storage potential. However, to our knowledge, postharvest experiment results with ‘Polka’ raspberries have not been published yet.

The aim of the current research was to determine the effect of normal and modified atmosphere storage on the postharvest quality of the raspberry ’Polka’, considering both the external quality and the nutritional value of the fruit.

MATERIALS AND METHODS

The ‘Polka’ raspberries were grown in a commercial plantation in South Estonia (NL 58º15’33’’; EL 26º35’33’’), where brown pseudopodzolic soils dominate. The plantation was 3 years old and was established using black polyethylene mulch and drip irrigation. The plant to plant spacing was 0.5 m and the distance between the rows was 3 m. Weather conditions in 2008 were not favourable for raspberries, since the summer was very rainy. The fruit development and ripening period in August was extremely wet, since 216 mm rained, which was almost three times more than the average (79 mm).

The raspberries were harvested at commercial maturity on September 14. The fruit with uniform size and colour and free from defects were picked directly into 250g macroperforated plastic punnets, transported to the university, cooled down to 1.6°C and packed as follows:

1) 250g macroperforated plastic punnets covered with a lid (control);
2) Xtend® raspberry bag (Stepac, Israel);
3) passive modified 30 μm low density polyethylene (LDPE) bag (Estiko, Estonia);
4) actively modified 30 μm LDPE bag, flushed with a gas mixture containing 10% O_2 and 15% CO_2).

One treatment consisted of six replicate bags (four punnets in one bag). The raspberries were stored for 4 days: on the 3rd day, a half of the bags were moved into simulated retail conditions (6ºC) and a half remained at 1.6°C. The storage room relative humidity ranged from 96 to 98%.

The raspberries were weighed and the O_2 and CO_2 contents measured from the packages every day with a hand-held gas analyser OXYBABY V (WITT-Gasetechnik GmbH & Co KG, Germany). The fruit dry matter (DM) and soluble solids content (SSC), titratable acidity (TA), ascorbic acid content (AAC), and total anthocyanins (ACY) were determined at harvest and at the end of storage. Total antioxidant activity (TAA) and rotting (weight of berries with rots) were determined after storage. A fruit was considered rotten if even one of the drupelets was infected.

For determination of the AAC, ACY and TAA, ten randomly chosen fruit from each treatment were weighed into a titration vessel separately for each analysis and extraction solution was added immediately to avoid breakdown of the easily oxidised compounds in the air. For the AAC determination, the fruit were crushed quickly with a homogenizator and titrated with dichlorophenolindophenol; also, voltamperometric indication was used (method M569/570 (www.mt.com)). TA was determined by titration to pH 8.2 with 0.1 NaOH. The Titrator Mettler Toledo DL50 with the autosampler Rondolino was used for titration of the AAC and TA. The SSC (%) was measured using the digital refractometer PAL-1 (ATAGO CO., Ltd., Japan). The content of total anthocyanins was estimated by a pH differential method (Cheng & Breen, 1991). Total anthocyanins were calculated as cyanidin-3-glycoside, one of the major anthocyanins in raspberries (Boyles & Wrolstad, 1993). The TAA was determined using the 1.1-diphenyl-2-picrylhydrazyl (DPPH) discoloration assay described by Brand-Williams et al. (1995) with some modifications. The results of the TAA are reported as Trolox equivalents (TE) per 100 gram of fresh fruit weight.

Significant differences between treatments and the effect of retail and cool-store temperature were tested by a two-way analysis of variance. In figures and tables, the mean values followed by the same letter are not significantly different at $P \leq 0.05$.

RESULTS AND DISCUSSION

Gas composition in the MA packages

The O_2 content in both passively modified packages decreased rapidly during the first 24 hours, reaching 15.7% in the Xtend® film and 14.9% in the LDPE film (Fig. 1A). During the next two days, the decrease was very little and the final content of O2 in the Xtend® film was 15.1% and in the LDPE film 13.1%. In the actively modified LDPE package, the O_2 content increased slightly, being 12.4% after 24 hours and 11.9% at the end of cool storage.

The CO_2 content in the passively modified packages increased to 5.1% in the LDPE film and to 6.1% in the Xtend® film during the first 24 hours (Fig. 1B). The final CO_2 content in the LDPE film was 5.9% and in the Xtend® film 7.3%. In the actively modified LDPE package, the CO_2 content decreased rapidly, being 8.7% after 24 hours. At the end of cool storage, the CO_2 content in the active MAP was 5.9%, which was exactly the same as in the passive LDPE package.

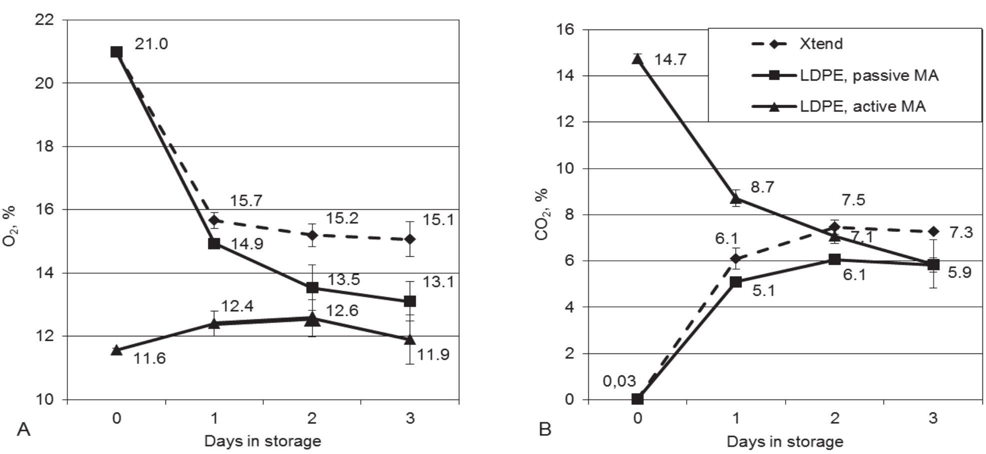

Figure 1. Changes in the O2 (A) and CO_2 (B) concentrations (% ± SD) in different modified atmosphere packages of 'Polka' raspberries stored at +1.6 °C for 3 days.

Fruit spoilage

The losses caused by rots were extensive in the present study, ranging from 9 to 23% (Table 1). The reason was obviously the extremely rainy weather during the fruit ripening period. The effect of the MA conditions on rotting in our trial was not significant. The mean effect of storage treatment showed that the Xtend® film decreased rotting compared to both LDPE films, but not compared to the control. Several authors have reported that high CO_2 concentrations (10, 20 and 30%) suppress rotting of raspberries (Agar & Streif, 1996; Haffner et al., 2002). In our trial, the CO_2 concentration in the passive MAP ranged from 5 to 7% and in the active MAP the CO_2 concentration also decreased below 10% after 24 hours. The mentioned CO_2 concentrations were probably too low to suppress rotting.

Table 1. The effect of different MA packages on fruit rotting, the SSC and TA of the raspberry 'Polka' after 4 days of storage in coolstore (+1.6 °C) and after 3 days in coolstore +24 hours in simulated retail conditions (+6ºC)

	Control	Xtend®	Passively modified LDPE	Actively modified LDPE	Mean
			Rotting weight, %		
Coolstore	16a	9a	16a	16a	14B
Retail	16a	13a	23a	22a	18A
Mean	*16AB*	*11B*	*20A*	*20A*	
			Soluble solids,%		
Coolstore	8.6b	9.3ab	9.7a	9.4ab	9.3A
Retail	9.2a	8.2b	8.7ab	9.1ab	8.8B
Mean	*8.9A*	*8.7A*	*9.2A*	*9.2A*	
			Titratable acids, %		
Coolstore	1.54b	1.66a	1.68a	1.53b	1.60A
Retail	1.50b	1.57a	1.48b	1.50b	1.51B
Mean	*1.52B*	*1.61A*	*1.58A*	*1.51B*	

Weight loss, dry matter and taste-related parameters

The average fruit DM content at harvest was 13.7 ± 0.4%. By the end of storage, it ranged from 12.7 to 13.3%. The effect of storage treatment on the DM content was not significant.

The weight loss of the control treatment ranged from 1 to 2% and in the MA packages from 0.1 to 0.2%. Thus, weight loss was not a limiting factor for berry quality during the experiment, since the loss according to Kenny (1975) needs to be at least 8% to cause a quality reduction. Haffner et al. (2002) also found in a trial with 5 raspberry cultivars that postharvest treatments did not affect fruit weight loss and dry matter content.

The initial SSC of the raspberries was 10.8 ± 0.4%, which is in agreement with the previously reported values for 'Polka' of 10.7–11.3% (Grajkowski & Ochmian, 2007). After storage, the SSC of the raspberries ranged from 8.6 to 9.7% (Table 1). In cool storage, the raspberries from the passive LDPE had retained the highest value of soluble solids. In retail conditions, the SSC was the highest in control fruit and the lowest in the Xtend® package. The average effect of storage temperature showed that 24 hours in retail conditions had decreased the SSC significantly.

At harvest, the raspberry TA was 1.84 ± 0.03% and after storage it ranged from 1.48 to 1.68% (Table 1). Grajkowski & Ochmian (2007) have reported the raspberry 'Polka' mean TA to be 1.75%, which is similar to our findings. After storage in cool conditions, the fruit TA was significantly higher in the passively modified LDPE and the Xtend® packages. In retail conditions, the TA content was higher in the Xtend® film. 24 hours in retail conditions had decreased the TA significantly.

Relatively high sugars and acids are required for good flavour of the fruit. The passively modified LDPE film maintained the highest SSC and TA in cool conditions, but not in retail conditions.

Bioactive compounds and total antioxidant activity

The AAC of the raspberry fruit before storage averaged 36 ± 3 mg 100 g FW^{-1}. Haffner et al. (2002) have studied the L-ascorbic acid content of 5 raspberry cultivars in Norway and the mean for all cultivars at the time of harvest was 23.2 mg in 100 g of berries. These results confirm that 'Polka' is a valuable cultivar with high ascorbic acid content. After 4 days of cool storage, the raspberry AAC had decreased and ranged from 22 to 27 mg 100 g FW^{-1} (Fig. 2). The AAC in the Xtend® film was lower compared to the LDPE films and the control after cool storage. As an average of the experiment, 24 hours in retail conditions did not cause a significant decrease in the AAC and no significant differences in the AAC between packages were found in retail conditions.

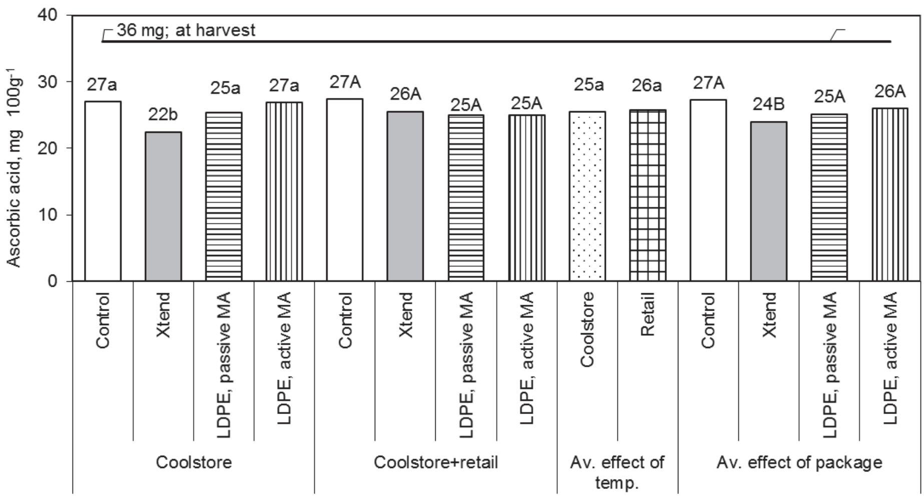

Figure 2. The effect of different MA packages on the ascorbic acid content of the raspberry 'Polka' after 4 days of storage in coolstore (+1.6°C) and after 3 days in coolstore +24 hours in simulated retail conditions (+6ºC).

The initial ACY content in the raspberries was 40 ± 3 mg 100 g FW^{-1}. Haffner et al. (2002) have found that the mean ACY level of 5 raspberry cultivars in Norway was 40 mg 100 g^{-1} fresh weight. After 4 days of cool storage, the fruit ACY content ranged from 34 to 43 mg 100 g FW^{-1} (Fig. 3). After cool storage, the raspberries held in the actively and passively modified LDPE packages had significantly lower ACY contents compared to the control. Thus, in the MA packages, the ACY synthesis was slowed down. Haffner et al. (2002) also found that compared to the raspberries stored in normal atmosphere, the ACY content of the raspberries from controlled atmosphere conditions was significantly lower. Among other phenolic compounds, anthocyanins are derived from the phenylpropanoid pathway, which is activated by the enzyme phenylalanine ammonia-lyase (PAL). It has been demonstrated with table grapes (Romero et al., 2008) that CO_2-treated fruit have lower PAL activity and consequently also lower ACY content.

In retail conditions, the ACY content in both LDPE films had increased to the similar level with the control and the fruit from the Xtend® film had the lowest ACY content. The average effect of the last diurnal temperature was significant: as expected, warmer temperature increased the ACY content, which was not a favourable result in the particular cultivar. Darkening of the attractive red colour is considered to be one of the characteristics of quality loss in raspberries (Haffner et al., 2002). The fruit of the raspberry 'Polka' are of dark colour compared to some other cultivars. According to the experience of the growers, when selling 'Glen Ample' and 'Polka' fruit side by side, consumers prefer 'Glen Ample', which is of lighter colour. The dark colour of 'Polka' fruit is associated with overripeness. There are very few published studies identifying the sensory properties important to the consumer acceptance of raspberries. Villamor et al. (2013) have found that high colour intensity and green aroma were associated with negative drivers of liking of fresh raspberries.

Haffner et al. (2002) have stated that cultivars with a lighter red colour with less blue will keep a better colour after harvest compared to darker and more bluish cultivars.

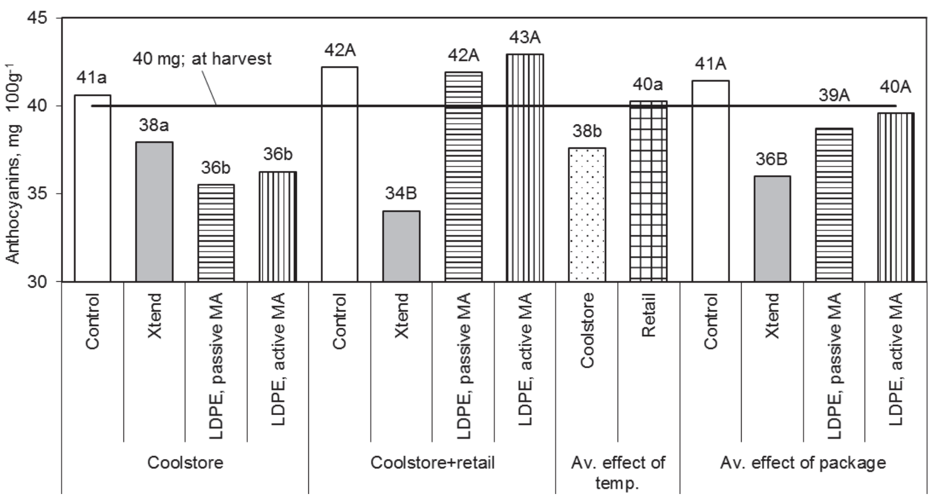

Figure 3. The effect of different MA packages on the anthocyanin content of the raspberry 'Polka' after 4 days of storage in coolstore (+1.6°C) and after 3 days in coolstore +24 hours in simulated retail conditions (+6ºC).

The TAA of the raspberries ranged from 95 to 154 TE mg 100 g FW^{-1} (Fig. 4). In cool conditions, the raspberries from the passively modified LDPE had the highest TAA, followed by the actively modified LDPE bag, the Xtend® bag and finally the control, where the raspberry TAA was 32% lower than in the first mentioned treatment. In retail conditions, the situation had changed and the highest TAA was determined in the raspberries stored in the Xtend® package. Both LDPE bags had decreased raspberry TAA. The average effect of storage temperature was significant: 24 hours in retail conditions had significantly decreased the TAA. It has been reported that cyanidin-based anthocyanins with a *o*- dihydroxy moiety have the greatest antioxidant activity among anthocyanins (Rice-Evans et al., 1996). Therefore it was expected that in treatments where the ACY concentration was high, the TAA would also be high. For an unknown reason, negative correlation between the ACY and TAA was found. Schotsmans et al. (2007) carried out a controlled atmosphere storage experiment with rabbiteye blueberries and found that the antioxidant activity and total phenolic content were positively correlated when the berries were stored in a regular atmosphere, but negatively correlated after storage in a controlled atmosphere. The mechanisms for reversed correlation remain unclear.

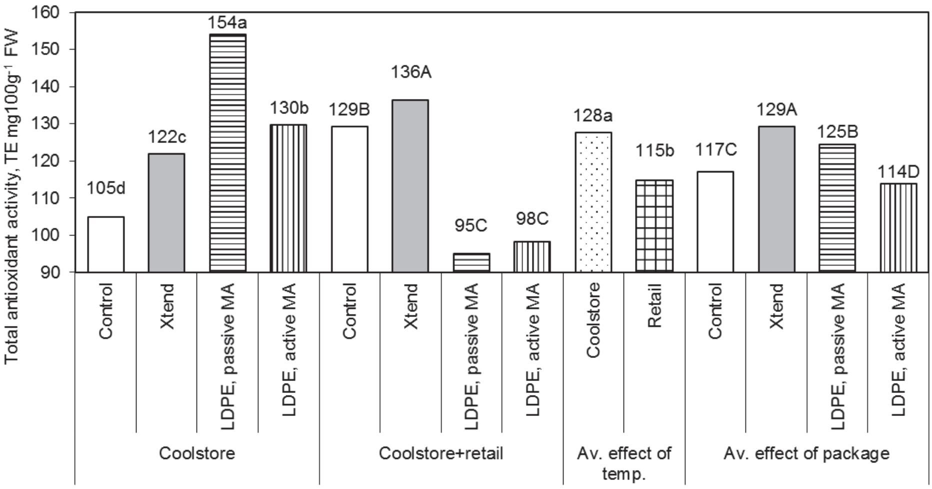

Figure 4. The effect of different MA packages on the total antioxidant activity of the raspberry 'Polka' after 4 days of storage in coolstore (+1.6 °C) and after 3 days in coolstore +24 hours in simulated retail conditions (+6ºC).

CONCLUSIONS

The modified atmosphere packages used in the current experiment did not suppress *Botrytis* rot probably due to the insufficient content of carbon dioxide (less than 10%). It would be worth trying other materials less permeable to oxygen and carbon dioxide in order to increase the CO_2 content to a sufficient level for suppressing microbial activity. However, the effect of MA on the fruit taste-related parameters and the antioxidant properties indicates the possibility to improve the consumer acceptability of 'Polka' raspberries by using modified atmosphere. The raspberries stored at 1.6°C, had the best quality in passively modified LDPE bags, since the fruit had higher SSC and TA and lower ACY content compared to the control, meaning that these fruits might have a more intensive taste and lighter red colour compared to others. After simulated retail conditions, the Xtend® bags turned out to be the most suitable, since the fruit had the lowest ACY content (the fruit did not become too dark), but the highest antioxidant activity.

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