Original article

Fruit quality as affected by 1-MCP treatment and DCA storage – a comparison of the two methods

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Summary

Two new tools for better preservation of fruit quality have been developed in recent years, the treatment of apples with 1-MCP and dynamic controlled atmosphere storage (DCA). The effect of 1-MCP treatment and DCA on ethylene production and quality of 'Golden Delicious' apples harvested at two different ripening stages was evaluated in our study over two consecutive years. 1-MCP treatment delayed the climacteric increase of ethylene production and led to better retention of quality during RA- and ULO-storage and subsequent shelf life compared to non-treated apples. In order to achieve the optimum effect of 1-MCP, the treatment must be carried out within 7 days after harvest, as recommended by the supplier of 1-MCP. In most cases, DCA improved quality retention during storage in terms of fruit firmness and acidity compared to ULO-storage. The use of the two methods depends on the cultivars stored and conditions such as the infrastructure of the storage facility and type of handling and marketing of the apples.

Keywords
DCA, 1-MCP, ethylene, fruit quality, maturity

Significance of this study

What is already known on this subject?

- The application of 1-MCP and of the dynamic CA-storage (DCA) are well known technological methods in order to retain apple fruit quality during industrial storage and during subsequent shelf life. The two methods are widely used today in Western Europe.

What are the new findings?

- Based on long-term storage trials with identical fruit of selected apple cultivars, 1-MCP treatment and DCA could be compared directly with regard to fruit quality and physiological behavior of fruit.

What is the expected impact on horticulture?

- Results show, that both methods are effective, but that the fruit quality retention during storage and subsequent shelf life is more consistent for the 1-MCP treatment than for DCA. However, the question, which method is best applied in practice, depends on the specific situation of consumer demands, logistics and marketing of apples.

Introduction

In order to better retain quality and extend the marketing period of apples, controlled atmosphere (CA) storage (atmosphere with reduced O_2 and elevated CO_2 level) has been widely used since the 1990s in Switzerland. During the years following the introduction of CA, LO (low oxygen) and ULO (ultra-low oxygen) storage were introduced, with even lower levels of oxygen in storage rooms down to 1.0 kPa for apples. Two new tools for better preservation of fruit quality have been developed in recent years, the treatment of apples with 1-MCP and dynamic controlled atmosphere storage (DCA).

The substance 1-methylcyclopropene (1-MCP, trade name SmartFresh™) is an ethylene inhibitor that blocks the ethylene-binding receptors and thus slows down the ethylene production and the respiration respectively of apples during storage. As a result of 1-MCP application, fruit quality, in terms of fruit firmness, total soluble solids and acidity, is retained better than that of non-treated apples (Watkins, 2006). The application of 1-MCP was approved by the EU in 2005. 1-MCP not only maintains fruit quality during storage, but also during the shelf life and the marketing period of the fruit (Xuan and Streif, 2005; Höhn et al., 2007). The improved quality retention during the marketing period has provided distributors with greater flexibility in the handling of apples.

The concept of dynamic controlled atmosphere storage (DCA) involves the reduction of the oxygen concentration in the storage atmosphere close to the lowest level that can be tolerated by the fruit without inducing excessive anaerobic metabolism, which would affect fruit quality. Fruit respiration and thus quality loss during storage is assumed to be slowed down compared to normal ULO storage. The safe establishment of very low oxygen levels in the storage atmosphere is only possible, if the onset of fermentation in the fruit can be detected during oxygen reduction. Current approaches for the monitoring of the fruit metabolism include methods such as the measurement of chlorophyll fluorescence, the measurement and calculation of the respiration quotient (Gasser et al., 2010) and the determination of ethanol production in the stored fruit (Schouten et al., 1997).

The objective of this study is to assess and compare the effect of 1-MCP treatment, the timing of its application and DCA-storage on fruit quality. The ethylene production of the fruit was measured to better understand the physiological behavior of the fruit as influenced by the storage conditions. Finally, the advantages and disadvantages of the two methods are discussed, based on our experiments and other studies.

Materials and methods

Fruit samples

Apples of the variety 'Golden Delicious' grown in 2006 and 2007 in two experimental orchards of Agroscope (Switzerland) research station were used for this study ('Reinders' from WA96 in 2006, 'Type B' from WA54 in 2007). To investigate the influence of harvest date on the effect of 1-MCP treatment and storage conditions, two picking dates were selected: optimum [in the middle of the commercial harvest window for 'Golden Delicious' as described by Höhn et al. (2006)] and late (10 days later). To further investigate the effect of fruit maturity on ethylene production, fruit were harvested at two additional dates (two weeks and one week before optimum harvest). Fruit were randomly picked from selected trees and an homogeneous fruit batch was prepared by sorting fruit according to size and color. Half of those fruit used in storage experiments was treated with 625 ppb 1-Methylcyclopropene (1-MCP, SmartFresh™ powder at 0.14%, AgroFresh Inc.) in a 389 liter sealed chamber at 0.5°C for 24 hours. In addition, the effect of delaying 1-MCP treatment on the quality of 'Golden Delicious' apples was evaluated with the fruit harvested in 2007 by applying the treatment 6, 12 and 20 days after harvest. Treated and non-treated fruit were stored under regular atmosphere (RA) at 0.5-1.0°C and 92% relative humidity (r.H.) and under ultra-low oxygen atmosphere (ULO) at 1.0°C, 92% r.H., 3.0 kPa CO_2 and 1.0 kPa O_2. 40 kg of fruit were stored for each condition. After 16 and 30 weeks (in 2006) and 16 and 36 weeks (in 2007) of storage duration, half of the apples was analyzed immediately and the other half was kept at 20°C for 7 days in normal atmosphere (shelf life period) before being analyzed.

DCA trials were performed on fruit of the same orchards and picking dates at different DCA conditions as described in Table 1 in a flow-through system (Gasser et al., 2010) and in conventional small CA-containers (fruit load 80 kg). Depending on the harvest date and the year, the critical oxygen levels varied in a range of 0.2–0.5 kPa. Fruit samples removed from storage containers were also stored for a subsequent shelf life period as described above.

Ethylene measurements

Measurements of ethylene production were performed on one batch of 5 fruit by enclosing them in airtight boxes (volume 5.6 L) for 16 hours at 20°C. Ethylene concentration was then measured by gas chromatography (Varian 3900, HP-Plot U DVB/EGDMA Column (30 m x 0.53 mm x 20 µm), oven temperature 40°C, FID-detector, external standard 100 ppm ethylene) and expressed in terms of ethylene production related to the fruit weight (µg kg^{-1} h^{-1}).

Quality measurements

Fruit quality was determined before harvest, at the time of harvest and at the end of the storage period and shelf life respectively by measuring fruit firmness, total soluble solids, titratable acidity, starch pattern index, fruit weight and fruit color. Fruit color was measured using a Minolta Chroma Meter CR-400 (Konica Minolta Sensing Europe B.V., München, Germany) at the greenest part of the skin (ground color), resulting in L^*, a^* and b^* values. Hue angle (h) was calculated as $\tan^{-1}$ (b*/a*). Firmness was measured on two opposite sides of each fruit with an ART instrument (UP Umweltanalytische Produkte GmbH, Ibbenbüren, Germany) using a plunger with cutting edge (diameter 11 mm) and expressed in kg cm^{-2}. The fruit were then cut in half across the equatorial line, dipped for 30 seconds in an iodine solution (10 g potassium iodide + 3 g iodide / liter H_2O) and air dried at 20°C for 5 minutes. The color patterns appearing after the iodine treatment were compared to the color reference charts (CTIFL, France). Further reference analyses were performed on the juice: an electronic refractometer (Model PR32, Atago Co., Tokyo, Japan) was used to measure total soluble solids (TSS, °Brix). Titratable acidity was determined by titration (Titrator DL67, Mettler-Toledo GmbH, Greifensee, Switzerland) with 0.1 M NaOH to pH 8.1 and expressed as g malic acid L^{-1}.

Results

Effect of harvest date, 1-MCP treatment and storage conditions on ethylene production

The effect of harvest date and 1-MCP-treatment on ethylene production of 'Golden Delicious' apples was evaluated by monitoring fruit harvested at 4 ripening stages and stored under shelf life conditions for up to 125 days. 1-MCP treatment of fruit harvested at the optimum and late date (denoted as "pick 3" and "pick 4") delayed the onset of ethylene production (Figure 1). Independent of the harvest date, ethylene production and thus the climacteric ripening of non-treated fruit were initiated around the same date (5th to 10th October). On- and off-tree ripening had little impact on the onset of ethylene production, as the comparison of fruit from early harvest and optimum harvest shows.

The influence of storage conditions (RA, ULO and DCA) and 1-MCP treatment on ethylene production of 'Golden Delicious' apples is illustrated in Figure 2. For non-treated fruit, both ULO- and DCA-conditions reduced ethylene production when compared to RA. 1-MCP treatment completely inhibited ethylene production during 16 weeks of stor-

Table 1. DCA storage conditions applied for each harvest date of 'Golden Delicious' (storage temperature 1°C) in the trials 2006/2007 and 2007/2008 (initial oxygen level before oxygen reduction = 1.0 kPa).

DCA-conditions	Storage system	CO_2 (kPa)	Rate of oxygen reduction (kPa)
Control	Flow-through	3.0	1.0 kPa, constant
Slow	Flow-through	3.0	0.2 per week
Fast	Flow-through	3.0	0.2 per day
Proportional	Flow-through	3.0 [z]	0.2 per day
Slow	Conventional CA-container	3.0	0.2 per week

[z] Reduction of CO_2 during oxygen reduction proportional to the level of oxygen, based on a proportion of 3:1 (CO_2:O_2)

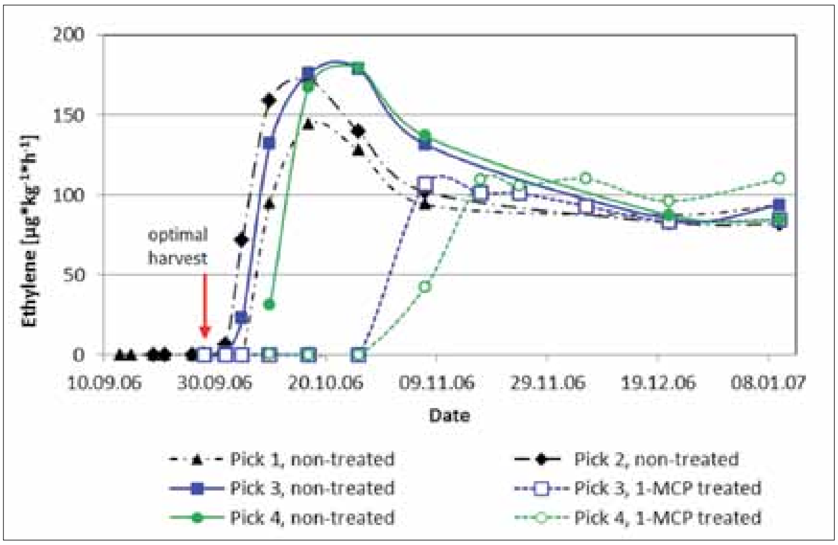


Figure 1. Effect of harvest date and 1-MCP treatment on ethylene production of 'Golden Delicious' apples picked at 4 harvest dates (pick 1: 2 weeks before optimum harvest, pick 2: 1 week before optimum harvest, pick 3: optimum harvest and pick 4: late harvest). Data are means of duplicate measurements of one batch of 5 fruit.

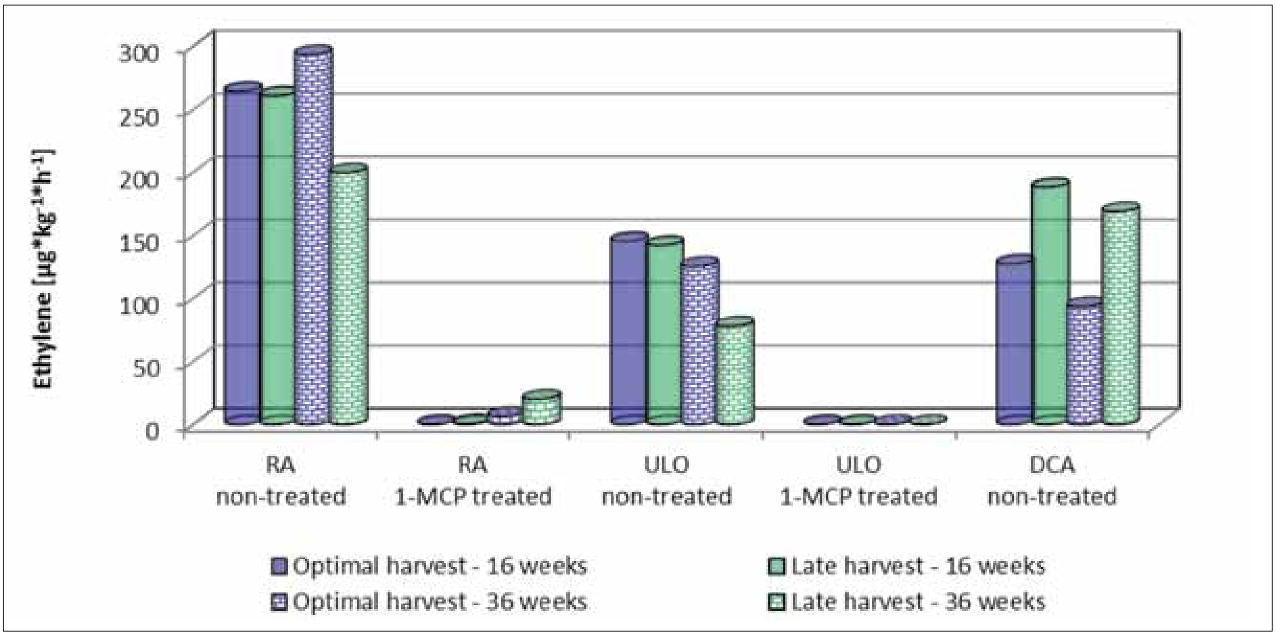


Figure 2. Ethylene production of 1-MCP treated and non-treated 'Golden Delicious' apples picked at two harvest times in 2007 (optimum and late) and stored under regular atmosphere (RA), ultra-low oxygen (ULO) and dynamic controlled atmosphere (DCA) conditions for 16 and 36 weeks. Data are means of duplicate measurements of one batch of 5 fruit.

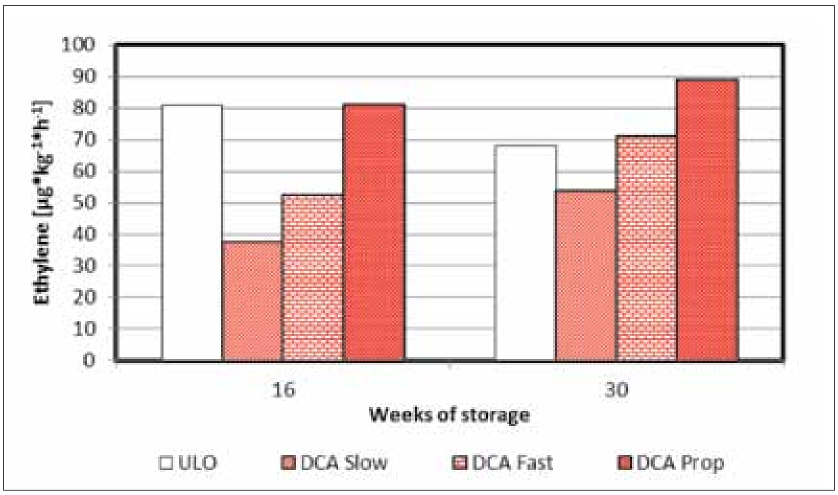


Figure 3. Effect of the oxygen reduction rate on the ethylene production of DCA stored apples ('Golden Delicious'). Data are means of duplicate measurements of one batch of 5 fruit.

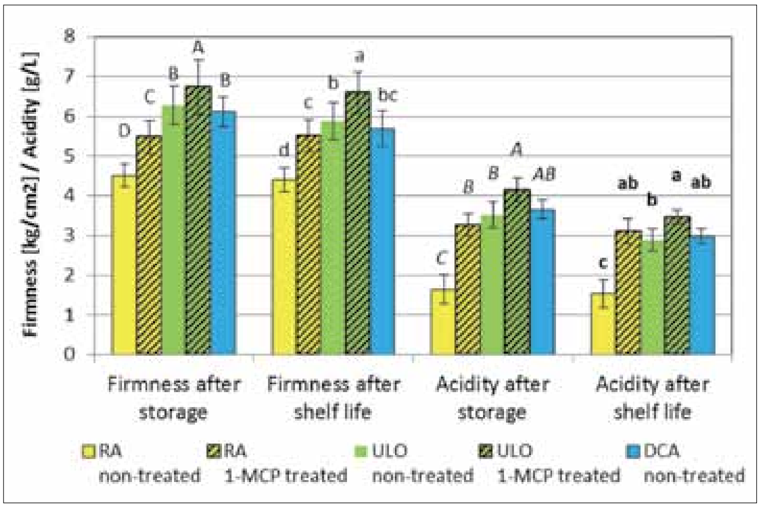


Figure 4. Effect 1-MCP treatment on firmness and acidity of late-harvested 'Golden Delicious' apples (2007) after 36 weeks of storage under regular atmosphere (RA), ultra-low oxygen (ULO) or dynamic controlled atmosphere (DCA) and during shelf life at 20°C for one week. Bars correspond to standard errors and means with the same letter are not significantly different at p≤0.05 in Duncan's multiple range test.

age under RA- and ULO-conditions for both harvest dates. After 36 weeks of storage, a small increase in ethylene production was observed for 1-MCP treated fruit stored under RA conditions, but not for fruit stored under ULO conditions. The influence of DCA conditions (in CA-container) on the ethylene production compared to ULO-stored fruit without 1-MCP was not consistent. However, the overall picture shows that DCA-conditions did not reduce ethylene production compared to ULO-conditions.

As shown in Figure 3, ethylene production of fruit was consistently influenced by the DCA conditions in the flow-through system: slow oxygen reduction resulted in a lower ethylene production than fast oxygen reduction, whereas the oxygen reduction with proportional reduction of carbon dioxide resulted in ethylene production equal to or even higher than the ULO-control conditions over the storage periods of 16 and 30 weeks.

Effect of 1-MCP treatment and storage conditions on fruit quality

The influence of 1-MCP treatment and storage conditions on fruit quality was evaluated based on measurements of firmness, TSS, titratable acidity and ground color. 1-MCP treatment delayed softening and the loss of titratable acidity during storage under RA- and ULO-conditions, particularly for long-term storage (Table 2, data of 2006/2007 are not shown, but follow the same patterns as those in 2007/2008). The additional effect of 1-MCP on quality retention was much higher under RA- than under ULO-conditions. TSS were significantly higher in 1-MCP-treated fruit compared to non-treated fruit stored under RA, whereas the treatment had no influence on this parameter under ULO-conditions. Fruit skin color was more influenced by storage conditions than by 1-MCP treatment (data not shown). The benefit of 1-MCP treatment on fruit quality was observed for both harvest dates. Finally, the fruit firmness of DCA-stored apples held in a conventional CA-container was equivalent to that of ULO-stored fruit, whereas acidity of DCA stored apples was slightly higher than that of ULO-stored fruit.

As illustrated in Figure 4, 1-MCP treatment delayed softening and loss of titratable acidity not only during storage under RA- and ULO-conditions, but also during shelf life. The combination of ULO and 1-MCP treatment was superior in this respect to all other variants tested. Quality retention during shelf life of DCA-stored apples was comparable

Table 2. Firmness, total soluble solids (TSS), acidity and skin color of 'Golden Delicious' apples harvested in 2007, treated and non-treated with 1-MCP and stored under RA-, ULO- and DCA-conditions for 16 and 36 weeks respectively. Means with the same letter are not significantly different at p≤0.05 in Duncan's multiple range test. nd means not determined.

	Firmness ($kg\ cm^{-2}$)		TSS (°Brix)		Acidity (g malic acid L^{-1})		Color (h)	
	16 weeks	36 weeks	16 weeks	36 weeks	16 weeks	36 weeks	16 weeks	36 weeks
Optimum harvest								
RA	5.3 C	4.6 D	13.2 C	13.0 B	3.5 C	2.1 D	103.5 B	95.1 C
RA MCP	6.8 B	5.5 C	14.2 B	13.7 AB	4.6 B	3.5 C	105.1 B	98.4 B
ULO	7.2 AB	6.0 B	13.8 BC	14.4 A	4.6 B	4.1 AB	108.1 A	104.2 A
ULO MCP	7.4 A	6.7 A	14.8 A	14.5 A	5.0 A	4.4 A	107.9 A	105.8 A
DCA	7.0 B	6.3 B	13.3 C	14.0 A	4.6 B	3.7 BC	nd	nd
Late harvest								
RA	5.1 D	4.5 D	14.0 AB	12.8 B	3.5 B	1.6 C	104.0 BC	95.8 B
RA MCP	6.2 C	5.5 C	14.2 A	14.0 A	4.5 A	3.3 B	101.5 C	94.5 B
ULO	6.8 B	6.3 B	13.5 C	14.0 A	4.1 A	3.5 B	108.5 A	106.0 A
ULO MCP	7.3 A	6.7 A	13.6 BC	14.4 A	4.4 A	4.2 A	105.8 B	104.5 A
DCA	6.4 C	6.1 B	13.9 AB	14.3 A	4.1 A	3.7 AB	nd	nd

Table 3. Firmness, total soluble solids (TSS), and acidity of 'Golden Delicious' apples stored under three different DCA conditions in the year 2006/2007.

	Firmness (kg cm-2)				TSS (°Brix)				Acidity (g malic acid L-1)			
	16 weeks		36 weeks		16 weeks		36 weeks		16 weeks		36 weeks	
Optimum harvest												
ULO	7.8	A	7.1	B	14.4	A	14.5	A	4.68	A	4.27	A
DCA Slow	7.6	A	7.6	A	14.5	A	14.5	A	4.71	A	4.17	A
DCA Fast	7.7	A	7.7	A	14.8	A	14.5	A	4.72	A	4.26	A
DCA Prop	7.4	A	7.6	A	14.3	A	14.4	A	4.39	A	4.29	A
Late harvest												
ULO	6.5	A	6.1	B	13.91	A	14.33	A	3.71	A	3.61	A
DCA Slow	6.6	A	6.7	A	13.09	A	14.10	A	3.56	A	3.75	A
DCA Fast	7.0	A	6.8	A	14.32	A	13.94	A	3.90	A	3.79	A
DCA Prop	6.9	A	6.7	A	13.91	A	13.83	A	3.89	A	3.62	A

to that of ULO-stored fruit for firmness and acidity, so no advantage could be identified for DCA for fruit held in a conventional CA-container.

However, the influence of different DCA-conditions on fruit quality was also evaluated and compared to ULO-conditions in a flow-through system. Independent of the harvest date, DCA-conditions significantly delayed softening of fruit stored for longer periods up to 6 months compared to ULO conditions (Table 3, data of 2007/2008 not shown, but follow the same patterns as those in 2006/2007). No significant differences between DCA- and ULO-conditions were measured for titratable acidity and TSS. Although not significant, the acidity of DCA-stored apples was slightly higher than that of ULO fruit for the second harvest date.

Effect of delaying 1-MCP treatment

During harvest time, work load in storage facilities is quite high. Under these conditions, it may happen that 1-MCP treatment is not carried out within the recommended time frame of 7 days after harvest. In order to evaluate the influence of the timing of treatment on fruit quality, 1-MCP was applied 6, 12 and 20 days after harvest. The influence of each treatment on ethylene production during storage is shown in Figure 5: non-treated control fruit produced higher amounts of ethylene than 1-MCP-treated fruit. Treatment conducted 6 days after harvest inhibited the climacteric increase of ethylene much more effectively than the treatments after 12 and 20 days. The same pattern was observed for both optimum and late harvested fruit.

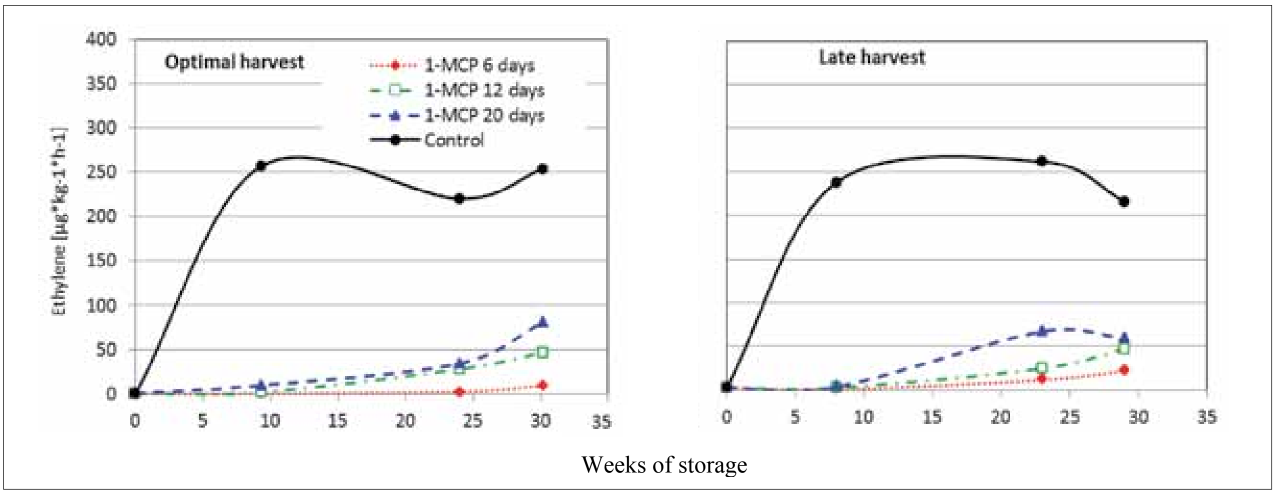
Quality of fruit treated 6 days after harvest with 1-MCP was better maintained in terms of firmness, acidity and TSS during 29 weeks of storage under RA conditions than that of fruit treated 12 and 20 days after harvest (Table 4). This difference was observed for both, optimum and late harvest. No substantial differences were observed between treatments carried out 12 and 20 days after harvest except in the case of optimum harvest, where the firmness of fruit treated 12 days after harvest was higher than that of fruit treated 20 days after harvest. However, applying 1-MCP 12 or 20 days after harvest still improved fruit quality compared to non-treated fruit. As a consequence, the recommendations for the timing of treatment should be respected.

Discussion

Effectiveness of 1-MCP

This study deals with the effect of 1-MCP treatment and different storage conditions on ethylene production and quality of 'Golden Delicious' apples harvested at two differ-

Figure 5. Ethylene production of 1-MCP treated (treatment performed 6, 12 and 20 days after harvest) and non-treated 'Golden Delicious' apples harvested in 2007 at optimum and late harvest time and stored under RA-conditions. Week 0 corresponds to harvest date. Data are means of duplicate measurements of one batch of 5 fruit.



ent ripening stages during two consecutive years. 1-MCP treatment clearly delayed the climacteric increase of ethylene production during the shelf life period immediately after harvest. These results are in line with similar studies conducted on ethylene production of other cultivars such as 'Golden Delicious' (Fan et al., 1999), 'Fuji' (Fan and Mattheis, 1999), 'Anna' (Pre-Aymard et al., 2003) and 'Jonagold' (Xuan and Streif, 2005).

The reduction of ethylene production following 1-MCP treatment was observed in our study for both RA and ULO storage conditions. However, this appears to be variable, depending on the cultivar, storage conditions and storage duration, as described in the study of Watkins et al. (2000). Although 1-MCP is thought to block ethylene receptors permanently (Blankenship and Dole, 2003), it is assumed that new binding sites appear during ripening of climacteric fruit (Lelièvre et al., 1997), leading to a delayed increase of ethylene production of treated fruit. This was shown in our study, in which 1-MCP treated fruit stored under RA conditions initiated ethylene production after 36 weeks of storage.

Table 4. Firmness, total soluble solids (TSS), and acidity of 'Golden Delicious' apples harvested in 2007, treated (treatment performed 6, 12 and 20 days after harvest) and non-treated (control) with 1-MCP and stored under RA conditions for 29 weeks. Means with the same letter are not significantly different at p≤0.05 in Duncan's multiple range test.

	Firmness ($kg\ cm^{-2}$)		TSS (°Brix)		Acidity (g malic acid L^{-1})	
			Optimum harvest			
MCP 6 days	5.9	A	14.1	A	3.7	A
MCP 12 days	5.2	B	13.3	B	3.2	B
MCP 20 days	4.8	C	13.2	B	3.0	B
Control	4.6	C	12.9	B	2.2	C
			Late harvest			
MCP 6 days	5.7	A	14.4	A	3.7	A
MCP 12 days	5.1	B	13.4	BC	3.0	B
MCP 20 days	5.0	B	13.7	B	2.9	B
Control	4.6	C	13.0	C	1.7	C

The effectiveness of 1-MCP treatment is influenced both, by the ripening stage at harvest and by the period of time during which fruit are kept in cold storage before treatment (Watkins, 2006). In our study, we demonstrated that 1-MCP treatment was effective even on late harvested 'Golden Delicious' apples, which were already in the climacteric rise. Additionally, even a late treatment 12 or 20 days after harvest reduced ethylene production compared to non-treated fruit. However, the effectiveness was higher when fruit were treated 6 days after harvest. This was also observed by Watkins and Nock (2005), who showed that the effect varies depending on cultivar and storage method. This may be due to the competition between endogenous ethylene and 1-MCP to bind ethylene receptors (Tatsuki et al., 2007), which increases with fruit ripening. In general, the shorter the delay between harvest and treatment, the better is the efficiency. For most apple cultivars it is therefore recommended to apply 1-MCP treatment within 7 days after harvest (AgroFresh, 2012).

Our study shows that the climacteric increase of ethylene production of fruit harvested at 4 different ripening stages occurred around the same timepoint, independently of on-tree or off-tree ripening. This indicates that climacteric increase of ethylene is initiated both on- and off-tree, which is in accord with a study of Song and Bangerth (1996) who observed similar patterns of ethylene production measured in 'Golden Delicious' apples harvested at different dates.

Ethylene controls fruit ripening, which is characterized by changes in color, firmness, flavor and titratable acidity (Lelièvre et al., 1997). Inhibition of ethylene production therefore delays fruit ripening and maintains fruit quality during storage. The reduction of oxygen in the storage atmosphere is known to reduce both respiration rate and enzymatic activity in the ethylene signaling pathway (Beaudry, 1999). This approach is, therefore, widely used in ULO-storage to slow down fruit softening and loss of acidity. In our study, fruit quality was best preserved by the combination of ULO storage conditions and 1-MCP treatment. This is probably the result of an additive effect of reduced enzymatic activity in the ethylene signaling pathway and the blocking of ethylene receptors by 1-MCP treatment. Similar results were found in the studies of Rupasinghe et al. (2000) and Watkins et al. (2000). In addition, using 1-MCP is particularly interesting for maintaining fruit quality under shelf life conditions, since the inhibition of ethylene receptors by 1-MCP is permanent even at 20°C (Blankenship and Dole, 2003). Using the example of 'Golden Delicious' stored for 36 weeks under ULO-conditions, the rate of firmness reduction during shelf life was 20 g per day for MCP-treated apples against 58 g per day for non-treated fruit. The same pattern was found for other experimental variants.

TSS were slightly higher in 1-MCP treated fruit stored under RA, but 1-MCP had no influence under ULO conditions. According to Watkins (2006), TSS in 1-MCP treated fruit can be higher, lower or at the same level as in non-treated fruit, depending on the cultivar, storage conditions and storage duration. Interestingly, fruit color was more influenced by storage condition than by 1-MCP treatment. Apples stored under ULO conditions were generally greener than fruit stored under RA. However, 1-MCP treatment helps to maintain the ground color of fruit during shelf life, as has been shown by Zanella et al. (2003).

Effectiveness of DCA

In our study, DCA storage was superior to ULO-storage for firmness and, to a lesser extent, for acidity in the experimental flow-through system during two consecutive years, whereas in one DCA trial in a conventional CA-container no quality difference could be found in terms of firmness and acidity. The overall picture of our DCA experiments over the past years shows that, depending on cultivar and storage duration, DCA may improve quality retention during long-term storage in some years but not in other years when compared to ULO. Our experiments with the cultivars 'Braeburn', 'Maigold' and 'Elstar' showed that DCA resulted in better firmness retention compared to ULO for 'Braeburn' and 'Maigold', but not for 'Elstar' (Gasser et al., 2008). Schouten et al. (1997) found, that 'Elstar' stored under DCA-conditions (called DCS in this publication, since fruit stress was detected based on ethanol measurement) retained fruit firmness better after removal from storage and after shelf life than ULO-stored fruit. Köpcke (2010), in his study on DCA storage of 'Elstar', showed that there is a relationship with sigmoid character between the fruit firmness after shelf life and the oxygen concentration during storage: when oxygen concentration is reduced from 1.0 kPa to about 0.4 kPa, the gain in firmness retention after shelf life is relatively small. This shows that the quality benefit of DCA may not be as consistent as for 1-MCP treatment.

DCA *vs.* MCP

The two methods may be compared in the light of fruit quality and physiological aspects, from a technological point of view and based on marketing considerations. Because of the appearance of physiological disorders, 1-MCP cannot be applied for all cultivars, such as 'Braeburn' (Köpcke, 2010). On the other side, 1-MCP may inhibit skin browning in certain cultivars. Furthermore, the effectiveness of the treatment depends on the cultivar, a fact which is also true for DCA. DCA, as well as providing better quality retention, inhibits physiological disorders such as skin browning for 'Maigold' cultivar (Gasser et al., 2008).

DCA requires an initial investment in the fluorescence sensors and, if necessary, in highly leak-proof storage rooms and in CO_2-adsorbers with a high adsorption capacity. This is important in order to reduce CO_2-levels proportionally to the oxygen reduction during DCA storage. However, at least our experiments on 'Golden Delicious', 'Braeburn', 'Maigold' and 'Elstar' showed that the CO_2-level can be maintained at the initial level recommended for ULO-storage without causing physiological disorders (Gasser et al., 2008). The treatment with 1-MCP does not require any investments in infrastructure, but incurs costs for each treatment.

DCA requires higher skills for the control of storage rooms than ULO. But, in contrast, DCA offers greater safety because the fluorescence sensors indicate the occurrence of sub-optimally low oxygen levels. Treatment with 1-MCP does not change anything in the management of storage rooms, although the treatment must be carried out following the recommendations of the supplier.

Because of the "chemical" treatment, 1-MCP may not be used for organically grown apples, whereas DCA may be used for organic fruit. With regard to the handling of apples from the storage facility to the point of sale, 1-MCP probably offers greater flexibility than DCA, because the quality retention during shelf life is better with 1-MCP than with DCA. 1-MCP-treated apples may have a "green taste" and excessive crispness, because of premature harvesting. It is therefore important to harvest fruit destined for 1-MCP treatment in the second half of the recommended harvest window. This approach may increase the harvest quantity, but also entails the risk of harvesting too late.

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