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POSTHARVEST QUALITY OF 'GLEN AMPLE' RASPBERRY AS AFFECTED BY STORAGE TEMPERATURE AND MODIFIED ATMOSPHERE PACKAGING

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A B S T R A C T

The aim of the experiment was to determine the effect of two storage temperatures (+1 °C and +4 °C) and modified atmosphere packaging (MAP) on the postharvest quality of 'Glen Ample' raspberry. Fruits were picked into 450-g well-ventilated plastic punnets, cooled down for 24 hours and packed as follows: control – unpacked ventilated punnets covered with a lid; punnets wrapped in Xtend® film, punnets wrapped with PP30 – 30 μm polypropylene film and punnets wrapped with OPP25 – 25 μm oriented polypropylene film. One treatment consisted of eight replicate bags. After 3 days in cool storage, all packages were kept at +15 °C for 24 hours to simulate retail conditions.

The O_2 and CO_2 content in the packages was measured daily. Soluble solids content (SSC), titratable acidity (TA), fruit firmness, ascorbic acid content (AAC), anthocyanins (ACY) and total antioxidant capacity (TAC) were determined at harvest and at the end of storage. The number of spoiled fruits was recorded and a sensory evaluation was carried out at the end of the experiment.

During the first 24 hours, the concentration of CO_2 increased to 10% in the PP30 and OPP25 packages at +4 °C, while at +1 °C it took 48 hours to reach that level. In the Xtend® packages, CO_2 concentration increased above 10% only after the shelf life simulation. The environment in the PP30 and OPP25 packages became anaerobic in retail conditions. Fruit spoilage was significantly lower in the PP30 and OPP25 packages, where the CO_2 content increased rapidly. Raspberries had higher SSC, TA, SSC/TA and ACY at +4 °C than at +1 °C. Fruits in the Xtend® packages were significantly firmer than in the other treatments. The mean effect of MAP and the storage temperatures was such that they had no significant influence on raspberry fruit appearance, flavour and off-flavour. Raspberries kept at +4 °C tasted better to the evaluators.

Key words: raspberry, MAP storage, fruit firmness, sensory quality, total antioxidant capacity

INTRODUCTION

Raspberries (*Rubus idaeus* L.) are highly perishable fruits with a storage life limited by rots (*Botrytis cinerea*), loss of firmness and darkening of the attractive red colour (Haffner et al., 2002). It is generally known that the storage temperature for raspberries should not be higher than 0 °C. Several studies have shown that controlled or modified atmospheres can extend the shelf life of red raspberries (Callesen and Holm, 1989; Haffner et al., 2002). However, to maintain the quality of raspberry fruit after harvest requires high energy inputs (refrigeration), and large investments (controlled atmosphere equipment). In the current economic situation farmers are looking for possibilities to cut down production costs. The „Europe 2020" strategy has set the goal to cut down greenhouse gas emissions to 20% below the 1990 levels by 2020 (Hedegaard, 2010). Consequently, there is a need for developing more cost-effective and eco-friendly postharvest storage technologies.

Besides the local market, Finland is the main destination for Estonian berry fruits. The time needed for Estonian raspberries to be sold on the Finnish market is 3 to 4 days, including harvesting, cooling, packaging, transportation and shelf life. Therefore, producers are seeking cultivars which would withstand long-distance transport and technologies that would make possible to maintain the quality of raspberries over the period mentioned. 'Glen Ample' is considered a suitable cultivar for the fresh market and has been the most widely grown raspberry cultivar in Norway (Heiberg et al., 2002). Haffner et al. (2002) found that 'Glen Ample' had firmer berries and showed a better potential for the fresh market compared with the cultivar 'Veten'. In that experiment it was found that a controlled atmosphere reduced rotting.

The aim of the current experiment was to determine the effect of two storage temperatures (+1 °C and +4 °C) and modified atmosphere packaging on the post-harvest quality of 'Glen Ample' raspberry after 4-days in storage.

MATERIAL AND METHODS

'Glen Ample' raspberries were grown on a commercial plantation in South Estonia (58º15'33"N; 26º35'33"E) using black polyethylene mulch and drip irrigation. Fruits were harvested on 30 July (day 0) into 450 g ventilated plastic cups, transported to a forced-air cool store and cooled down to +1 °C or +4 °C for 24 hours. The next morning (day 1), the fruits were packed as follows: 1) control – punnets were not packed, but covered with a lid (which had holes in it to ensure ventilation); 2) punnets were packed with Xtend® film for raspberry (product of StePac, Israel),

3) punnets were wrapped with PP30 – 30 μm polypropylene film; 4) punnets were wrapped with OPP 25 – 25 μm oriented polypropylene film. The last two were products of Muovijaloste, Finland. The weight of all the packages was made equal and the bags were sealed from the loose end to simulate the action of a flow pack machine. Half of the packages were kept at +1 °C and the other half at +4 °C. During days 2 and 3, MA storage at +1 °C and at +4 °C continued. On day 4, retail simulation was carried out at +15 °C for 24 hours. O_2 and CO_2 content in the packages were measured every day using a hand-held gas analyser OXYBABY V (WITT-Gasetechnik GmbH & Co KG, Germany). Fruit firmness, soluble solids content (SSC), titratable acidity (TA), ascorbic acid content (AAC), anthocyanins (ACY) and total antioxidant capacity (TAC) were determined at harvest and at the end of storage. The number of fruits with rots was recorded and their percentage in the total number of fruits was calculated after storage. A raspberry fruit was considered rotten if even one of the drupelets was infected. Fruit firmness was determined using the Food Texture Analyzer TMS, (Food Technology Corporation, Virginia, USA). Fruit SSC (%) was measured using a digital refractometer (ATAGO CO., Ltd., Japan). TA was determined by titration to pH 8.2 with 0.1 NaOH. To determine AAC, titration with dichlorophenolindophenol was used. The total anthocyanins content was estimated with a pH differential spectrophotometric method; the calculation was based on cyanidin-3-glycoside and reported in mg per 100 g. TAC was determined using the 1.1-diphenyl-2-picrylhydrazyl (DPPH) discoloration assay. The values of TAC were calculated as equivalents of Trolox content (Tr) and reported in mg Trolox per 100 g of fruit fresh weight.

Sensory evaluation was carried out at the end of the experiment. After removal from cool storage, the packages were opened and kept for 5 hours at room temperature (+20 ºC). The quality of the raspberries was evaluated by 15 employees of the Department of Horticulture who had previously been trained for sensory evaluation. The evaluated characteristics were: the overall appearance and taste (5-point scale: 1 = very bad…5 = very good) and raspberry aroma and off-flavour (5-point scale: 1 = very weak…5 = very strong).

Significance of differences between the packages and the effect of the storage temperatures were tested with a two-way analysis of variance. In the figures and tables below, the mean values followed by the same letter are not significantly different at $p \leq 0.05$.

RESULTS

Gas composition in MA packages

The O_2 content in the PP and OPP packages decreased rapidly and after 24 hours of storage it decreased to about 10% (Fig. 1 A and B). At the same time, in the Xtend® packages, the O_2 content decreased to 15% and 13% at +1 °C and +4 °C, respectively,

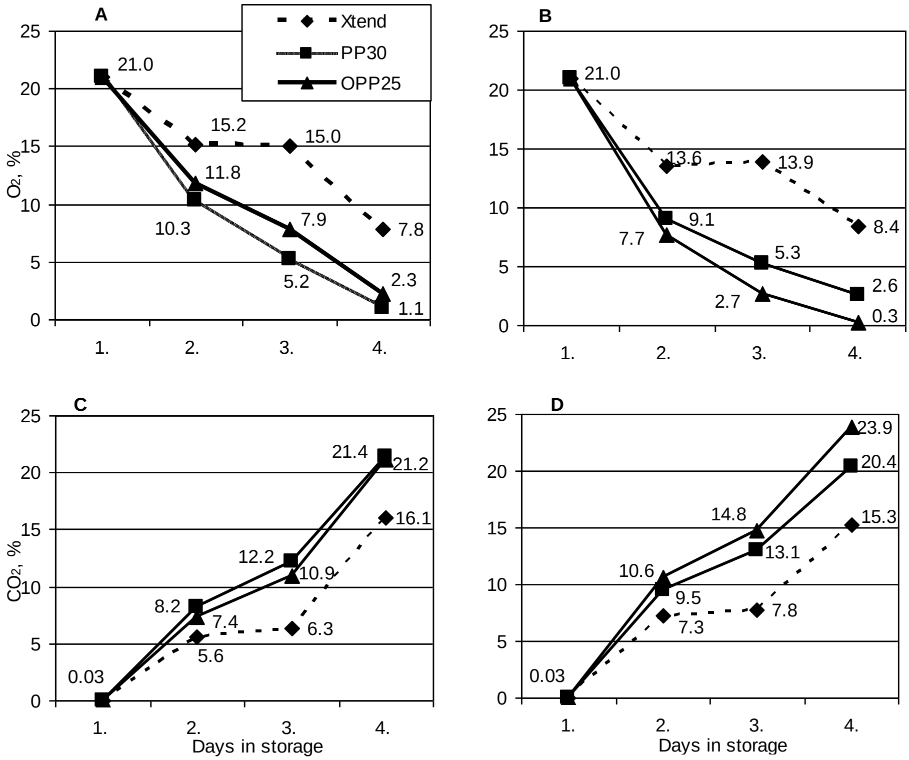

Figure 1. Changes in O_2 and CO_2 concentration in different modified atmosphere packages of 'Glen Ample' raspberries stored at +1 °C (A and C) and +4 °C (B and D). Day 1: raspberries packed into different MA packages and stored both at +1 °C and +4 °C. Day 2 and 3: MA storage at +1 °C and +4 °C continued. Day 4: retail simulation at +15 °C for 24 hours

and remained stable in cool storage. After the retail simulation, an anaerobic environment developed in the PP and OPP packages. The O_2 content in the Xtend® packages after the retail simulation decreased to around 8%.

The CO_2 content in the PP and OPP packages increased to around 10% at +4 °C whereas at +1 °C it took 48 hours to reach that level (Fig. 1C and D). In the Xtend® packages, the CO_2 content increased up to 6 and 8% during storage at +1 °C and +4 °C, respectively. Following the retail simulation, the CO_2 content reached 20% in the OPP and PP packages, and 15% in the Xtend® packages.

Fruit spoilage and fruit firmness

After storage, the number of spoiled fruits in the packages ranged from 6 to 16% (Tab. 1). At +1 °C,

Table 1. Fruit quality characteristics of 'Glen Ample' raspberries at harvest and after 4-days of storage as affected by MA packaging and storage temperature

Packaging material					
	Control	Xtend	PP 30	OPP 25	Mean
Spoiled fruits after storage [%]					
After storage at +1 C	12a	16a	6c	7bc	11A
After storage at +4 C	16a	9bc	12ab	9bc	11A
Mean	14A	15A	9B	8B	
Fruit firmness [mN]					
At harvest	5.3a	5.3a	5.3a	5.3a	5.3A
After storage at +1 C	2.7c	3.7b	3.2bc	3.3bc	3.2B
After storage at +4 C	3.0bc	3.9b	2.6c	2.6c	3.0B
Mean after storage	2.8B	3.8A	2.9B	2.9B	
Soluble solids content [%]					
At harvest	9.0d	9.0d	9.0d	9.0d	9.0B
After storage at +1 C	8.7e	9.8c	9.0d	8.6e	9.0B
After storage at +4 C	9.9c	10.3b	10.9a	9.9c	10.2A
Mean after storage	9.3B	10.0A	10.0A	9.2B	
Titratable acids [% citric acid]					
At harvest	2.30bd	2.30bd	2.30bd	2.30bd	2.30B
After storage at +1 C	2.36abc	2.37ab	2.27cd	2.22d	2.31B
After storage at +4 C	2.31bc	2.38ab	2.42a	2.42a	2.38A
Mean after storage	2.34AB	2.38A	2.34AB	2.32B	
Soluble solids content / Titratable acids					
At harvest	3.9d	3.9d	3.9d	3.9d	3.9B
After storage at +1 C	3.7e	4.1c	4.0cd	3.9d	3.9B
After storage at +4 C	4.3b	4.3b	4.5a	4.1c	4.3A
Mean after storage	4.0B	4.2A	4.2A	4.0B	
Anthocyanins [mg/100 g f.w.]					
At harvest	23d	23d	23d	23d	23C
After storage at +1 C	29c	29c	30c	23d	30B
After storage at +4 C	37a	35ab	31bc	35ab	34A
Mean after storage	34A	32AB	30B	33A	
Total antioxidant capacity [mg Trolox / 100 g f.w.]					
At harvest	115b	115b	115b	115b	115B
After storage at +1 C	151a	145a	152a	145a	148A
After storage at +4 C	147a	148a	149a	149a	148A
Mean after storage	149A	147A	151A	147A	
Ascorbic acid [mg/100 g f.w.]					
At harvest	30bc	30bc	30bc	30bc	30B
After storage at +1 C	33ab	32abc	31bc	30bc	31AB
After storage at +4 C	30bc	35a	29c	33ab	32A
Mean after storage	32AB	33A	30B	31AB	
Raspberry taste [points]					
After storage at +1 C	2.83cd	3.22bc	2.71d	2.89cd	2.92B
After storage at +4 C	3.72a	3.67a	3.33ab	3.11bd	3.46A
Mean after storage	3.28AB	3.44A	3.03B	3.00B	

spoilage was significantly lower in the PP30 and OPP25 films, while in the Xtend® packages it was not significantly different from the control. At +4 °C, the number of spoiled fruits in the Xtend® and OPP25 packages was lower than in the control packages. The mean effect of the storage temperature on spoilage was not significant. On average, the number of spoilt fruits in the OPP25 and PP30 packages was lower than in the control or the Xtend® packages.

Compared with the initial firmness, the raspberry fruits were significantly softer after storage (Tab. 1). Those from the Xtend® packages were firmer than the control fruits stored at +1 °C and firmer than the fruits from all the other combinations stored at +4 °C. The mean effect of the storage temperature was not significant.

Soluble solids and titratable acidity

The SSC of the raspberries at harvest was 9% and was subsequently affected by the storage temperature: at +4 °C, the SSC was higher compared with the initial value and with that of the raspberries kept at the lower temperature (Tab. 1). At +1 °C, the raspberries in the Xtend® packages had the highest SSC.

At harvest, the raspberries contained 2.30% titratable acids and this content was not significantly changed in the fruits kept at +1 °C (Tab. 1). At +4 °C, the TA content increased significantly in the fruits in the PP30 and OPP25 packages. The mean effect of the storage temperature was significant: the TA in the raspberries stored at +1 °C was lower than in those kept at +4 °C.

The SSC/TA of the raspberries generally increased during storage (Tab. 1). The only exception was the control treatment at +1 °C, where the SSC/TA after storage was lower than at harvest. The differences in SSC/TA had the same pattern as those in the SSC in the experiment.

Bioactive compounds content and total antioxidant capacity

At harvest, the AAC of the raspberries was 30 mg 100 g^{-1} f.w. and this value remained quite stable during storage; only the Xtend® type of packaging appeared to have a positive effect on AAC at +4 °C (Tab. 1). The mean effect of the storage temperature on AAC was not significant.

The ACY content of the raspberries increased significantly during storage, except in the OPP25 packages at +1 °C. The ACY content was more influenced by the storage temperature than by MA packaging (Tab. 1). At +4 °C, the ACY content increased more than at +1 °C.

Total antioxidant capacity was 115 mg Tr 100 g^{-1} f.w. at harvest and was significantly increased during storage (Tab. 1). The effect of temperature and packaging on TAC was not significant.

Sensory characteristics

Raspberry fruit appearance, flavour and off-flavour were not affected by the storage treatments (data not shown). The taste of the raspberries was affected both by temperature and MA packaging. The fruits kept at

+4 °C tasted better compared with those kept at +1 °C (Tab. 1). The effect of packaging depended on the storage temperature: at +1 °C, the Xtend® film retained fruit taste better than the other materials, although the difference was significant only when compared with the PP30 packages. At +4 °C, the raspberries from the control treatment and those sealed in the Xtend® film turned out to be significantly better than the fruits from the OPP25 packages.

DISCUSSION

Our experiment revealed that in order to reduce fruit spoilage, PP30 and OPP25 packages in combination with a storage temperature of +1 °C were effective, but the packages should be opened before being transferred to retail conditions, otherwise the atmosphere inside the packages becomes anaerobic. It seems that a higher CO_2 content in those packages contributed to the suppression of *Botrytis* infection. Callesen and Holm (1989) also found that raspberry fruit rot decreased with increasing CO_2 and decreasing O_2 concentration in a controlled atmosphere. But there can be undesirable side-effects. It has been demonstrated that high concentrations of CO_2 in storage atmospheres can increase the accumulation of acetaldehyde, ethanol and ethyl acetate, and induce the development of off-flavours (Larsen and Watkins, 1995). In our experiment, considering the different packaging in relation to fruit taste, the Xtend® film gave the best results. The raspberry fruits from the Xtend® packages stored at +1 °C were also significantly firmer than the control fruits and firmer than the fruits from the other MA packages stored at +4 °C. Mencarelli et al. (1993) found that the loss of firmness in raspberry fruit was correlated with the development of an off-flavour.

Regarding the temperature, in a normal atmosphere (control), storage at +1 °C did not reduce spoilage compared with +4 °C. Neither did the storage temperature have a significant effect on fruit firmness.

The instrumental analysis of taste-related parameters showed that the fruits stored at the higher temperature had a higher SSC/TA compared with the fruits kept at +1 °C. Apparently, the differences in SSC/TA were large enough to affect consumer perception since the sensory evaluation also revealed that the fruits kept at +4 °C had a better taste compared with the fruits kept at +1 °C.

The anthocyanin level in ‘Glen Ample’ raspberries was 23 mg $100g^{-1}$ f.w. at harvest and ranged from 23 to 37 mg $100g^{-1}$ f.w. after storage, which were levels comparable with Norwegian-grown raspberry cultivars (31 and 36 mg $100g^{-1}$ f.w.) (Haffner et al., 2002). At +4 °C, the ACY content increased more than at +1 °C, indicating that raspberries became darker in the warmer storage environment. However, since the evaluators found no difference in the appearance of the fruits, it could be concluded that the darkening would not be detected or disliked by the evaluators.

The AAC of the raspberries in our experiment was 30 mg 100 g^{-1} f.w. and was not significantly decreased during storage. Agar and Streif (1997) have also found that 'Meeker' raspberries contained nearly 30 mg 100 g^{-1} f.w. of vitamin C at the time of harvest and during storage at high CO_2 levels that content was not significantly decreased.

We can conclude that the PP30 and OPP25 packages, where CO_2 levels increased rapidly, were effective in reducing fruit spoilage, but had several negative side-effects. The Xtend® packaging was effective in retaining fruit firmness, taste and ascorbic acid content; however, fruit spoilage was not reduced. Storage temperature recommendations depend on the packaging technology – for a normal atmosphere, storage at +4 °C is adequate, but for MA packaging, storage at +1 °C is necessary.

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JAKOŚĆ POZBIORCZA MALINY ‘GLEN AMPLE’ W ZALEŻNOŚCI OD TEMPERATURY PRZECHOWYWANIA I RODZAJU OPAKOWANIA

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STRESZCZENIE

Celem badań było określenie wpływu dwóch temperatur przechowywania (+1 °C i +4 °C) oraz rodzaju folii używanych do pakowania (MAP) na jakość pozbiorczą maliny ‘Glen Ample’. Owoce zbierano do 450 g perforowanych plastikowych pojemników z dobrą cyrkulacją powietrza, chłodzono przez 24 godziny i pakowano w następujący sposób: kontrola – pojemniki zamknięto pokrywką zapewniającą dobrą wentylację; pojemniki pakowano w torebki wykonane z folii Xtend®; pojemniki pakowano w torebki wykonane z folii polipropylenowej PP30 o grubości 30 µm; pojemniki pakowano w torebki wykonane ze zorientowanego polipropylenu OPP o grubości 0,25 µm. Każde traktowanie wykonano w 8 powtórzeniach. Po 3 dniach przechowywania w chłodni wszystkie opakowania pozostawiono na 24 godziny W temperaturze +15 °C, symulując warunki obrotu handlowego.

Zawartość O_2 i CO_2 w opakowaniach mierzono każdego dnia. Zawartość ekstraktu, kwasowość miareczkową, jędrność owoców, zawartość kwasu askorbinowego, poziom antocyjanów oraz całkowitą aktywność antyoksydacyjną określano w dniu zbioru oraz po zakończeniu przechowywania. Liczono też liczbę zepsutych owoców i pod koniec doświadczenia przeprowadzono ocenę sensoryczną.

W ciągu pierwszych 24 godzin stężenie CO_2 wzrosło do 10% w opakowaniach PP30 i OPP25 w temperaturze +4 °C, podczas gdy w temperaturze +1 °C poziom ten został osiągnięty po 48 godzinach. W opakowaniach Xtend® stężenie CO_2 wzrosło powyżej 10% dopiero w okresie symulowanego obrotu handlowego. W warunkach symulowanego obrotu atmosfera w opakowaniach PP30 i OPP25 była beztlenowa. Stopień psucia się owoców w opakowaniach PP30 i OPP25, w których stężenie CO_2 szybko wzrosło, był istotnie niższy. Owoce malin przechowywane w +4 °C miały wyższą zawartość ekstraktu, kwasowość i poziom antocyjanów niż owoce przechowywane w +1 °C. Owoce w opakowaniach typu Xtend® były istotnie jędrniejsze niż w pozostałych kombinacjach. Badane opakowania typu MA oraz zastosowane temperatury przechowywania nie miały istotnego wpływu na wygląd owoców, ich smakowitość, czy powstawanie obcego smaku. Najwyżej oceniono smak malin przechowywanych w temperaturze +4°C.

Słowa kluczowe: *Rubus idaeus* L., MAP, jędrność owoców, jakość sensoryczna, całkowity potencjał antyoksydacyjny