

Shelf life of sweet cherries in different packages after 0 and 3 weeks of CA-storage

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Abstract

The positive effect of low oxygen and high CO₂ for sweet cherry (*Prunus avium* L.) storability is well known. In the present experiment, a combination of controlled atmosphere (CA; 2 °C, 5 % O₂ and 15 % CO₂) storage and modified atmosphere in consumer packaging (MAP) were assessed. Fruit of cv. Kordia were packaged directly (0-week CA) or after three weeks in CA storage (3-week CA). The different packages were 1: macro perforated polyethylene bag (carry bags), 2: trays wrapped in perforated films giving passive modified atmosphere with high CO₂ concentration (MAP-high CO₂), 3: similar as 2, but with low CO₂ concentration (MAP-low CO₂), 4: perforated shaker with lid containing cherries with stem and 5: similar as 4, but with fruit without stems. The consumer packages were stored at 4 °C for 5 days and thereafter for 3 days at 4 °C (Chill) or 20 °C (Retail) simulating different retail storage conditions. The weight loss was below 1 % for fruit in all packages stored at chill conditions. At retail conditions, weight loss for cherries in carry bags varied between 2.2 and 8.4 %, whereas MA packages had insignificant weight loss. Fungal fruit decay was below 0.5 % for 0-week CA cherries stored at chill conditions for 8 days, and from 7 to 14 % for 3-week CA cherries stored at chill conditions for 6 days after packaging. At retail conditions, 25 to 52 % decay was detected at end of storage period after previous storage in 0 and 3 weeks in CA, respectively. Sweet cherries of cv. Kordia did not maintain an acceptable quality in 3 weeks of CA with consecutive simulated distribution conditions during 6 days. Fungal decay was lower in carry bags and MA packaging with high CO₂, and the MA packages had additionally insignificant weight loss in mean of the different temperature regimes and storage times.

Keywords: modified atmosphere packaging, storage temperature, weight loss, fungal decay

INTRODUCTION

The shelf life of fresh sweet cherries are 7-14 days and limited by fungal decay, stem browning, desiccation and tissue softening (Habib et al., 2017; Padilla-Zakour et al., 2007). Commercial strategies to prolong shelf life of cherries are low temperature storage, CA-storage and MAP. Sweet cherries can have a shelf life of 14-21 days when stored at -1 to 0 °C with RH in the range 90 to 95 % (Paull, 1999). This optimal low storage temperature is difficult to maintain during the whole distribution chain from the packinghouse to the consumer. According to Paull (1999), it is important to conduct storage experiments simulating conditions in commercial practise.

Controlled atmosphere has positive effects on the storability of cherries; lowering the oxygen content to a level of 3 to 10 % increases the retention of firmness, less decay occurs and the fruit keeps a fresher, better appearance (Van Amerongen, 2017). By packaging in modified atmosphere, benefits such as reduced weight loss and decay and maintaining red fruit colour, firmness and green stems can be achieved (Habib et al., 2017; Koutsimanis et al., 2015; Padilla-Zakour et al., 2007). The recommended MA atmosphere for cherries is 3-10 % O₂ and 10-20 % CO₂ (Koutsimanis et al., 2015; Wani et al., 2014). MAP technology is most efficient in combination with low storage temperature, and is not a substitute for cold temperature in extending shelf life (Kupferman and Sanderson, 2001). However, Alique et al. (2003) and Koutsimanis et al. (2015)

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found that packages with CO₂ concentrations within the range 10 to 20 % significantly reduced fungal growth during two days at 23 °C after a previous storage period at 3 °C.

Micro-perforations is widely used to establish suitable gas atmospheres for fruit and vegetables in passive MA packages. The common practice is to design the package with perforations adapted to the highest temperature in the distribution chain (Beaudry, 2000; Larsen and Wold, 2016). Koutsimanis et al. (2015) proposed a temperature adaptive passive MA package for cherries. The gas transmission rate in the packages was modified by removing a strip covering additional micro-perforations when the packages was moved from 3 °C to 23 °C. To our knowledge, this solution is not yet commercially available.

In Norway, the sweet cherries are stored at 2 °C for 1 to 4 days after harvesting before sorting and packaging in open macro-perforated polyethylene bags or open paper pouches (2017 season). Air storage in macro-perforated bags or open containers induce desiccation of fruit and stems giving fruit weight loss and brown stems (Kappel et al., 2002; Koutsimanis et al., 2015; Padilla-Zakour et al., 2004). In regards to storage temperature in the distribution chain, some grocery stores display cherries in chill cabinets, and others display them at ambient temperature. The cherries may be kept at room temperature for one to three days in the grocery stores. Consumers may also store the cherries at room temperature for many hours.

The main harvesting period for firm fleshed sweet cherries in Norway is approximately 4 weeks from mid-July to mid-August. Due to increased cherry production, harvesting peaks could give challenges to the packinghouses. There is need for technologies that can prolong the shelf life of the cherries and hence even out the production peaks and extend the marketing season. A comparison of shelf life and quality of the cherries in other packaging solutions than carry bags is also of interest.

The aim of this work was to evaluate the quality of sweet cherries using the combination of 0 and 3 weeks of CA-storage in pallet pouches and subsequent packaging in different packaging solutions stored at two simulated storage temperatures for 8 or 6 days. The trial was adapted to the temperature and storage facilities available at the packinghouses today and realistic time and temperature scenarios in the distribution chain.

MATERIALS AND METHODS

Packaging and storage

'Kordia' cherries of a commercial delivery harvested in Lærdal (southwest in Norway) were cooled to 2 °C before packaging. At the packinghouse (Lærdal Grønt, Lærdal), cherries with colour 4-5 (Planton, 1995) were sorted and packaged in macroperforated polyethylene carry bags (standard packaging today with approximately 500g cherries in each bag, hereafter denoted CB). After packaging, the cherries were transported to Ullensvang Fruktlager packinghouse (Ullensvang, Norway) by a truck with cooling. At Ullensvang Fruktlager half of the cherries were repacked and stored directly in a simulated distribution chain (0 weeks CA storage), and the other half were stored for 3 weeks in CA Palliflex pallet pouches (Van Amerongen CA Technology B.V., Tiel, Netherlands), with a target gas atmosphere of 5 % O₂ and 15 % CO₂ (3 weeks of CA storage) at 2 °C.

At 0 and 3 weeks of CA storage, the cherries were divided in 5 different variants: 1: 500 g CB (1: control), 500 g in polypropylene (PP) trays flow-wrapped in laser perforated 25 µm biaxially oriented PP films giving passive modified atmosphere with high and low CO₂ concentrations (2: MAP-high CO₂ and 3: MAP-low CO₂) and 250 g in PP cups (shakers) with stems and 300 g without stems (4: Shaker with stems, 5: Shaker without stems). The packaging materials were delivered from NORGRO (Hamar, Norway). The number of perforations in the MA packages were calculated on basis of previously measured respiration rates in order to achieve a CO₂ concentration around 15 % at the highest storage temperature at 20 °C for the MAP-high CO₂ package. The target gas atmosphere in the MAP-low CO₂ package was close to air atmosphere, and 20 holes were made in these packages using a gas syringe needle. Ten samples were packaged for each treatment of cherries stored at NIBIO and Nofima. After repacking at 0 and 3 weeks of CA storage, half of the cherry packages were transported to NIBIO Ullensvang (Lofthus) and the other half was transported to Nofima at Ås by a truck with cooling. At NIBIO and Nofima the cherries were stored for 8 days (0 week in CA) and 6 days (3 weeks in CA) at 4 °C (Chill) or 5 days at 4 °C plus 3 days (0 week in CA) and 1 day (3 weeks in CA) at 20 °C (Retail) simulating storage at chill or room temperature in the grocery stores.

Temperature was recorded in the boxes at the storage room using Testo 175HI (Testo SE &Co, Peyaling Jaya, Malaysia) and within the pallet pouches and in the distribution boxes using KoolTrack temperature loggers type 212004 (Palm Beach Gardens, Florida, USA). The temperature in the room with the pallet pouches was 2.4 to 2.6 °C, whereas average temperature (mean of two logging units) within the pallet pouches was 3.41 ± 0.19 °C.

Analyses

Oxygen and CO₂ in the headspace of the MA packages was measured by a Checkmate 9900 gas analyser (Dansensor, Ringsted, Denmark) at Nofima and by a Tiempo Test Silver gas analyser (Janny MT, Péronne, France) at NIBIO. The gas samples were withdrawn through a septum placed on the packages using a needle connected to the gas analysers.

Weight loss was determined by weighing each of the packages with cherries at the day of packaging and after 8/6 days of storage. The number of packages weighed at chill and retail storage was 10 for each packaging variant. The weight loss was calculated as percentage loss of the initial total fruit weight.

At start of experiment at NIBIO, 3x10 fruit were taken out of one CB of each maturity grade and analysed for fruit quality. After five days at 4 °C and after 8 days at chill and retail storage another 3x10 fruit from the different experiment units were analysed. Fruit quality analysis included firmness (g/mm) on one side of each fruit by use of a Firmtech 2.0 texture analyser (BioWorks Inc, Wamego, KS, USA) and fruit colour on every fruit judged by support of a scale from 1-7, where 1 is light red and 7 mahogany (Planton, 1995). Total soluble solids content (TTS, %) in mean of 10 fruit were measured on a mixture of 2 drops from each fruit in a refractometer (PR 101, Atago Co. Ltd., Tokyo, Japan). Stem colour on individual fruit was judged according to (Toivonen, 2014) where the visual stem browning was defined as: 1=0-25 % of stems showing browning, 2=25-50 % of stems showing browning, 3=50-75 % of stems showing browning and 4=75-100 % of stems showing browning.

Nofima analysed changes in firmness on the cheek area of 10 fruit (two replicates) by puncture on a TA-XT2i, Stable Microsystems Texture Analyser (Surrey, UK) equipped with a 35 mm-diameter tip. The crosshead speed was 1 mm sec⁻¹ and maximum puncture force (Rmax) was measured in newton. Skin colour (L* - lightness, a* - redness and b* - yellowness) was measured on the cheek area of 10 fruit (two replicates) using a Minolta Chroma Meter CR-400 (Konica Minolta, Inc., Tokyo, Japan) with a 8 mm viewing port, 2° viewer angle and illuminant D65. The instrument was calibrated against a white tile (L* = 97.16, a = 0.25 and b* = 2.09). Minolta a* and b* values were used to compute values for hue angle ($\theta = \arctan b^*/a^*$) and chroma ($C^* = a^{*2} + b^{*2}$)^{1/2} (McGuire, 1992).

At end of storage, the number of fruit showing decay was counted. Fungal decay was diagnosed by typical visible signs and by use of microscopy. The fungal decay observed included Mucor rot caused by *Mucor piriformis*, grey mould caused by *Botrytis cinerea*, blue mould caused by *Penicillium* spp., brown rot caused by *Monilina* spp., Cladosporium rot caused by *Cladosporium* spp., and non-identified small spots of rotting (only first assessment). The latter was most probably mainly caused by Mucor rot since Mucor rot dominated on fruit assessed after a longer period.

Analysis of variance (ANOVA) was performed for all data (significance level $p < 0.05$) using general linear model in Minitab 17 Statistical Software (Minitab Inc., State College, PA, USA) and means were separated by Tukey's multiple comparison test.

RESULTS AND DISCUSSION

Headspace gas concentrations in MA packages

The gas atmosphere in the headspace of the MA packages was measured after 1, 5 and 8 days of storage for the samples packaged after 0 weeks in CA storage (Figure 1). The gas concentrations in the MAP high-CO₂ packages was 15-16 % O₂ and 5 % CO₂ until day 5. After moving the samples to 20 °C, the increased respiration rate at higher temperature gave an O₂ concentration of 4.3 % and a CO₂ concentration of 17 % after 3 days of storage. The recommended concentrations is 3-10 % O₂ and 10-20 % CO₂ (Koutsimanis et al, 2015; Wani et al, 2014). For all

the other MA packages, O₂ concentration was above 15 % and CO₂ concentration below 5.5 % during the 8 days of storage. After 3 weeks at CA storage, the cherries showed a similar overall picture in gas development. However, the cherries showed higher respiration rate after the CA storage, giving an O₂ concentration of 2.2 % and CO₂ concentration of 22.2 % for MAP high-CO₂ packages and 13.1 % O₂ and 10.3 % CO₂ for MAP low-CO₂ packages after only one day at 20 °C, respectively.

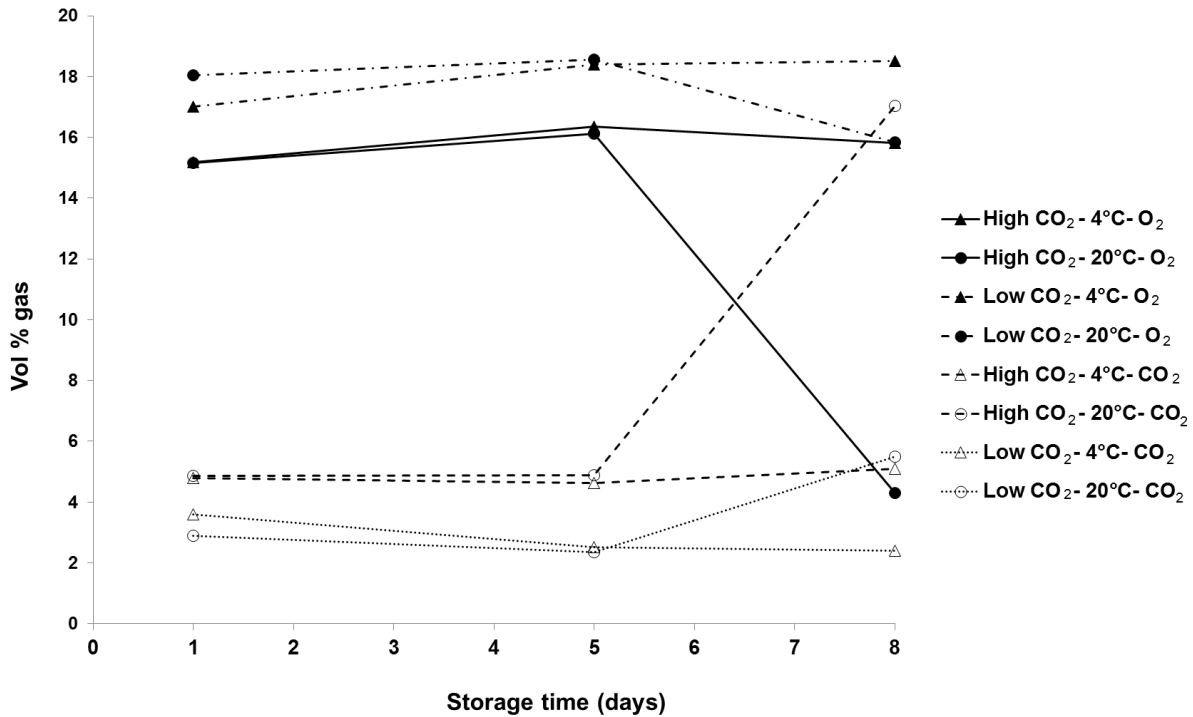


Figure 1. Changes in O₂ and CO₂ concentration measured at Nofima in MA packages with sweet cherry fruit of cv. Kordia stored for 8 days at 4 °C (Chill) or 5 days at 4 °C and 3 days at 20 °C (Retail) without previous storage in CA (0 week in CA). Mean of 10 packages of about 500 g.

Weight loss

The weight loss was below 1 % for fruit in all packages stored at chill conditions, whereas the fruit in carry bags had a weight loss between 2.2 and 8.4 % at retail conditions depending on the relative humidity in the warm storage room (Figure 2). At retail conditions, fruit in shakers had a weight loss of 1.5 % and 3.7 % in the two different storage rooms, whereas fruit in MA packages had insignificant weight loss.

The relative humidity in the warm room at Nofima was 30.1 ± 3.8 %, and at NIBIO, it was only measured when the fruit was one day at 20 °C. In that period the relative humidity between carry bags was about 99 %. The low relative humidity at Nofima tripled the weight loss from the open carry bags and macro perforated shakers, whereas the closed MA packages prevented weight loss. Kappel et al. (2002) and Koutsimanis et al. (2015) also experienced significant differences in weight loss for micro perforated packages and macro perforated bags.

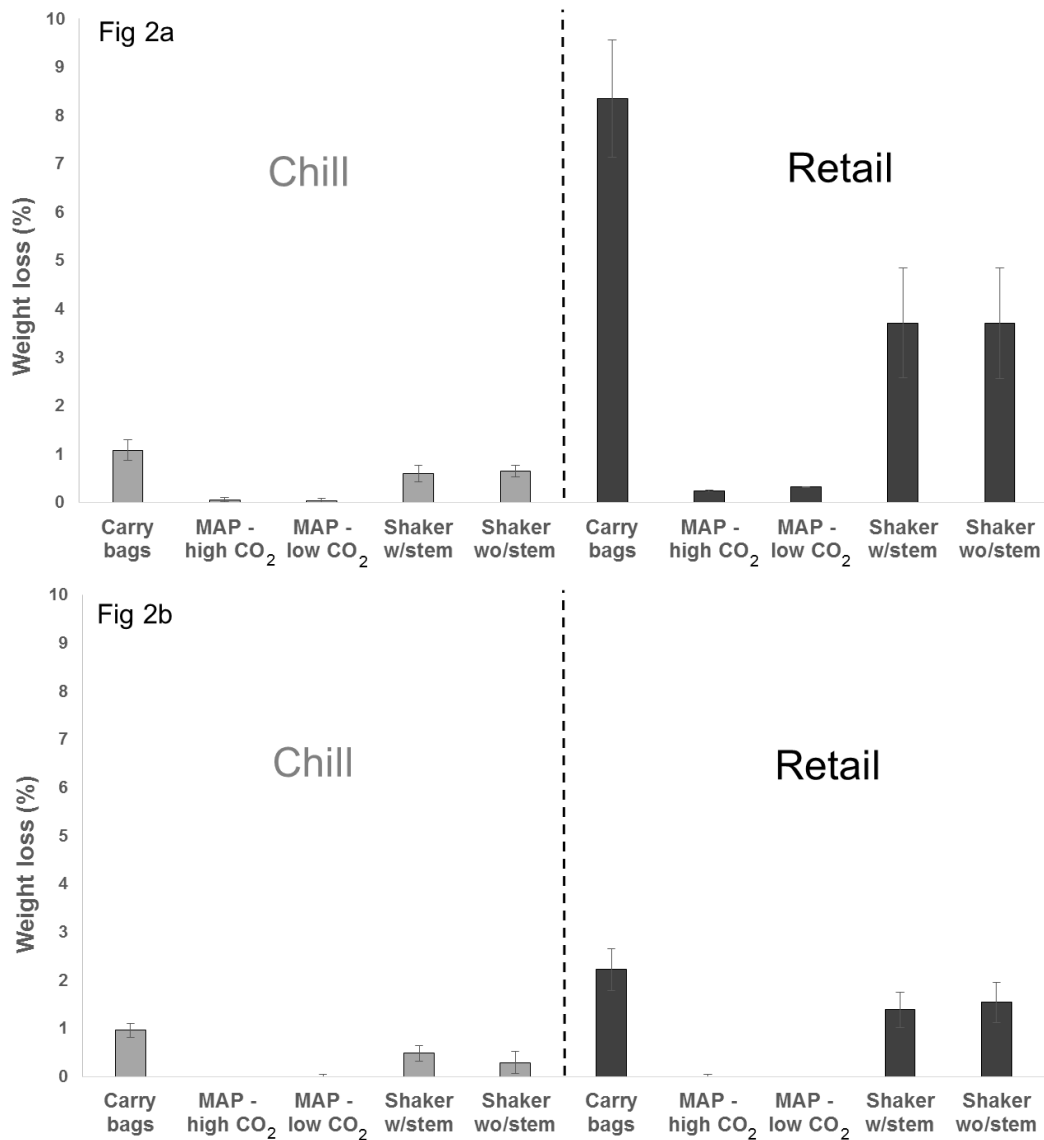


Figure 2. Weight loss after 0 weeks CA measured at Nofima (2a) and NIBIO (2b) for sweet cherry fruit of cv. Kordia packaged in different packages and stored for 8 days at 4 °C (Chill) or 5 days at 4 °C and 3 days at 20 °C (Retail). Mean of 10 packages with from 250 to 500g fruit depending on type of packaging.

Fruit quality

Fruit quality analysis at NIBIO included firmness (g/mm), fruit colour (scale from 1-7), total soluble solids content (TSS, %) and stem colour on individual fruit (scale from 1-4). Nofima analysed firmness and fruit colour using other equipment. Analyses of variance demonstrated that only the firmness measured by the Firmtech texture analyser at NIBIO showed significant differences of practical relevance (Figure 3). The factor “weeks in CA” explained 6.6 % of the variance, and cherries stored for three weeks in CA had a lower mean firmness (218 g/mm) than the cherries not stored in CA (mean = 243 g/mm). Temperature explained 2.1 % of the variance, and cherries stored at 20 °C had lower firmness (224 g/mm) than cherries stored at 4 °C (237 g/mm). Cherries in the packages with MAP-high CO₂ had the highest mean value for firmness, even if the data for the 0-week CA + retail storage samples were missing. CA or MAP is demonstrated by other researchers to increase or maintain the firmness of the cherries during storage, but only combined with low temperature (Ai-Li et al., 2002; Koutsimanis et al., 2015; Wani et al., 2014).

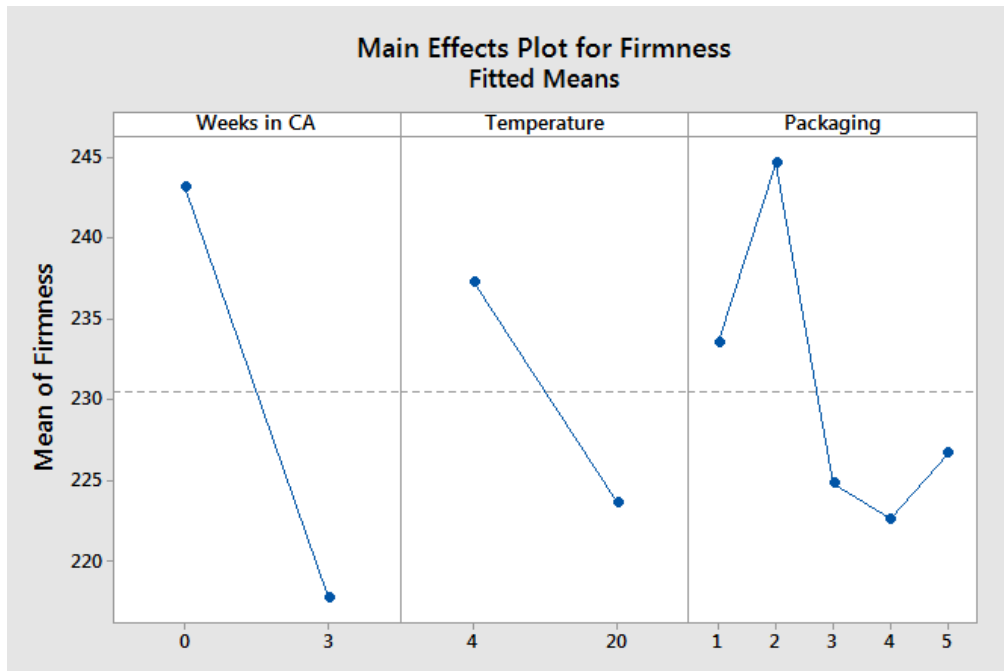


Figure 3. Main effects plot for firmness of sweet cherry fruit of cv. Kordia stored for 0 or 3 weeks in CA and then stored in different packages for 8 days at 4 °C (4 in Figure 3 = Chill storage) or 5 days at 4 °C and 3 days at 20 °C (20 in Figure 3 = Retail storage). Packaging numbering; 1=Carry bags, 2=MAP-high CO₂, 3=MAP-low CO₂, 4=Shaker w/stem and 5=Shaker wo/stem. Mean of 10 packages with from 250 to 500 g fruit depending on type of packaging.

Lightness (L*) and colour intensity (C*) was reduced by time in CA-storage and high storage temperature in the simulated retail chain, whereas the type of packaging had no effect on these two parameters. High storage temperature in the simulated retail chain reduced the hue angle (h°) values giving slightly darker cherries. Gonçalves et al. (2007) also found a reduction in L*, C* and h° values affected by storage time and temperature. In opposite, Aglar et al. (2017) found that MAP for cherries cv. 0900 Ziraat retarded colour development during storage for up to 24 days.

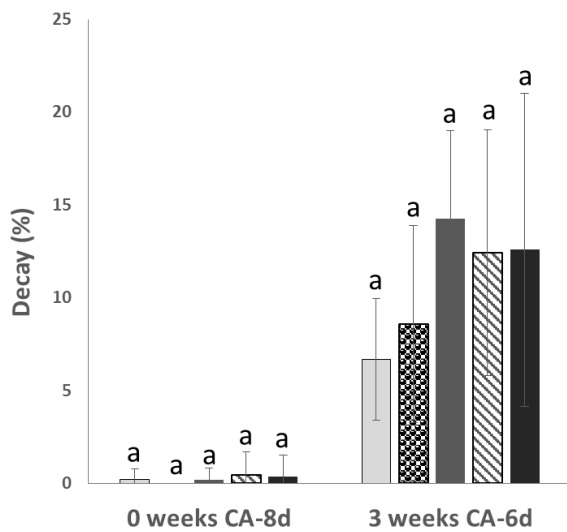
Fungal fruit decay

Fungal fruit decay was assessed in NIBIO storage room with less weight loss at retail conditions (Fig 2b). Fungal fruit decay was below 0.5 % for 0-week CA cherries stored at chill conditions for 8 days, and from 7 to 14 % for 3-week CA cherries stored at chill conditions for 6 days after packaging (Figure 4a). At retail conditions (Figure 4b), the fungal decay incidence was higher than at chill conditions. After 0 weeks of CA followed by 5 days at 4 °C and 3 days at 20 °C the incidence of decayed fruit was 25 to 47 %, and after 3 weeks in CA followed by 5 days at 4 °C and 1 day at 20 °C it was 27 to 52 %. At chill conditions, the incidence of decay was higher after 3 weeks in CA than after 0 week in CA, whereas no difference was found after 0 and 3 weeks of CA at retail conditions.

No differences in fungal fruit decay was found between the different packages when continuously kept at chill temperature. At retail conditions after 0 weeks in CA, less fungal fruit decay developed in MAP high-CO₂ than in MAP low-CO₂ and shaker containing fruit without stem. Incidence of fungal fruit decay in MAP high-CO₂ was not significantly different from decay in carry bags and shaker with stem. At retail conditions after 3 weeks in CA, fruit in carry bags had less fruit decay than MAP low-CO₂ and shakers, but no significant difference was found between fruit in MAP high-CO₂ and carry bags. Less fungal fruit decay developed in MAP high-CO₂ compared to shakers. The main cause of fungal decay in the present experiment was *Mucor rot*. Tolerance of *M. piriformis* to CO₂ is not known, but the similar and closely related fungi *Rhizopus stolonifer* was retarded by high CO₂ (Koutsimanis et al., 2015). No significant difference in fungal fruit decay was found

4a) Chill

Carry bags
 Shaker w/stem
 MAP - high CO₂
 MAP - low CO₂
 Shaker wo/stem



4b) Retail

Carry bags
 Shaker w/stem
 MAP - high CO₂
 MAP - low CO₂
 Shaker wo/stem

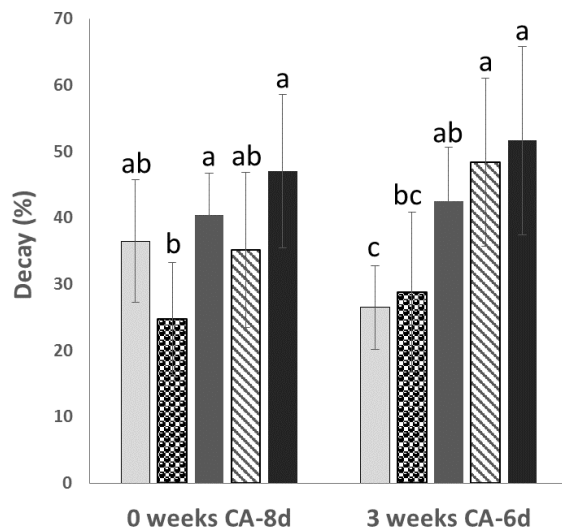


Figure 4. Fungal fruit decay (%) in sweet cherry fruit of cv. Kordia packaged in different packages and stored for 8 or 6 days at 4 °C (4a: Chill) or 5 days at 4 °C and 3 or 1 days at 20 °C (4b: Retail) after 0 or 3 weeks in CA storage, respectively. Samples with similar letters are not significantly different ($p < 0.05$). Mean of 10 packages with from 25 to 60 fruit depending on type of packaging.

between cherries in shakers with and without stem. Koutsimanis et al. (2015) also found that removal of stem not resulted in increased fungal growth.

The overall picture is that the MA packaging did not add extra time of shelf life compared to carry bags (current packaging solution). This result is different from results obtained with sweet cherries cv. Skeena stored in simulated domestic and international supply chain conditions (Koutsimanis et al., 2015) where MAP packaged cherries had significant lower fungal fruit decay than cherries packaged in carry bags. However, in the trial performed by Koutsimanis et al. (2015), the specially designed packages with removable strips kept the high CO₂ concentration within the optimal level during the whole storage period at both chill and room temperature. In our trial, the CO₂ concentration was above 10 % only for the last two days likely giving too short time with optimal gas conditions. For the 3-week fruit, the fruit also was more ripe than optimal. The CA atmosphere in the pallet pouches was optimal during the storage time, but the temperature was 3 °C inside the pallet pouches even though the room temperature was 2 °C. Many reports emphasize the importance of low temperature for sweet cherries (Paul, 1999; Wani et al., 2014). The main fungal decay Mucor rot has definitely lower incidence at 1 °C compared to at 4 °C (Kupferman and Sanderson, 2001).

CONCLUSIONS

Weight loss in open carry bags and shakers with large macro holes was high compared to closed MA packages, and was greatly affected by the relative humidity in the warm storage room. Sweet cherries of cv. Kordia did not maintain an acceptable quality in 3 weeks of CA with consecutive simulated distribution conditions during 6 days. According to literature, a shelf life of 4-6 week for cherries is achievable in other countries, dependent on variety and quality of the cherries at harvest. The low storage capability of cv. Kordia in our experiment could be due to the wet climate conditions in Norway giving a high level of fungal inoculum on the fruit. Lowering the storage temperature further is another option to be explored in later trials. MA packaging with high CO₂ gave the best overall result with low fungal decay development and no weight loss both when packaged after 0 and 3 weeks of CA.

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