STORABILITY AND FRUIT QUALITY OF 'GOLDEN DELICIOUS' AS AFFECTED BY HARVEST DATE, AVG AND 1-MCP TREATMENTS

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A B S T R A C T

The effects of preharvest AVG and postharvest 1-MCP treatments on 'Golden Delicious', clone 'Reinders' apples (*Malus domestica* cv. 'Golden Delicious') stored in controlled atmosphere (CA) were studied during the 2003/04 growing and storage season. Retain™ (15% a.i.) was used as AVG source, and AVG treatment (125 ppm) was applied 4 weeks before optimal harvest date (OHD). Fruits were harvested at three different stages of maturity (OHD, OHD + 1 week, OHD + 2 weeks). After harvesting, the fruits of each stage of maturity (ca. 40 kg) were divided in two samples. One sample was treated with 1-MCP 625 ppb, the other one remained untreated. After treatment the samples were stored for approximately 270 days under CA conditions (temperature 1.0°C, O_2 1.5%, CO_2 3.5%).

Preharvest sprays of AVG delayed ripening for about 7 days and retarded postharvest ripening during CA-storage. Whereas AVG and 1-MCP untreated fruits showed excessive firmness losses and reduction of titratable acidity during shelf-life, AVG and 1-MCP delayed softening and stabilised titratable acidity. These effects were related to the stage of maturity, and a significant synergistic effect of AVG and 1-MCP on fruit quality was observed. Fruits in a stage of over maturity lost more in firmness and acidity than fruits harvested at their optimal stage of maturity. Total soluble solids (TSS) were also affected by AVG and 1-MCP treatments positively.

Fungal decay, CO_2 damages and senescent scald were the main problems after long term storage. The ability of 1-MCP to reduce fungal decay varied considerably among the stage of maturity. If apples, harvested too late, were treated with 1-MCP, only very little or no response occurred. AVG treatments strongly reduced fungal decays (from 18,4% to 3,4%) by delaying ripening. Overripe fruits treated with 1-MCP additionally showed a higher incidence of internal browning disorders (brown core, flesh browning, cavities) and scald. These fruits should be excluded from 1-

MCP treatments. 1-MCP treated fruits tended – independent of the stage of maturity – to be more susceptible to higher CO_2 concentrations than the untreated.

Key words: *Malus* x *domestica*, apple, 'Golden Delicious', optimal harvest date, controlled atmosphere, AVG, 1-MCP, fruit quality, firmness, storage disorders

INTRODUCTION

Golden Delicious' is the most important apple cultivar grown in the province of Styria in Austria. A unique set of climatic conditions in this area allows 'Golden Delicious' to grow better than in most other areas in Europe. In recent years, mainly 'Reinders'. a Dutch strain of 'Golden Delicious', has been planted. 'Reinders' showed less russeting than other types of 'Golden Delicious'. However, 'Reinders' has a smaller harvest window than clone B and should not be harvested late. It is prone to excessive pre-harvest fruit drops. 'Reinders' ripens rapidly after harvest because of its high respiration and ethylene production rates (Brackmann and Streif, 1994). In commercial apple production, NAA (naphthaleneacetic acid) and NAAm (naphthaleneacetamide) are usually used to control fruit drop, but increase respiratory rate (Bangerth, 1978). Pre-harvest treatment with AVG (aminoethoxyvinylglicine) can reduce pre-harvest fruit drop, delay ripening, and reduce loss of quality during storage. AVG significantly increased fruit firmness when applied as a pre-harvest spray (Williams, 1980). When applied four weeks before the optimal harvest date, AVG suppresses ethylene biosynthesis in apples (Autio and Bramlage, 1982; Bramlage et al., 1980; Halder-Doll and Bangerth, 1987). Ethylene plays an important role in fruit ripening, senescence, and the abscission of plant organs. When climacteric fruits begin to ripen, one of the earliest recognizable biochemical changes is an increase in ethylene biosynthesis (Yang and Hoffmann, 1984). AVG is a very potent inhibitor of the key enzyme in the ethylene biosynthetic pathway (ACC synthase). On the other hand, 1-MCP (1-methylcyclopropene) binds preferentially to ethylene receptors. 1-MCP reduces the response to ethylene in climacteric fruits (Watkins et al., 2000). 1-MCP is a particularly attractive ethylene inhibitor because it is non-toxic, volatile, and does not leave any residue. It acts at very low concentrations and produces relatively long effects (Binder and Bleecker 2003). In practice, 1-MCP is a potent inhibitor of ethylene production in apples. Quality benefits from post-harvest application of 1-MCP include retention of firmness and reduced incidence of scald (Fan et al., 1999b). 1-MCP effectively reduces many undesirable effects such as accelerated ripening, softening, and physiological disorders (Fan et al., 1999a). The ability of 1-MCP to reduce excessive fruit softening and physiological disorders varies considerably among cultivars and depends on storage conditions and stage of maturity. The effectiveness of 1-MCP treatment seems to depend on ethylene producing capacity and maturity (Cambiaghi et al., 2003).

The overall objective of these investigations was to evaluate the storage responses in Golden Delicious apples harvested at different stages of maturity (treated with AVG and 1-MCP) and stored under typical CA conditions. The antagonistic and synergistic interactions between AVG and 1-MCP treatments were also investigated.

MATERIAL AND METHODS

The effects of pre-harvest AVG and post-harvest 1-MCP treatments on 'Golden Delicious' clone Reinders apples stored in controlled atmosphere (CA) were studied during the 2003/04 growing and storage season. Retain^{TM} (15% a.i.) was used as AVG source, and AVG treatment (150 ppm) was applied four weeks before the estimated optimal harvest date (OHD). Fruits were harvested at five different stages of maturity (OHD – 2 weeks, OHD – 1 week, OHD, OHD + 1 week, OHD + 2 weeks). Maturity was assessed by the Streif index (Streif and Bufler, 1990). After harvesting, fruits at each stage of maturity (approx. 40 kg) were divided in two samples and cooled down to 2°C overnight. The samples were transferred to stainless steel, gas-tight storage containers. 1-MCP (625 ppb) was applied to one sample per variety at 2°C for 24 hours. 1-MCP is formulated as a powder. To release the a.i., 25 ml warmed water was added to the powder immediately before the treatment chamber was sealed for the duration of the treatment period. After 24 hours at cold storage temperatures, the chamber was opened and the apples were transferred to permanent CA storage for approximately 270 days (1°C, O_2 1.5%, CO_2 3.5%). They were then kept for seven days at 3°C and seven days at 20°C. A sample which was not treated with 1-MCP served as a reference.

Immediately after harvest, firmness, total soluble solids and titratable acidity were automatically determined on fifteen apples using the 'Pimprenelle' device (Setop-Giraud Technology, Cavaillon, France). This was repeated on twenty apples immediately after storage and after a cold storage period of seven days at 3°C followed by a shelf-life period of seven days at 20°C. Storage disorders and diseases were visually evaluated on fifty fruits after shelf-life. The number of fruits affected by each type of disease or disorder was recorded, and the percentage of storage losses was calculated. The sensory quality of apples was also evaluated by ten to fifteen trained judges using the Klosterneuburg quality scale from 0 to 100, where 0 equals very poor taste and 100 equals excellent taste.

RESULTS AND DISCUSSION

Fruit quality and maturity

Preharvest sprays of AVG delayed ripening for about 7 days and retarded postharvest ripening during CA-storage. Firmness decreased during storage and shelf-life depending on harvest date, AVG and 1-MCP treatment.

Table 1. Effect of AVG and 1-MCP treatments on firmness of 'Golden Delicious' (5 picking dates, I–V) after storage. Averages of firmness were analysed with the LSD method for a significance level of 5%

Treatments	Harvest dates	Firmness [kg/cm²]			
		at harvest	11.03.2004	17.06.2004	01.07.2004
CA-I	08.09.03	7.7 a	7.2 a	6.7 b	5.5 b
CA-II	16.09.03	7.4 ab	7.0 a	6.5 b	5.1 bc
CA-III	23.09.03	6.8 b	6.5 b	6.3 b	5.5 b
CA-IV	02.10.03	6.7 b	4.5 d	4.8 cd	4.1 c
CA-V	07.10.03	6.1 c	5.7 c	4.5 d	4.5 c
CA+AVG-III	23.09.03	7.4 a	6.5 b	6.1 bc	5.6 b
CA+AVG-IV	02.10.03	6.3 bc	5.4 c	5.1 c	4.5 c
CA+AVG-V	07.10.03	6.1 c	6.2 b	4.7 cd	4.7 bc
CA+MCP-I	08.09.03	7.7 a	7.3 a	7.5 a	6.8 a
CA+MCP-II	16.09.03	7.4 ab	7.4 a	7.0 ab	6.5 a
CA+MCP-III	23.09.03	6.8 b	7.2 a	6.2 bc	6.2 ab
CA+MCP-IV	02.10.03	6.7 b	6.2 b	6.0 bc	5.5 b
CA+MCP-V	07.10.03	6.1 c	5.8 bc	4.6 cd	4.9 bc
CA+AVG+MCP III	23.09.03	7.4 a	7.1 a	6.9 ab	6.2 ab
CA+AVG+MCP IV	02.10.03	6.3 bc	6.9 ab	6.0 bc	5.8 b
CA+AVG+MCP V	07.10.03	6.1 c	6.2 b	5.8 bc	5.4 b

Significant differences in firmness were observed between the picking dates (Tab. 1). Fruits harvested too late (OHD + 1, OHD + 2) lost more in firmness than fruits harvested at their optimal stage of maturity. Whereas untreated fruits showed excessive losses in firmness during shelf-life, AVG and especially 1-MCP delayed softening. These effects were related to stage of maturity, and a significant synergistic effect of AVG and 1-MCP on fruit flesh firmness was observed (Fig. 1). Apples treated with AVG alone retained firmness less than untreated apples, but the difference was not significant. Apples treated only with 1-MCP were also significantly firmer than untreated apples. 1-MCP at 625 ppm effectively prevented softening at all stages of maturity compared to the untreated controls, except for the latest harvest date

(OHD + 2). The ability of 1-MCP to retard softening in CA-stored fruit declined with delay in harvest. The results indicate that the efficacy of 1-MCP is affected by the stage of maturity. 'Golden Delicious' apples harvested later require higher a 1-MCP dosage to maintain firmness and should be removed from storage in the middle of March at the latest. For a high sensory estimation by the consumer, firmness of 'Golden Delicious' fruits should not be lower than 5.5 kg/cm² at the time of consumption. Apples which were harvested late and apples which had not been treated with 1-MCP were too soft after long-term CA storage. Only apples harvested at the optimal stage of maturity stored in CA remained firm. AVG followed by 1-MCP treatment strongly delayed post-storage ripening. Whereas either AVG or 1-MCP alone only slowed loss of firmness, when combined, they perfectly stabilized firmness in apples which had been harvested late during long-term storage (Tab. 1).

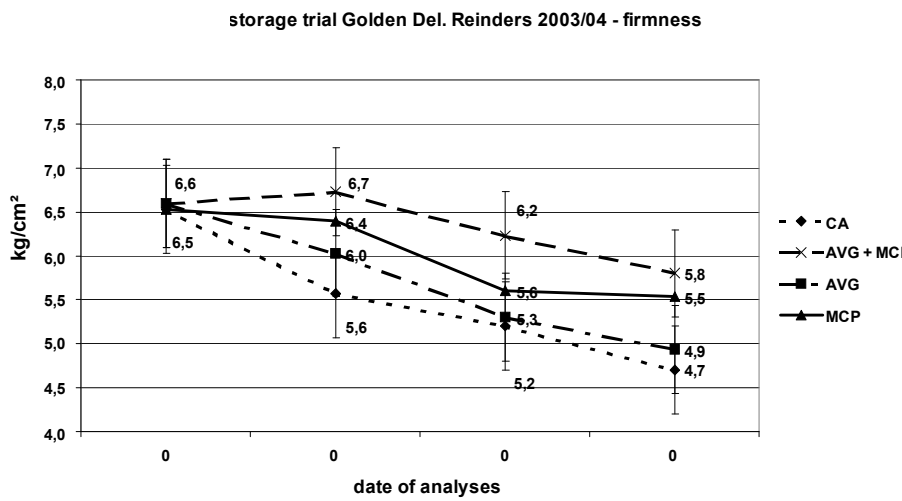

Figure 1. Effect of AVG and 1-MCP treatments on firmness of 'Golden Delicious' during CA storage (average of the last 3 picking dates, OHD, OHD+1, OHD+2)

Total soluble solids (TSS) was also improved by AVG and 1-MCP treatments (data not presented). Apples treated with AVG showed a higher increase of TSS during storage more than untreated apples. 1-MCP stabilized TSS content during storage. Titratable acidity was higher in apples treated with AVG and 1-MCP (data not presented). Sensory evaluation showed also

a synergistic effect of AVG and 1-MCP treatments. After long-term storage, the sensory quality of the apples from the latest harvest was inadequate. Only fruits treated with AVG and 1-MCP had high sensory quality (Fig. 2).

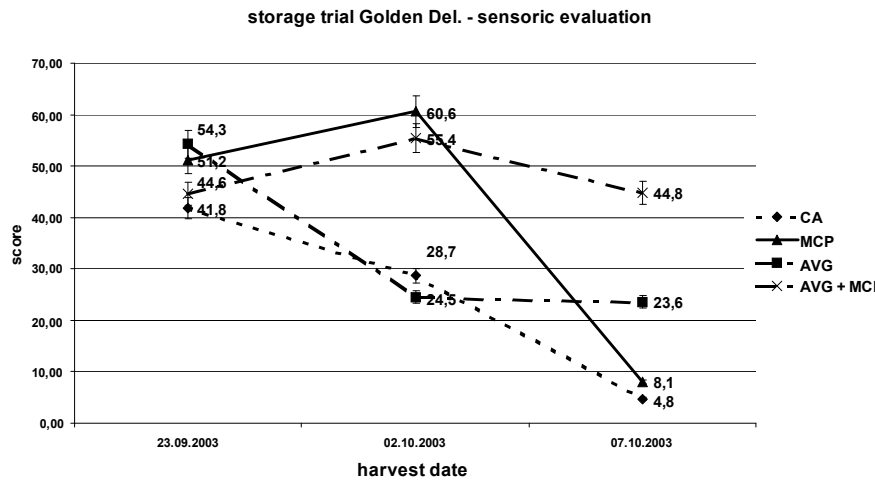

Figure 2. Effect of AVG and 1-MCP treatments on sensoric evaluation of 'Golden Delicious' of the last 3 picking dates (OHD, OHD+1, OHD+2)

Storage disorders and fungal decay

An overview of total storage losses with all treatments is presented in Table 2. Losses were caused by scald, internal browning disorders (senescence breakdown and cavities), external CO_2 injury and fungal decay during about nine months of storage. Harvest date was strongly correlated with the incidence of storage diseases and disorders. AVG alone reduced fungal rot by 33 to 88%, depending on harvest date. The ability of 1-MCP to reduce fungal decay varied considerably among the harvest dates. A late picking date resulted in substantially higher fungal rot compared to early or optimally harvested fruits (Tab. 2). AVG and 1-MCP clearly showed a synergistic effect on prevention of fungal rot.

Internal browning disorders and scald mainly occurred in the apples treated with 1-MCP and tended to be influenced by the harvest date. The later the picking date, the more frequently the incidence of browning disorders. All overripe samples treated with 1-MCP showed a higher incidence of internal browning disorders than untreated apples. The incidence of 'senescence breakdown' increased dramatically. AVG had no clear effect on internal browning disorders. Overripe apples and unripe apples were affected negatively by 1-MCP treatments. Unripe apples showed a higher incidence of external CO2 injury. Overripe apples

were extremely susceptible to internal browning disorders. Apples treated with 1-MCP tended to be more susceptible to higher CO_2 concentrations than the untreated apples at any stage of maturity.

Table 2. Effect of AVG and 1-MCP treatments on incidence of disorders and fungal decay of 'Golden Delicious' (5 picking dates, I–V) after storage. Averages were analysed with the LSD method for a significance level of 5%

Treatments	Harvest dates	Storage disorders and diseases in %				
		fungal decay	scald	internal browning disorders	external CO_2 injury	total storage losses
CA-I	08.09.03	0.0	0.0	0.0	0.0	0.0 e
CA-II	16.09.03	2.3	0.0	0.0	0.0	2.3 d
CA-III	23.09.03	2.1	0.0	3.3	0.0	5.4 d
CA-IV	02.10.03	7.1	0.0	0.0	0.0	7.1 d
CA-V	07.10.03	45.3	0.0	0.0	0.0	45.3 b
CA+AVG-III	23.09.03	0.0	0.0	0.0	0.0	0.0 e
CA+AVG-IV	02.10.03	4.7	0.0	0.0	0.0	4.7 d
CA+AVG-V	07.10.03	5.6	0.0	10.0	0.0	15.6 c
CA+MCP-I	08.09.03	1.0	0.0	0.0	33.3	34.3 b
CA+MCP-II	16.09.03	0.0	0.0	0.0	13.3	13.3 c
CA+MCP-III	23.09.03	0.0	0.0	0.0	13.3	13.3 c
CA+MCP-IV	02.10.03	1.2	0.0	13.3	3.3	17.9 c
CA+MCP-V	07.10.03	22.1	16.7	66.7	0.0	105.4 a
CA+AVG+MCP III	23.09.03	1.1	0.0	0.0	20.0	21.1 c
CA+AVG+MCP IV	02.10.03	0.0	20.0	10.0	0.0	30.0 b
CA+AVG+MCP V	07.10.03	2.2	0.0	6.7	0.0	8.9 cd

The incidence of senescent scald also tended to be higher in overripe apples treated with 1-MCP. No senescent scald was observed on AVG treated apples, but only in CA stored fruits.

CONCLUSION

Pre-harvest spraying with AVG delayed ripening for about seven days and retarded post-harvest ripening during CA storage. Whereas apples which had not been treated with AVG and 1-MCP showed excessive firmness losses and reduction of titratable acidity (TA) during shelf-life, AVG and 1-MCP delayed softening and stabilised TA. These effects were related to the stage of maturity, and a significant synergistic effect of AVG and 1-MCP on fruit

quality was observed. Overripe apples lost more in firmness and acidity than fruits harvested at the optimal stage of maturity. Total soluble solids (TSS) was also improved by AVG and 1-MCP treatments.

Fungal rot, internal browning, CO_2 damage and senescent scald were the main problems after long term storage. The ability of 1-MCP to reduce fungal rot varied considerably depending on the stage of maturity. When apples which had been harvested too late were treated with 1-MCP, there was little or no response. AVG treatments delayed ripening and strongly reduced fungal rot by 3.4 to 18.4%. Overripe apples treated with 1-MCP also showed a higher incidence of scald and internal browning disorders such as brown core, flesh browning and cavities. These apples should not be treated with 1-MCP. Apples treated with 1-MCP tended to be more susceptible to higher CO_2 concentrations than the untreated apples at any stage of maturity. Therefore, the reduction of CO_2 concentration in CA storage from 3.5% to a maximum of 2.5% seems to be necessary so that fruits treated with 1-MCP do not suffer large storage losses caused by CO_2 damage.

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WPŁYW TERMINU ZBIORU, TRAKTOWANIA AVG I 1-MCP NA TRWAŁOŚĆ PRZECHOWALNICZĄ I JAKOŚĆ OWOCÓW 'GOLDEN DELICIOUS'

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S T R E S Z C Z E N I E

W sezonie 2003/2004 badano wpływ przedzbiorczego traktowania AVG i pozbiorczego traktowania 1-MCP na jabłka 'Golden Delicious', clon 'Reinders' (*Malus Domestica*) przechowywane w kontrolowanej atmosferze (CA). Traktowanie AVG (125 ppm) przeprowadzono 4 tygodnie przed optymalnym terminem zbioru (OHD). Owoce zbierano w 3 różnych stadiach dojrzałości (OHD, OHD + 1 tydzień, OHD + 2 tygodnie). Po zbiorze owoce z każdego stadium dojrzałości (ok. 40 kg) podzielono na dwie próbki. Jedną próbkę owoców traktowano 1-MCP w stężeniu 625 ppb, pozostała część owoców nie była traktowana. Następnie owoce przechowywano przez 270 dni w warunkach kontrolowanej atmosfery (temperatura 1°C, O_2 – 1,5%, CO_2 – 3,5 %).

Opryskiwanie jabłek roztworem AVG przed zbiorem opóźniało ich dojrzewanie o około 7 dni i hamowało pozbiorcze dojrzewanie owoców przechowywanych w kontrolowanej atmosferze. Owoce nietraktowane ani AVG, ani 1-MCP wykazywały nadmierną utratę jędrności i redukcję kwasowości podczas symulowanego obrotu towarowego. Traktowanie AVG i 1-MCP opóźniało mięknięcie owoców i stabilizowało kwasowość miareczkową. Wpływ ten był zależny od stadium dojrzałości i obserwowano istotny synergistyczny efekt traktowania AVG i 1-MCP na jakość owoców. Przechowywanie jabłek zbyt dojrzałych przyczyniało się do większej utraty ich jędrności i kwasowości niż w przypadku owoców zebranych w optymalnym stadium dojrzałości. Traktowanie AVG i 1-MCP wpływało korzystnie również na zawartość ekstraktu.

Głównymi problemami podczas długiego przechowywania były choroby grzybowe, uszkodzenia CO_2 i oparzelizna. Zdolność 1-MCP do ograniczania chorób grzybowych była różna i zależała od stadium dojrzałości owoców. Jeśli 1-MCP stosowano na owocach zebranych zbyt późno, to 1-MCP miał niewielki wpływ lub żadnego na występowanie chorób grzybowych. Traktowanie AVG silnie ograniczało występowanie chorób grzybowych (od 18,4 do 3,4%) przez opóźnianie dojrzewania. U owoców przejrzałych traktowanych 1-MCP częściej występowały zbrązowienia wewnętrzne i oparzelizna. Takie owoce nie powinny być traktowane 1-MCP. Jabłka traktowane 1-MCP, niezależnie od stadium dojrzałości, miały skłonność do większej wrażliwości na wysokie stężenie CO_2 niż owoce nietraktowane.

Słowa kluczowe: *Malus x domestica*, jabłka, 'Golden Delicious', optymalny termin zbioru, kontrolowana atmosfera, AVG, 1-MCP, jakość owoców, jędrność, choroby przechowalnicze