ATO

Registration of 1-MCP treatments on Elstar and Tentation apples

Report of experiments storage season 2002-2003

April 2003

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Summary

Experiments on 1-methylcyclopropene (1-MCP, SmartFresh™) were carried out by ATO for AgroFresh Inc. To test the efficacy of 1-MCP on apples, trials were performed on apple cultivars 'Elstar' and 'Tentation' in the storage season 2002-2003.
For conducting post-harvest treatments of agro-products, ATO has an official recognition to perform efficacy evaluation trials. This research was done following the rules of this recognition.

Apples were harvested at the optimum picking date and also 9 days later (Elstar) or 14 days later (Tentation) at a more mature stage. Treatments with 1-MCP started two days after harvest. Elstar was treated with 625 ppb 1-MCP. Tentation was treated with 312 and 625 ppb 1-MCP.

Subsequently apples were stored in normal air (cooling) or in ULO conditions (low O_2, high CO_2). Quality of Elstar apples was determined after 2, 4, and 6 months of air storage and after 4 and 6 months of ULO storage. Quality of Tentation apples was determined after 2 and 4 months of air storage and after 4 months of ULO storage. A shelf-life period of 14 days was simulated after each storage.

There were no clear differences between 312 and 625 ppb 1-MCP treatment of Tentation.

Very positive effects of 1-MCP were found on firmness retention of both cultivars. Positive effects were also found on retention of colour, retention of titratable acids, inhibition of rot (during shelf-life after 6 months air storage of Elstar) and prevention of scald (normal harvest Tentation). There were no important effects of 1-MCP on soluble solids content.
For Tentation both 312 and 625 ppb 1-MCP was tested, but there were no important differences between these concentrations.

1-MCP can be advantageous for ULO (CA) storage.
Both for Elstar (4 and 6 months ULO storage) and Tentation (4 months ULO storage), firmness after ULO storage was equal for control and 1-MCP treated apples. However, while control Elstar apples lost firmness during 14 days shelf-life, 1-MCP treated apples did not. This was the case both for normal and late harvest. Control Tentation apples only lost firmness during 14 days shelf-life in case of late harvest. Again 1-MCP prevented this firmness loss. In many cases, 1-MCP resulted in greener apples (Elstar and Tentation) and higher acidity (Tentation).
There were no important effects of 1-MCP on soluble solids content, % rot or skin spots (Elstar). The disorder scald did not occur in ULO stored apples.

For Elstar, 1-MCP could be used to replace ULO during a 4 and 6 months storage period. The advantage of 1-MCP above ULO was firmness retention during shelf-life. For Tentation 1-MCP could be used to replace ULO during a 4 months storage period, but only for normal harvest.

1-MCP can facilitate both air and ULO storage of apples that are harvested at a more mature stage. After 2, 4 and 6 months air storage plus shelf-life, firmness of 1-MCP treated Elstar of late harvest was still acceptable while firmness of control apples was not. Also after 4 and 6 months ULO storage plus shelf-life, firmness of 1-MCP treated Elstar of late harvest was still acceptable, while firmness of control Elstar was not. For the (extremely) late harvested Tentation, there was no big firmness loss of control apples. Application of 1-MCP resulted in apples of even better firmness and often greener colour and higher acidity.

In all cases, 1-MCP treatment (both normal and late harvest, all tested storage periods) prevented firmness loss of Elstar and Tentation during shelf-life following ULO storage.

1-MCP prevented development of scald in Tentation apples of normal harvest. 1-MCP could not prevent scald in (extremely) late harvested apples.

1 Introduction

To test the efficacy of 1-MCP on apples, experiments were performed on apple cultivars 'Elstar' and 'Tentation' in the storage season 2002-2003.
The following objectives were formulated before the start of the experiments:

- To reveal the efficacy of 1-MCP treatments on various quality aspects of CA (ULO) stored apples. In other words: does 1-MCP improve CA storage?
- To reveal the efficacy of 1-MCP treatments on various quality aspects of apples in comparison to CA (ULO) storage. In other words: can 1-MCP be used to replace CA under certain conditions?
- Does 1-MCP facilitate the storage of apples harvested at a more mature stage?
- Does 1-MCP improve the shelf-life of CA(ULO)-stored apples?
- Does 1-MCP inhibit development of scald in Tentation apples?

To find an answer to these questions, apples were harvested at the optimum picking date and also 9 days later (Elstar) or 14 days later (Tentation) at a more mature stage. The treatments of 1-MCP started 2 days after harvest. Subsequently apples were stored in normal air (only cooling) or in ULO conditions (low O_2, high CO_2). Quality of Elstar apples was determined after 2, 4 and 6 months of storage and after a simulated shelf-life period of 14 days. Quality of Tentation apples was determined after 2 and 4 months of storage and after a simulated shelf-life period of 14 days. The experiments were done following the rules of formal recognition.

2 Formal recognition

For conducting post-harvest treatments of agro-products, ATO has an official recognition to perform efficacy evaluation trials. This research was done following the rules of this recognition.

3 Materials and methods

Harvest
In September and October 2002 apples were harvested. Apples were harvested at their optimal harvest date (commercial advice) and also 9 days (Elstar) or 14 days (Tentation) after the optimal harvest date. Harvest of Elstar took place on September 9th and September 18th. Harvest of Tentation took place on September 30th and October 14th. For Elstar, the 'Elshof' mutant was used. In all cases, apples were picked from trees that had not been strip-picked before. For the late harvest of Tentation this was an uncommon situation.
Elstar was from an orchard in Randwijk, province Gelderland, The Netherlands (10 km from Wageningen). Tentation was from an orchard in Tholen, province Zeeland, The Netherlands (south-west).
After harvest, apples were placed in a temperature controlled room at 1.8 °C (Elstar) or 1.0 °C (Tentation).

Other pre and post-harvest treatments for post-harvest purposes
Within one month before harvest, only applications of fungicides, leave nutrition, and prevention of late drop of apples from the tree (Tentation, Luxan 10%) in the orchard were performed.

Storage issues in commercial storage
Both cultivars are commercially stored in air up to 3 months and in ULO up to 8 months.
Main problems of Elstar are firmness loss during shelf-life and the occurrence of skin spots in sensitive batches.
Main problem of Tentation is development of scald.

Sorting and randomisation
1 or 2 days after harvest, apples were sorted and randomised. Apples that were damaged or very small or very large were removed.

1-MCP treatment
Apples were treated during 24 hours with 1-MCP at 1.8 °C (Elstar) or 1.0 °C (Tentation). Treatments started two days after harvest. Elstar was treated with 625 ppb 1-MCP. Tentation was treated with 312 and 625 ppb 1-MCP. Treatment dates are given in table 1. Also control apples (0 ppb 1-MCP) were included in the experiments.

Table 1. Harvest dates, 1-MCP treatment dates and start of air/ULO storage for Elstar and Tentation (all dates were in year 2002).

	Harvest date	Treatment date	Start air or ULO storage
Elstar normal harvest	Sept 9th	Sept 11th	Sept 14th
Elstar late harvest	Sept 18th	Sept 20th	Sept 23th
Tentation normal harvest	Sept 30th	Oct 2nd	Oct 4th
Tentation late harvest	Oct 14th	Oct 16th	Oct 18th

To generate 1-MCP levels around the apples, 1-MCP (0.14%) as provided by AgroFresh Inc. was used. The 1-MCP treatments were performed in plastic covers (1.23 m^3 free volume, 100-110 kg apples). In this system airtight plastic is used to cover the fruits which are placed in crates on a pallet. Lime (±10 litre) was placed in each cover to prevent CO_2 accumulation. There was no significant decline in O_2 or rise in CO_2 during treatments. Also in each cover a closed bottle with the desired amount of dissolved 1-MCP was placed. Covers were closed tightly at the top end by a rope and tape. The air inside the covers was circulated by a pump.
1-MCP treatments started by opening the bottles. The flexibility of the cover allowed opening of the bottles from outside the cover.
Control apples were placed in a separate room to prevent any possible contact with 1-MCP.

1-MCP concentration and preparation

The active ingredient of 1-MCP is 0.14%. The free volume inside each pallistore cover was calculated to be 1.23 m^3. The following solutions were made:

- 312 ppb 1-MCP: 0.62 g powder + 98 ml water (ratio product:water 160)
- 625 ppb 1-MCP: 1.23 g powder + 197 ml water (ratio product:water 160)

For preparing each solution, a bottle (1 l) was filled with the correct amount of powder. The flask was closed with a lid containing a septum. Air was drawn from the closed flask with a syringe. The air volume taken out was equal to the volume of water that was added subsequently. The water (demineralised, ± 20 °C) was added with a syringe. The lid was then wrapped with parafilm. The solution was shaken by hand several times until all the powder had dissolved.

Storage conditions

During and after the 1-MCP treatment all apples were kept under ambient air at 1.8 °C (Elstar) or 1 °C (Tentation) for 1-2 days. Subsequently part of the apples were stored under ambient air (cooling) and part of the apples under standard CA conditions (ULO). Dates are given in table 1. Relative humidity during storage was 95-100%.

Temperature, relative humidity and ULO conditions were comparable to standard Dutch storage conditions.

ULO conditions Elstar : first month 1.2% O_2 and 2.5% CO_2
subsequently 1.0% O_2 and 2.5% CO_2

ULO conditions Tentation : all storage 1.2% O_2 and 2.0% CO_2.

Gas conditions were monitored every hour. All apples were stored in containers. Within each container, apples from the same cultivar and harvest date were stored. In order to expose apples from different 1-MCP treatments to equal temperature/gas conditions and to reach 2 replicates, apples from the different 1-MCP treatments were stored together in the containers. The number of replicates was 2 (containers).

Quality measurements

Initial quality of apples was measured within two days after harvest. Initial quality of each harvest was measured on 2 samples of 20 apples.

After storage, apples were sampled for quality measurements. A sample consisted of 20 apples. Again 2 samples (replicates) of 20 apples were measured from each treatment. Assessment dates are given in Table 2.

Table 2. Assessment dates for Elstar and Tentation directly after storage and after storage plus shelf-life.

Storage duration	Elstar cooling	Elstar ULO	Tentation cooling	Tentation ULO
2 months	Nov 8th 2002		Dec 3th 2002	
2 months + shelf-life	Nov 22th 2002		Dec 17th 2002	
4 months	Jan 9th 2003	Jan 9th 2003	Feb 3th 2003	Feb 3th 2003
4 months + shelf-life	Jan 23th 2003	Jan 23th 2003	Feb 17th 2003	Feb 17th 2003
6 months	March 10th 2003	March 10th 2003		
6 months + shelf-life	March 24th 2003	March 24th 2003		

Directly after storage, apples were measured on firmness, rot and scald. After a simulated distribution period of 14 days, measurements on more quality aspects were performed.

The simulation was performed in a temperature controlled room at 18 °C and 75-80% RH. Measurements were done on firmness (individual apples), colour (individual apples), content of soluble solids (sugars, mixed sample), titratable acidity (mixed sample), and external and internal disorders. Firmness was measured with a fruit texture analyser (Güss, electronic measuring system). Colour was measured visually using a colour chart (Unifruco Research Services LTD/Agricura) with a scale from 0.5 to 5 where 0.5=green and 5=yellow. The content of soluble solids was measured with a digital refracto-meter (ATAGO, PR-1 brix-meter). Titratable acidity was analysed with an automatic titrator using 0.1 M NaOH. Rot included core fungus, rot, and stalk rot. The occurrence of skin spots at Elstar apples was analysed separately (score of 0-100).

Statistical analysis

Data were analysed statistically without transformation. Different treatments were analysed for significant differences by analysis of variance (ANOVA) with the statistical package Genstat. When significant differences were found, comparisons between pairs of data were made using the least significant differences between means (LSD) at a significance level of 95%. ANOVA was not performed for % apples with disorders and % apples with skin-spots, as residuals were not normally distributed.

Summary of experimental set-up

Apple varieties:	Elstar ('Elshof'), Tentation
Harvest dates:	optimal, late
Treatment:	24 h. at 1.8 °C (Elstar) or 1.0 °C (Tentation)
1-MCP concentrations:	0 and 625 ppb, starting 2 days after harvest (Elstar)
	0, 312 and 625 ppb, starting 2 days after harvest (Tentation)
Storage gas conditions:	ambient air, ULO
Storage temperature:	1.8 °C (Elstar), 1.0 °C (Tentation)
Sampling dates:	2, 4, 6 months for air storage (6 months only for Elstar)
	4, 6, months for ULO (6 months only for Elstar)
Measurement dates:	0, 14 (days after storage)
Measurements:	firmness, colour, sugars, acidity, external and internal disorders
Apples per measurement:	40 (2 replicates * 20 apples)

4 Results Elstar

4.1 Elstar, initial quality

The mean firmness of Elstar at the start of the experiments was 65.3±0.2N (mean ± standard deviation) for normal harvest and 53.0±0.6 for late harvest. The mean colour was 3.7±0.0 and 4.2±0.0 respectively. The mean content of soluble solids was 12.5±0.1 and 13.9±0.2 °brix respectively. The mean % titratable acidity was 2.11±0.25 and 1.25±0.06 respectively.

4.2 Elstar, 2 months storage

After 2 months of storage, only the apples stored under normal air were assessed.

Apples of normal harvest date lost firmness during 2 months air storage, which was inhibited by 1-MCP treatment. Control apples showed also severe firmness loss during subsequent shelf-life which was again inhibited by 1-MCP (Fig 1A). After shelf-life, only 1-MCP treated apples had acceptable firmness.
Firmness at harvest was 65.3±0.2 N, the firmness after 2 months air storage was 54.4±0.7 N and 57.6 ±0.4 N for control and 625 ppb 1-MCP respectively.

There was no significant firmness loss of late harvested apples during 2 months air storage. Control apples showed severe firmness loss during shelf-life while 1-MCP treated apples did not. After shelf-life, only 1-MCP treated apples had acceptable firmness.
Firmness at harvest was 53.0±0.6 N, firmness after storage was 53.8±1.4 and 52.6±1.4 N for control and 625 ppb 1-MCP respectively.

1-MCP slightly inhibited yellowing of normal harvest (Fig. 2A, not statistically significant) and late harvest (Fig. 2B, statistically significant).

There were no clear effects of 1-MCP on soluble solids content (Fig. 3).

For late harvest, 1-MCP treatment resulted in higher titratable acidity (Fig. 4).

No skin spots were found. There were no clear effects of 1-MCP on other disorders (Fig. 5).

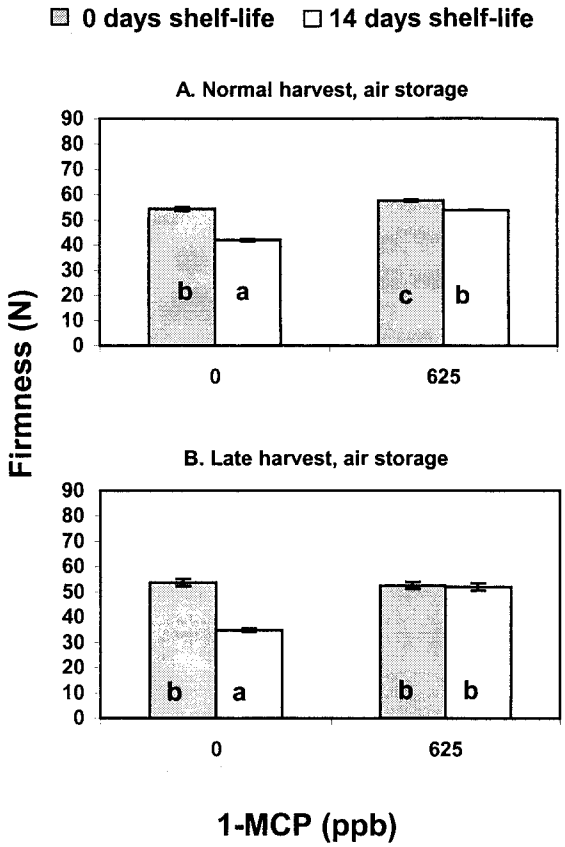

Fig. 1. Firmness of Elstar after 2 months of storage. Vertical bars indicate ± std of the mean of two replicates. Columns within a chart marked with a same letter are not statistically different (P=0.05).

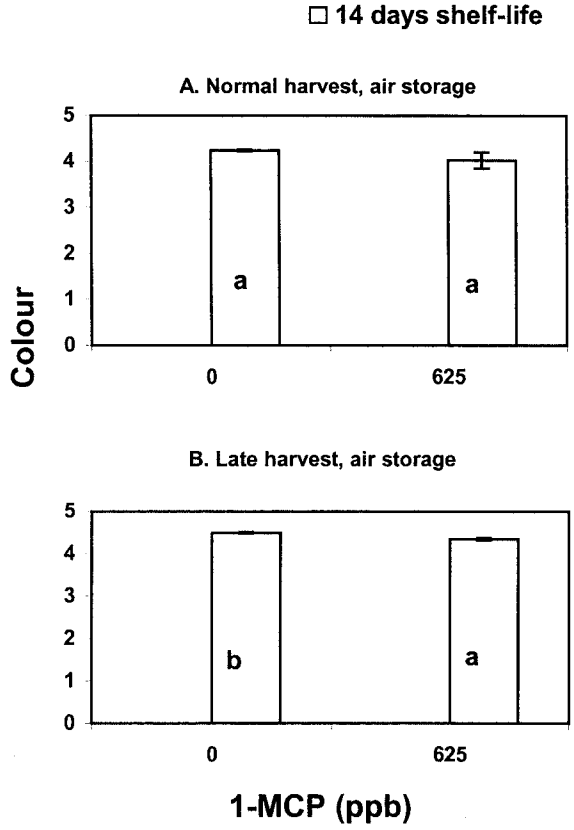

Fig. 2. Colour of Elstar after 2 months of storage. Vertical bars indicate ± std of the mean of two replicates. Columns within a chart marked with a same letter are not statistically different (P=0.05).

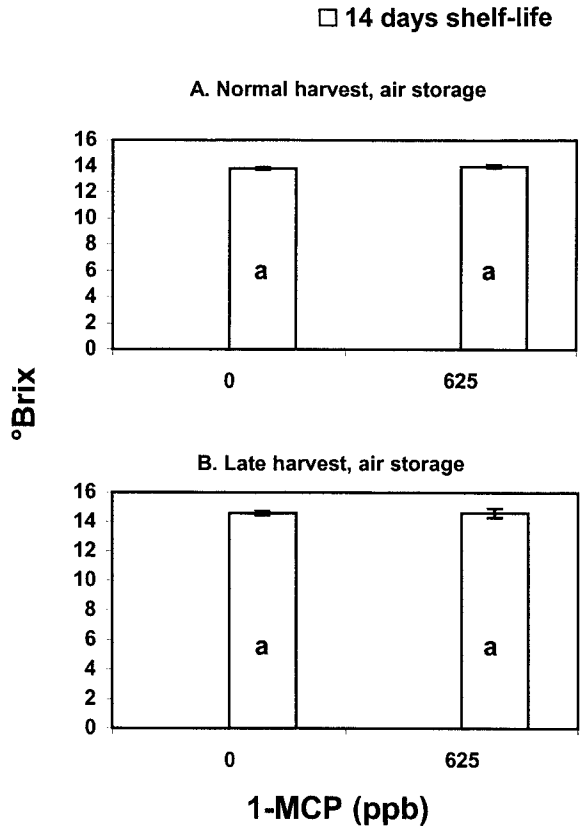

Fig. 3. Soluble solids content of Elstar after 2 months storage. Vertical bars indicate ± std of the mean of 2 replicates. Columns within a chart marked with a same letter are not stat. diff. (P=0.05).

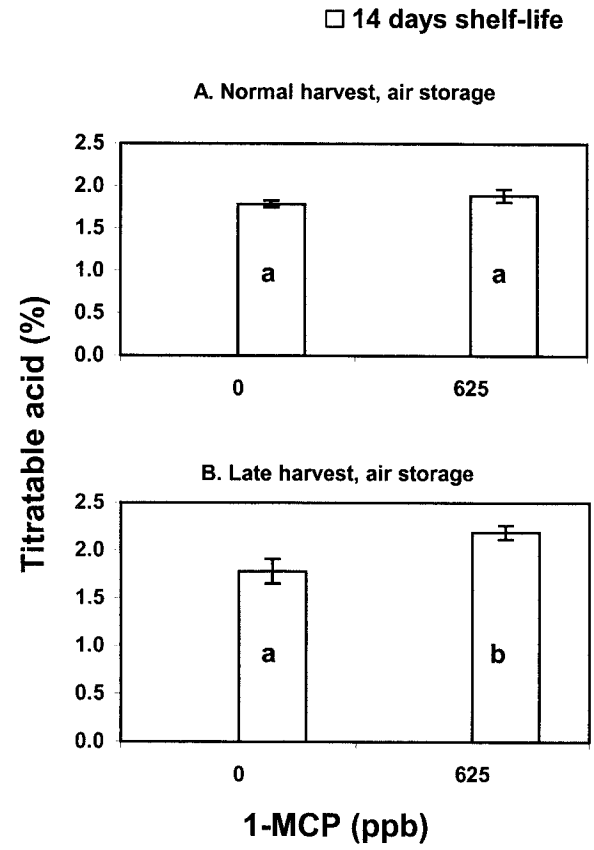

Fig. 4. Titratable acidity of Elstar after 2 months storage. Vertical bars indicate ± std of the mean of 2 replicates. Columns within a chart marked with a same letter are not statistically different (P=0.05).

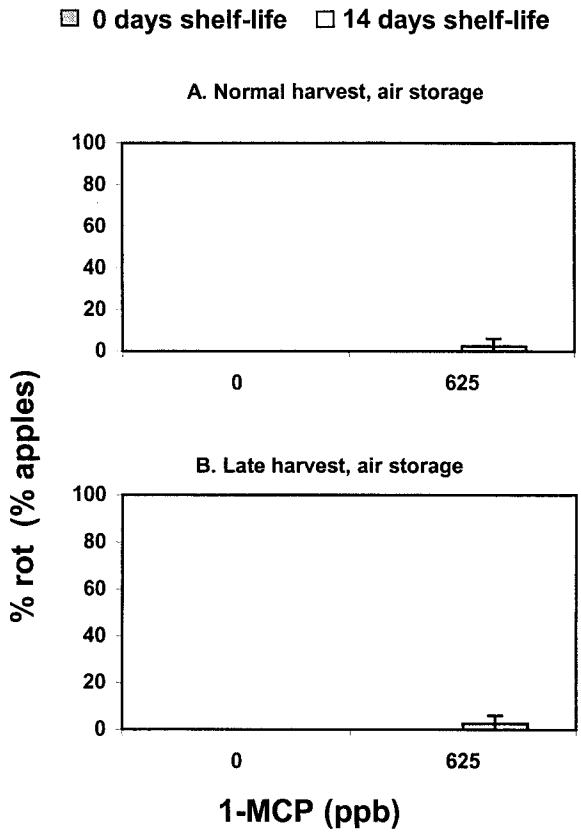

Fig. 5. % apples with disorders of Elstar after 2 months storage. Vertical bars indicate ± std of the mean of 2 replicates.

4.3 Elstar, 4 months storage

The firmness of control apples (0 ppb 1-MCP) of normal harvest after 4 months air storage was near the requirements for good quality (45-50 N) and decreased further during shelf-life (Fig. 6A). 1-MCP inhibited firmness loss during shelf-life, resulting in apples of still acceptable firmness after shelf-life. Firmness of 1-MCP treated apples after air storage + shelf-life (Fig. 6A) was better than the firmness of untreated apples after ULO storage + shelf-life (Fig 6C).

For late harvest, firmness loss of untreated apples during air storage and shelf-life was severe (Fig 6B). 1-MCP inhibited firmness loss during air storage and prevented further firmness loss during subsequent shelf-life. After 14 days shelf-life, 1-MCP treated apples were near the requirements for good quality.

The effect of 1-MCP on ULO stored apples of both normal and late harvest became clear only during shelf-life where firmness of apples was maintained after 1-MCP treatment (Fig. 6C and 6D).

1-MCP inhibited yellowing of normal harvest (Fig. 7A and 7C) and late harvest in case of ULO (Fig. 7D).

There were no large effects of 1-MCP on soluble solids content (Fig. 8).

For air storage of both normal and late harvest, 1-MCP treatments resulted in higher acidity (Fig. 9A and 9B). For ULO storage of both normal and late harvest, 1-MCP treatment had no effect (Fig. 9C and 9D).

There was no clear effect of 1-MCP on other disorders (Fig. 10).

Skin spots were found both for normal and late harvest, and both for air storage and ULO (Fig. 11). There was no clear effect of 1-MCP.

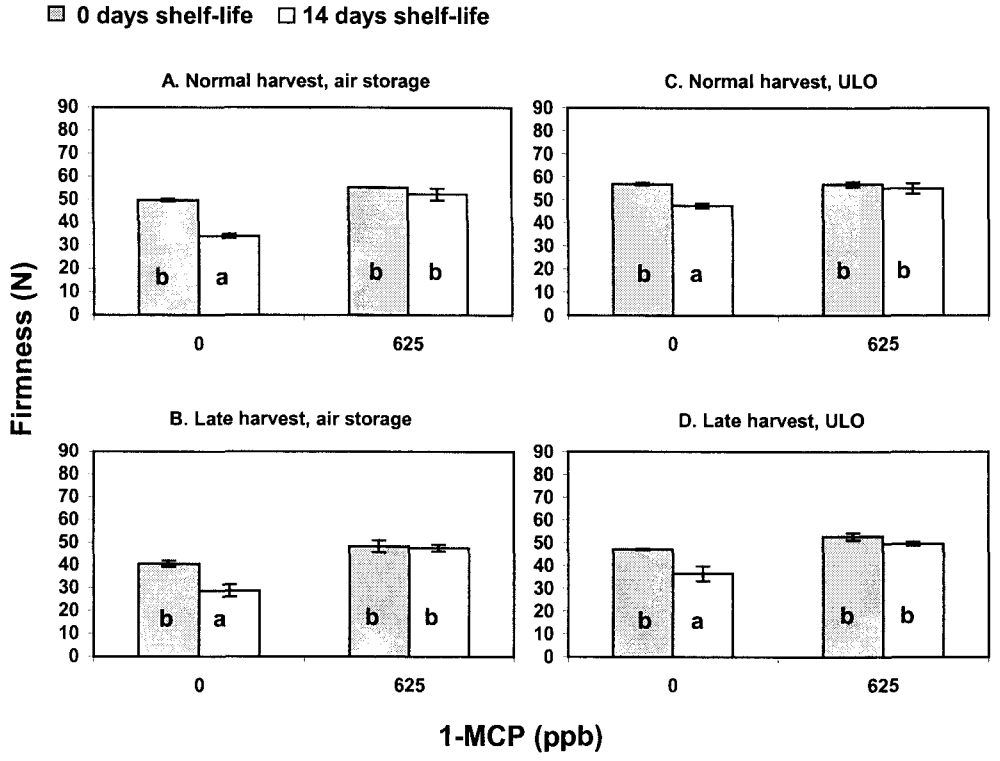

Fig. 6. Firmness of Elstar after 4 months of storage. Vertical bars indicate ± std of the mean of two replicates. Columns within a chart marked with a same letter are not statistically different (P=0.05).

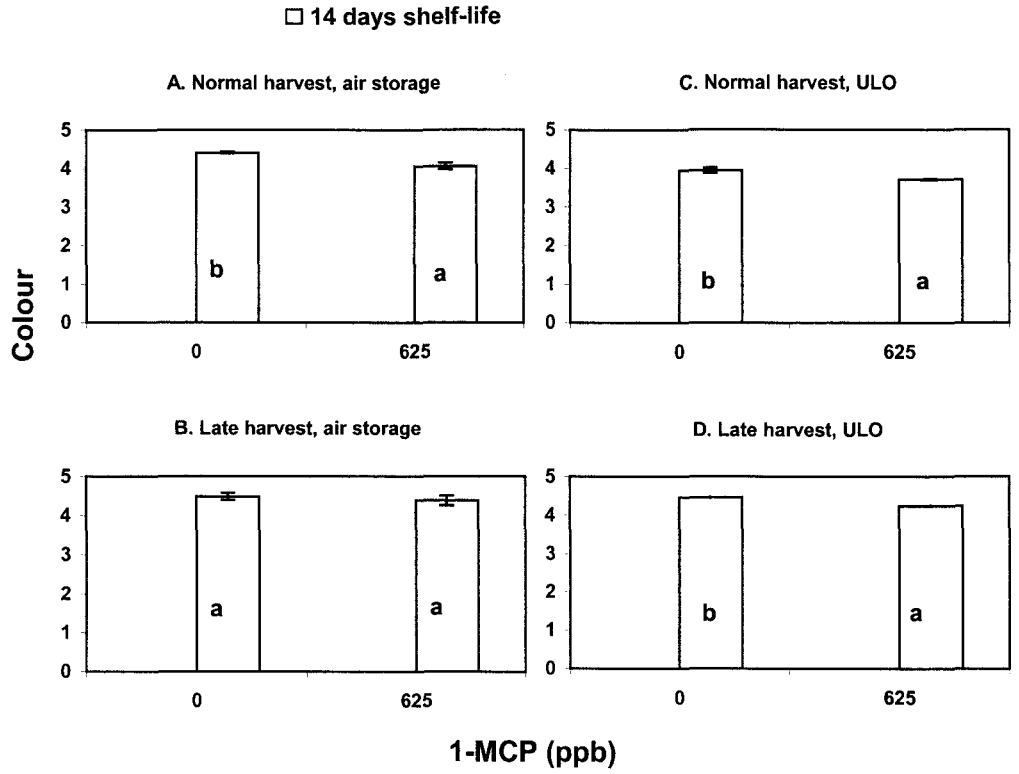

Fig. 7. Colour of Elstar after 4 months of storage. Vertical bars indicate ± std of the mean of two replicates. Columns within a chart marked with a same letter are not statistically different (P=0.05).

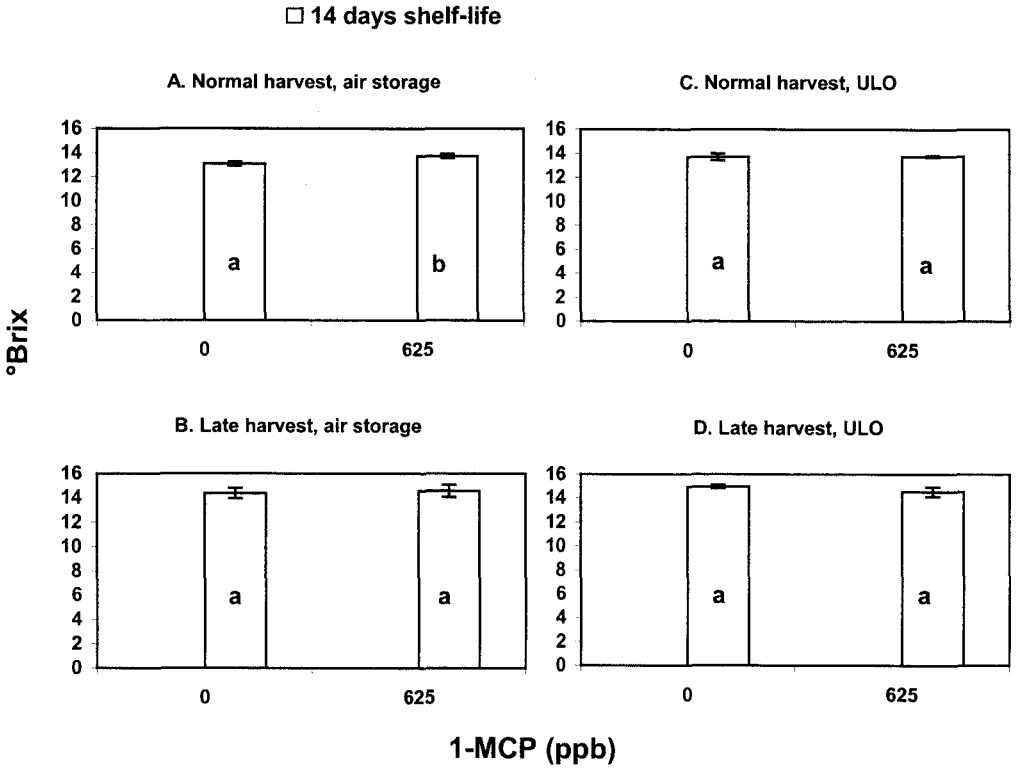

Fig. 8. Soluble solids content of Elstar after 4 months storage. Vertical bars indicate ± std of the mean of 2 replicates. Columns within a chart marked with a same letter are not statistically different (P=0.05).

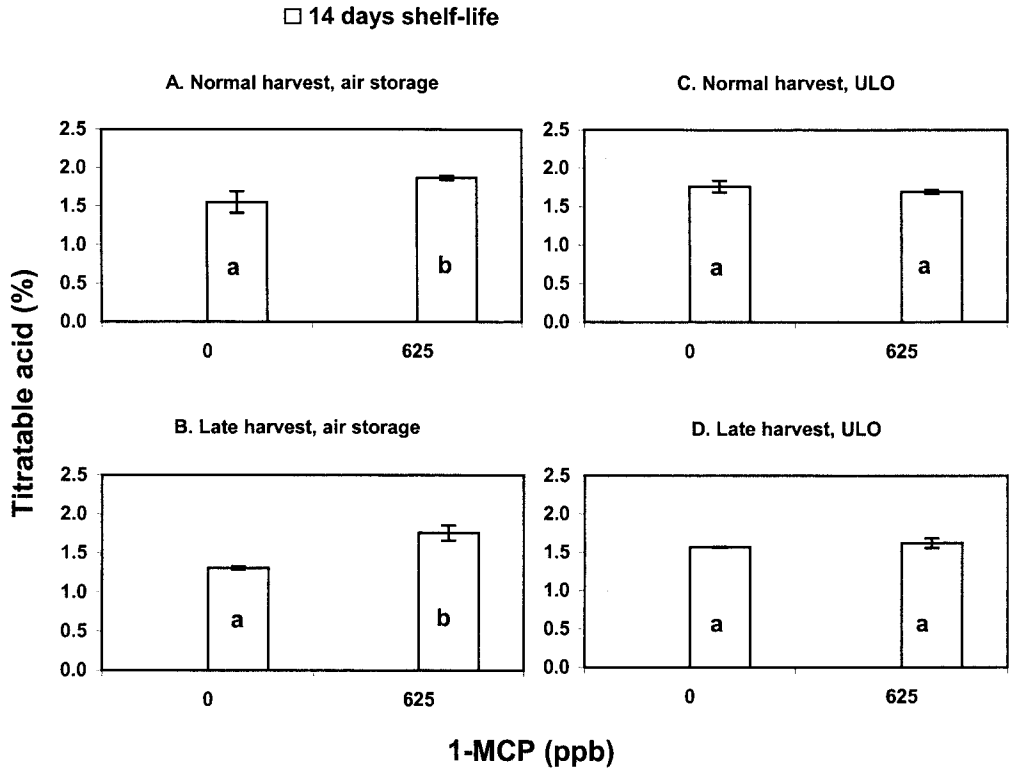

Fig. 9. Titratable acidity of Elstar after 4 months storage. Vertical bars indicate ± std of the mean of 2 replicates. Columns within a chart marked with a same letter are not statistically different (P=0.05).

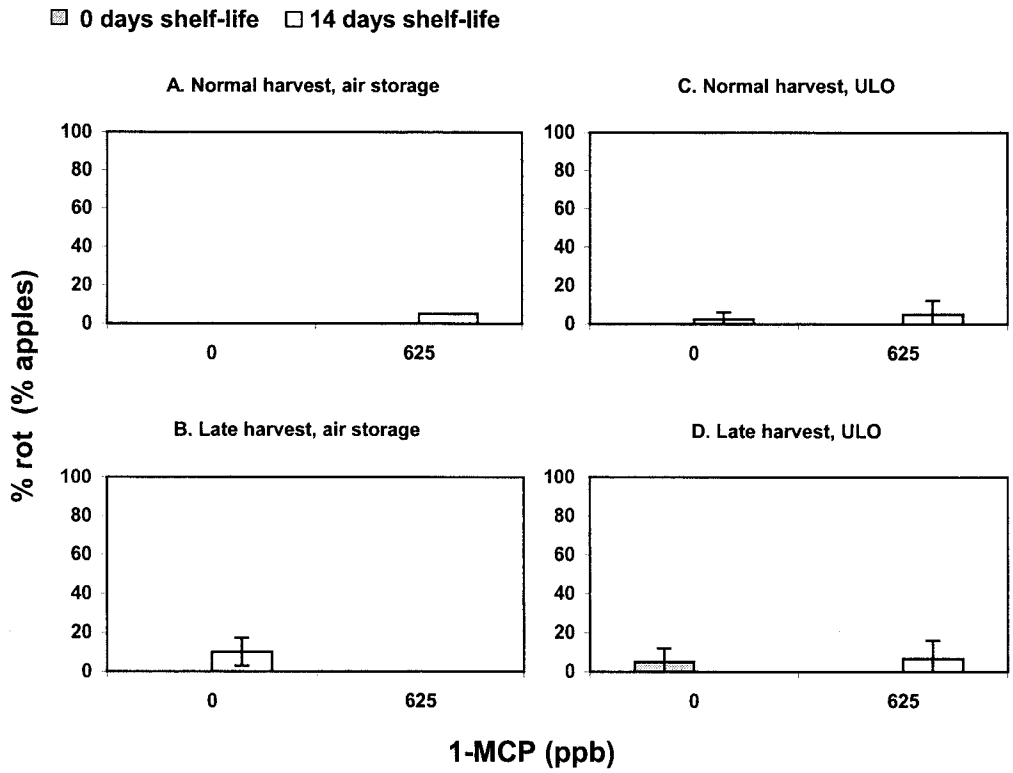

Fig. 10. % apples with disorders of Elstar after 4 months storage. Vertical bars indicate ± std of the mean of 2 replicates.

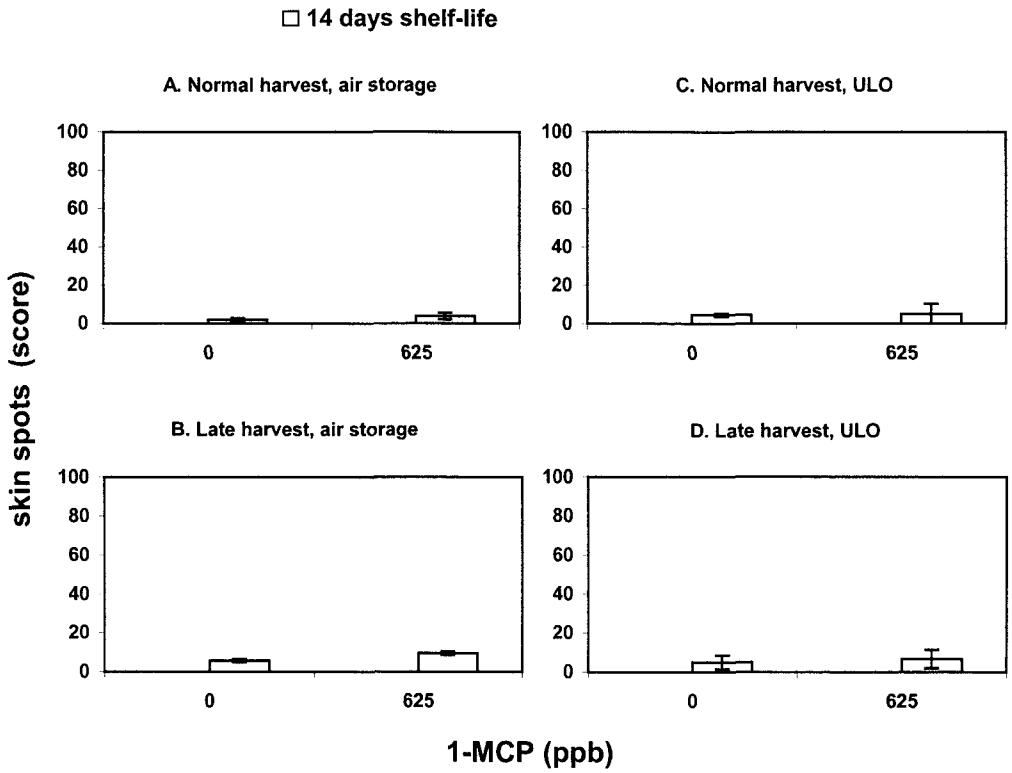

Fig. 11. Skin spots of Elstar (% of maximum score) after 4 months storage. Vertical bars indicate ± std of the mean of 2 replicates.

4.4 Elstar, 6 months storage

Firmness of control apples (0 ppb 1-MCP) of normal harvest was commercially unacceptable after 6 months air storage (Fig. 12A). Treatment with 1-MCP strongly inhibited firmness loss during storage and prevented firmness loss during shelf-life, resulting in acceptable quality. Firmness after 14 days shelf-life was equal for air storage + 1-MCP (Fig. 12A) and for ULO without 1-MCP (Fig. 12C).

Apples of late harvest without 1-MCP severely lost firmness during 6 months air storage, resulting in a commercially unacceptable quality (Fig. 12B). 1-MCP inhibited firmness loss both during storage and during shelf-life which resulted in apples still near acceptable firmness after 14 days shelf-life. Firmness after 14 days shelf-life was better for air storage + 1-MCP (Fig. 12B) than for ULO without 1-MCP (Fig. 12D).

Firmness of control apples of normal harvest was still high after 6 months ULO (Fig. 12C). In this case, the advantage of 1-MCP was especially shown during shelf-life where 1-MCP prevented firmness loss. Also for ULO storage of late harvest, the advantage of 1-MCP was shown during shelf-life where 1-MCP prevented firmness loss (Fig. 12D).

1-MCP inhibited yellowing of normal harvest, both for air storage and for ULO (Fig 13A and 13C). 1-MCP did not affect yellowing of late harvest (Fig. 13B and 13D).

There were no large effects of 1-MCP on soluble solids content (Fig. 14).

Similar to 4 months storage, 1-MCP treatments resulted in higher acidity for air storage (Fig. 15A and 15B) but had no effect on ULO storage (Fig. 15C and 15D).

1-MCP inhibited development of rot during shelf-life after air storage (Fig. 16A and 16B) but had no effect for shelf-life after ULO (Fig. 16C and 16D).

In all cases skin spots were found after 6 months storage, without clear effect of 1-MCP (Fig. 17).

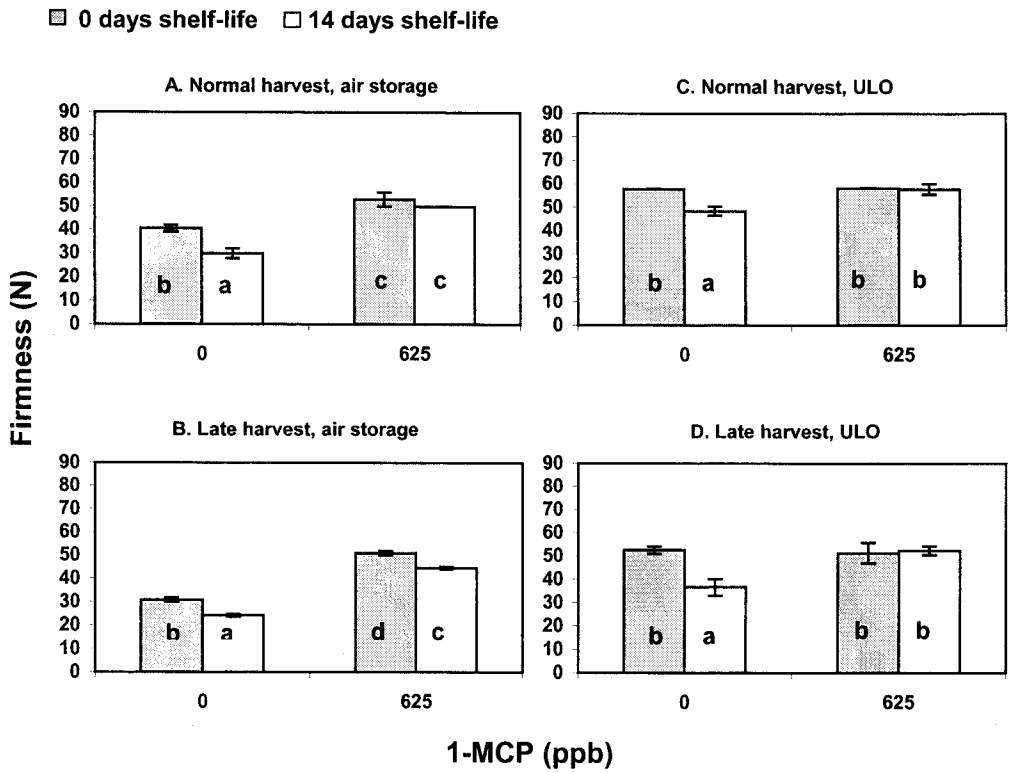

Fig. 12. Firmness of Elstar after 6 months of storage. Vertical bars indicate ± std of the mean of two replicates. Columns within a chart marked with a same letter are not statistically different (P=0.05).

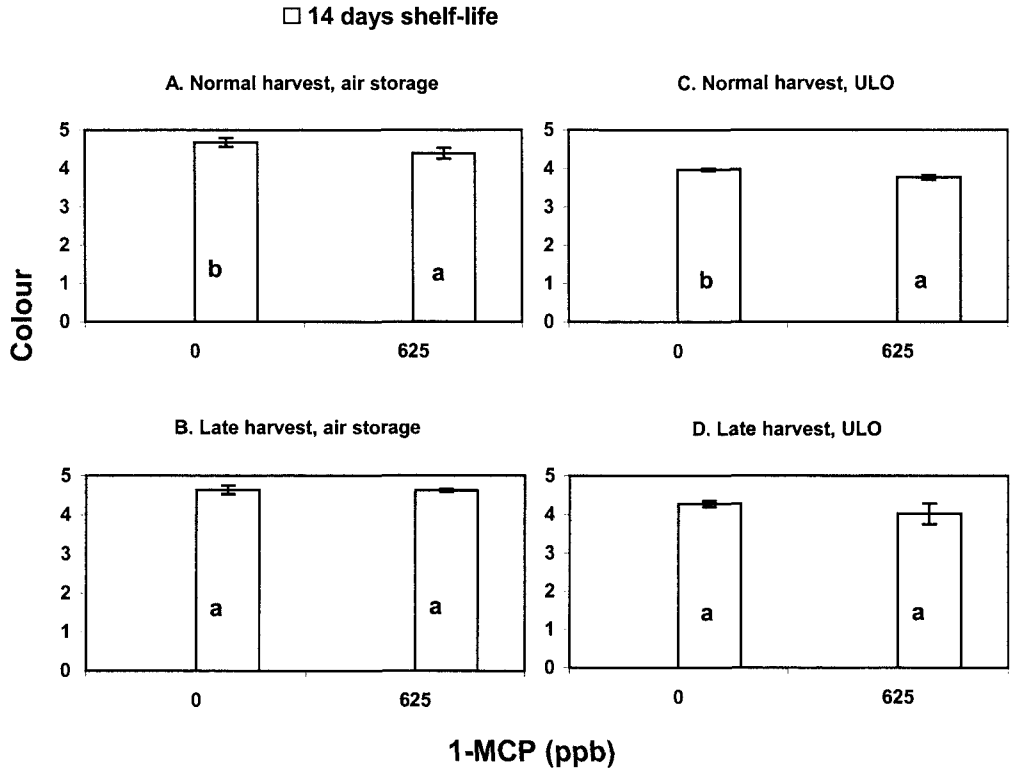

Fig. 13. Colour of Elstar after 6 months of storage. Vertical bars indicate ± std of the mean of two replicates. Columns within a chart marked with a same letter are not statistically different (P=0.05).

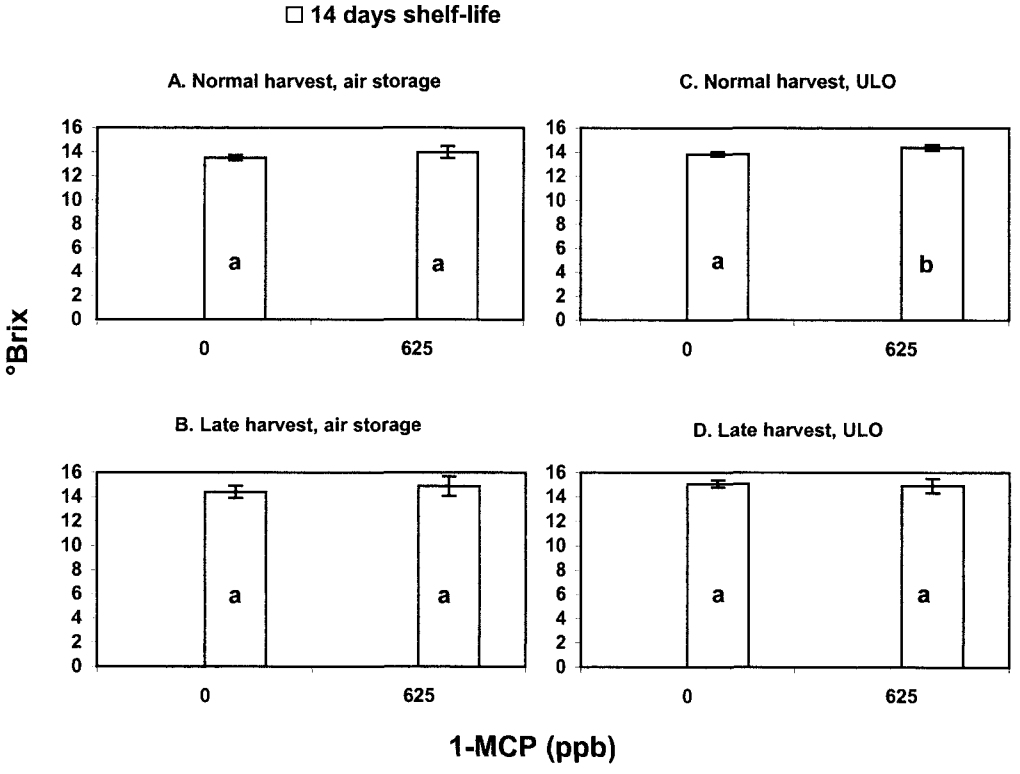

Fig. 14. Soluble solids content of Elstar after 6 months storage. Vertical bars indicate ± std of the mean of 2 replicates. Columns within a chart marked with a same letter are not statistically different (P=0.05).

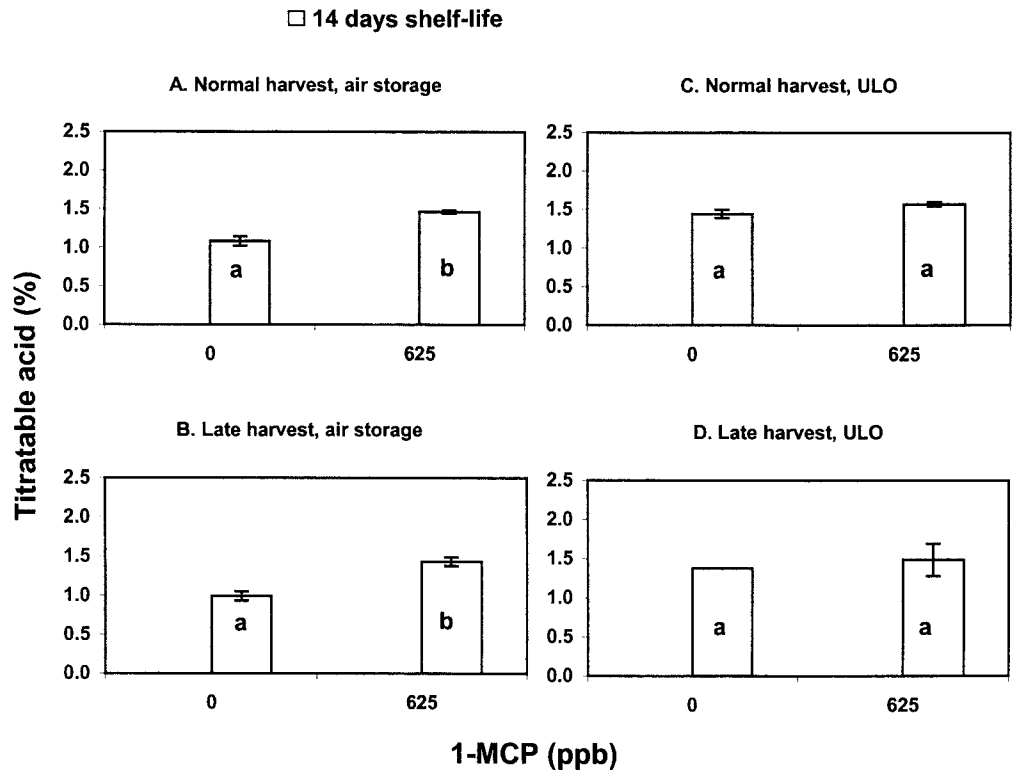

Fig. 15. Titratable acidity of Elstar after 6 months storage. Vertical bars indicate ± std of the mean of 2 replicates. Columns within a chart marked with a same letter are not statistically different (P=0.05).

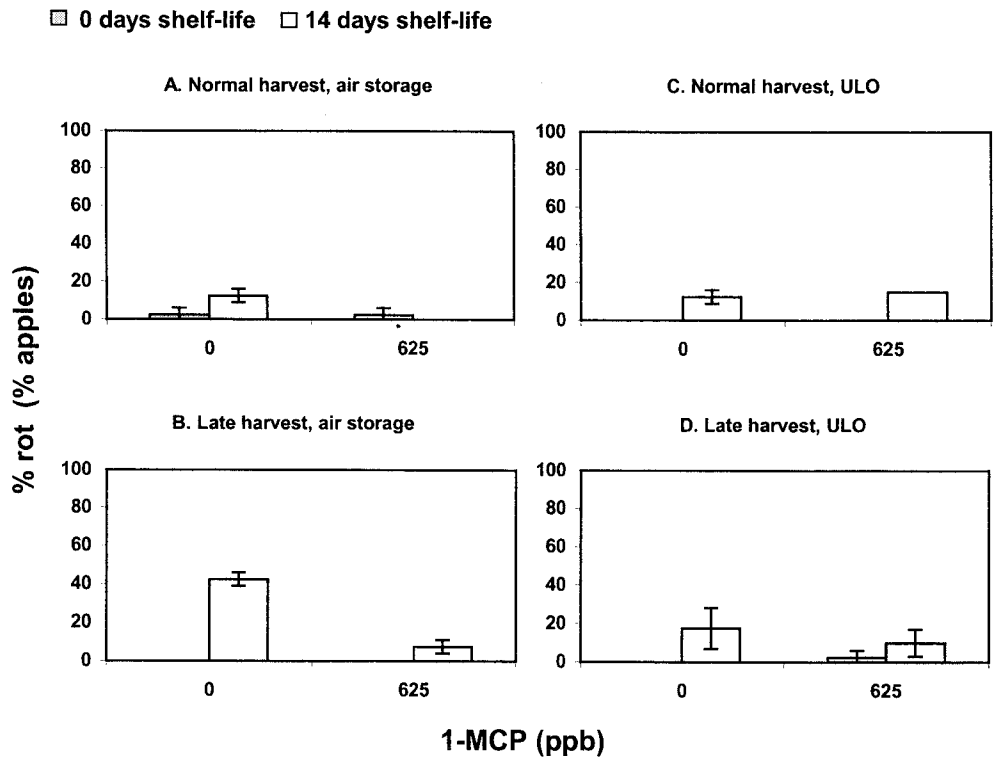

Fig. 16. % apples with disorders of Elstar after 6 months storage. Vertical bars indicate ± std of the mean of 2 replicates.

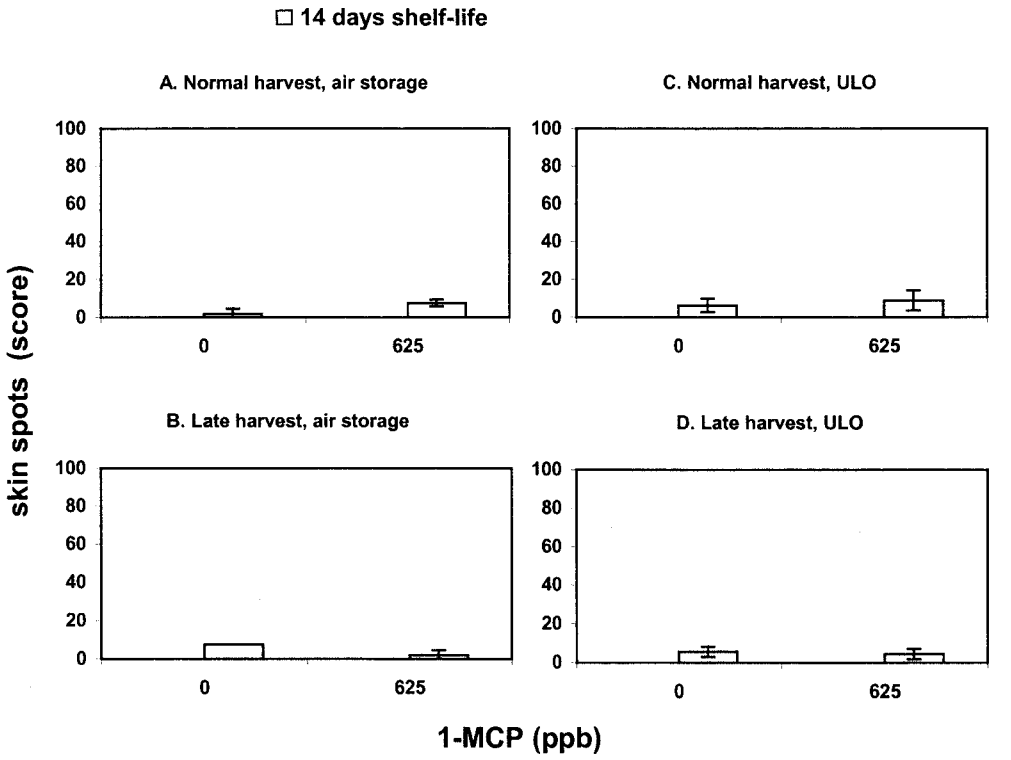

Fig. 17. Skin spots of Elstar (% of maximum scrore) after 6 months storage. Vertical bars indicate ± std of the mean of 2 replicates.

5. Results Tentation

5.1 Tentation, initial quality

The mean firmness of Tentation at the start of the experiments was 69.7±0.9 N (mean ± standard deviation) for normal harvest and 66.1±0.1 N for late harvest. The mean colour was 2.7±0.2 and 3.4±0.1 respectively. The mean content of soluble solids was 13.2±0.1 and 14.4±0.5 °brix respectively. The mean % titratable acidity was 1.20±0.06 and 0.94±0.02 respectively.

5.2 Tentation, 2 months storage

Firmness of control apples (0 ppb 1-MCP) of normal harvest had decreased during 2 months air storage (Fig. 18A). Treatment with 1-MCP completely prevented this decrease and also prevented firmness loss during 14 days shelf-life. The apparent increase in firmness during shelf-life is probably the consequence of some dehydration of the apples.
While firmness at harvest was 69.7±0.9 N, the firmness after 2 months air was 64.6±0.4, 70.4±0.3 and 70.1±0.8 for control, 312 ppb and 625 ppb 1-MCP respectively.

Also firmness loss of late harvested apples during air storage and subsequent shelf-life was completely prevented by 1-MCP (Fig. 18B).
Firmness at harvest was 66.1±0.1 N, firmness after storage was 61.9±0.6, 65.4±1.4 and 66.7±0.7 N for control, 312 ppb and 625 ppb 1-MCP respectively.

Yellowing was inhibited by 1-MCP for normal harvest (Fig. 19).

There were no clear effects of 1-MCP on soluble solids content (Fig. 20).

In general, 1-MCP treatments resulted in higher titratable acidity (Fig. 21).

There were no clear effects of 1-MCP on % apples with rot (Fig. 22).

No scald had developed during storage (0 days shelf-life) (Fig. 23). After 14 days shelf-life, scald was found in both normal and late harvested appels. 1-MCP treatment could only prevent scald development of normal harvest.

In general there were no clear differences between 312 ppb and 625 ppb 1-MCP treatments.

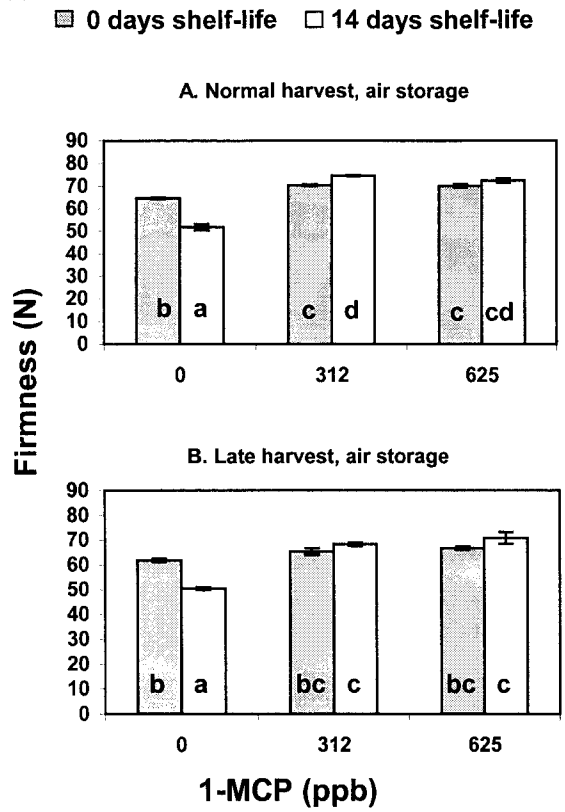

Fig. 18. Firmness of Tentation after 2 months of storage. Vertical bars indicate ± std of the mean of two replicates. Columns within a chart marked with a same letter are not statistically different (P=0.05).

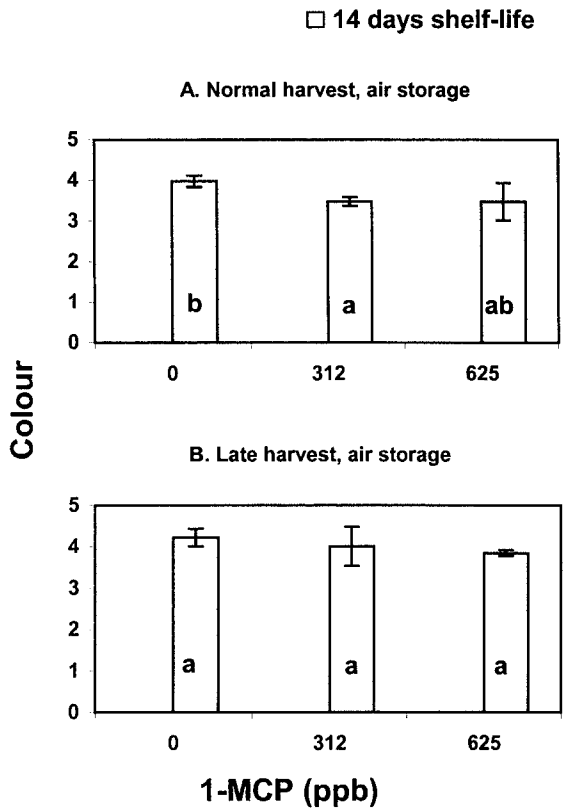

Fig. 19. Colour of Tentation after 2 months of storage. Vertical bars indicate ± std of the mean of two replicates. Columns within a chart marked with a same letter are not statistically different (P=0.05).

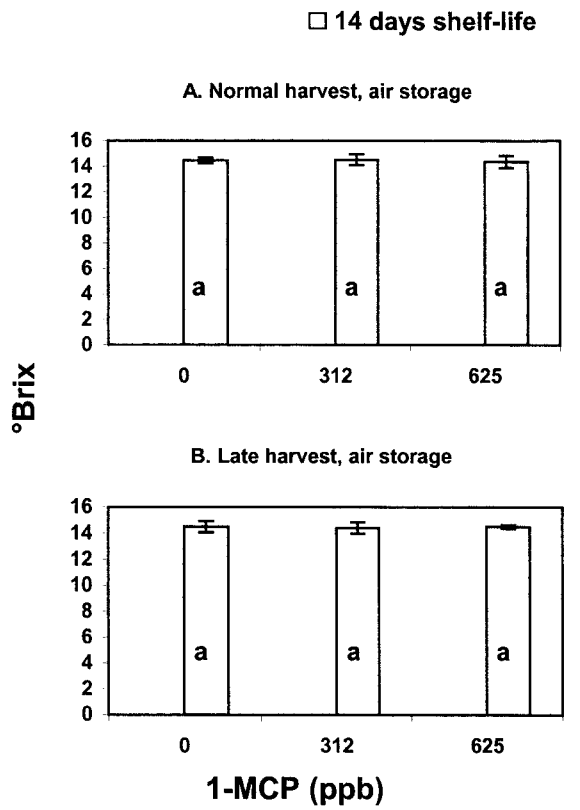

Fig. 20. Soluble solids content of Tentation after 2 months storage. Vertical bars indicate ± std of the mean of 2 replicates. Columns within a chart marked with a same letter are not statistically different (P=0.05).

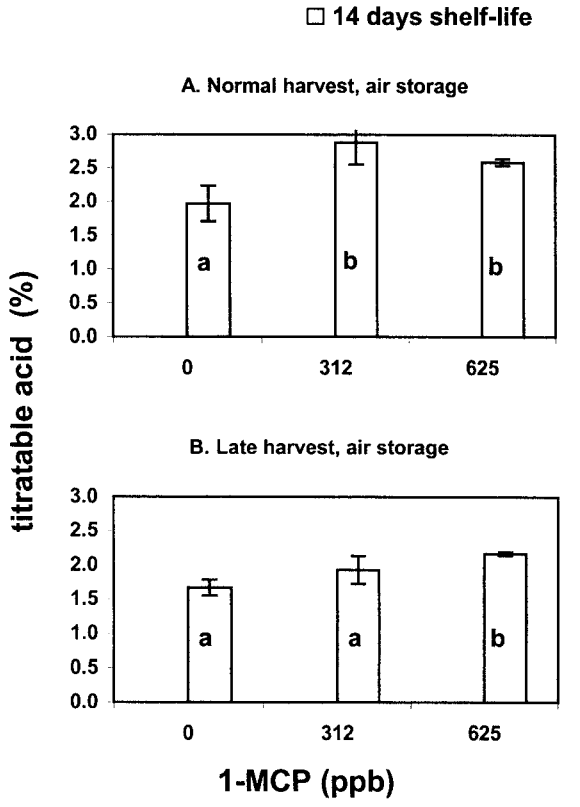

Fig. 21. Titratable acidity of Tentation after 2 months storage. Vertical bars indicate ± std of the mean of 2 replicates. Columns within a chart marked with a same letter are not statistically different (P=0.05).

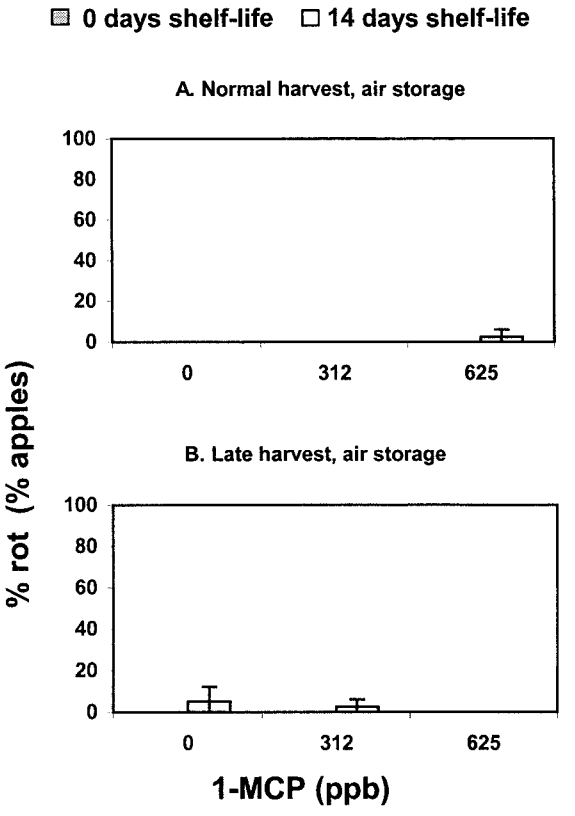

Fig. 22. % apples with rot of Tentation after 2 months storage. Vertical bars indicate ± std of the mean of 2 replicates.

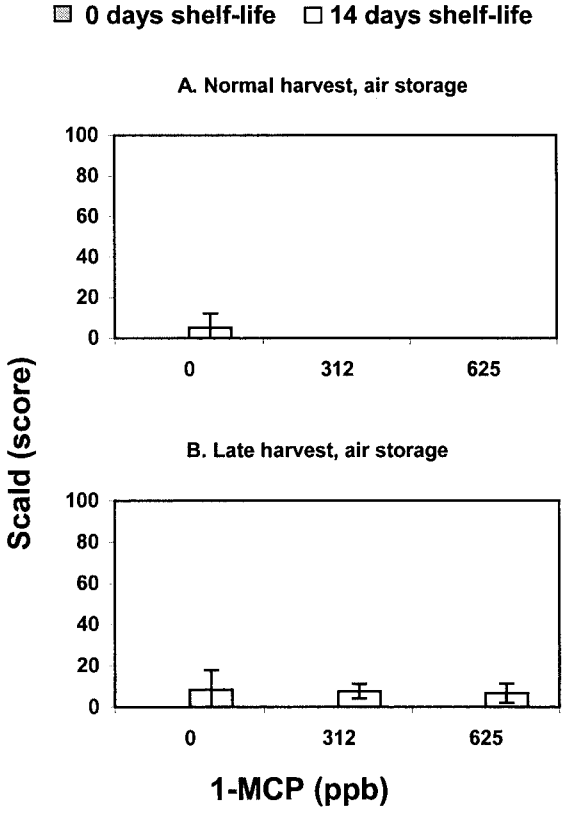

Fig. 23. Index for scald (% of maximum) of Tentation after 2 months storage. Vertical bars indicate ± std of the mean of 2 replicates.

5.3 Tentation, 4 months storage

Firmness loss of normal harvested apples, during air storage and subsequent shelf-life, was completely prevented by 1-MCP (Fig. 24A). Firmness of 1-MCP treated apples after air storage (0 or 14 days shelf-life) was equal to firmness of control apples after ULO (Fig. 24C).
While firmness at harvest was 69.7±0.9 N, the firmness after 4 months air was 57.8±1.4, 71.3±0.2 and 70.9±0.2 for control, 312 ppb and 625 ppb 1-MCP respectively.

Also firmness loss of late harvested apples during air storage and subsequent shelf-life was completely prevented by 1-MCP (Fig. 24B). Firmness of 1-MCP treated apples after air storage + 14 days shelf-life was better than firmness of control apples after ULO + 14 days shelf-life (Fig. 24D).
Firmness at harvest was 66.1±0.1 N, firmness after storage was 56.6±0.3, 66.3±0.3 and 66.8±0.8 N for control, 312 ppb and 625 ppb 1-MCP respectively.

Firmness loss during ULO and subsequent shelf-life was very small (Fig. 24C and 24D). An effect of 1-MCP was only found for shelf-life of late harvest (Fig. 24 D).

1-MCP treatments inhibited yellowing for normal harvest after air storage and for late harvest after ULO (Fig. 25).

There was no important effect of 1-MCP on soluble solids content (Fig. 26).

In all cases 1-MCP treatments resulted in higher titratable acidity (Fig. 27).

There were no clear effects of 1-MCP on development of rot (Fig. 28).

Scald was only found for air storage, not for ULO. For normal harvest, severe scald developed during shelf-life which was prevented by 1-MCP (Fig 29A). For late harvest (which was extremely late), scald already developed during storage (0 days shelf-life) which was promoted by 1-MCP. However after 14 days of shelf-life, 1-MCP treatment resulted in less scald than the control (Fig 29B).

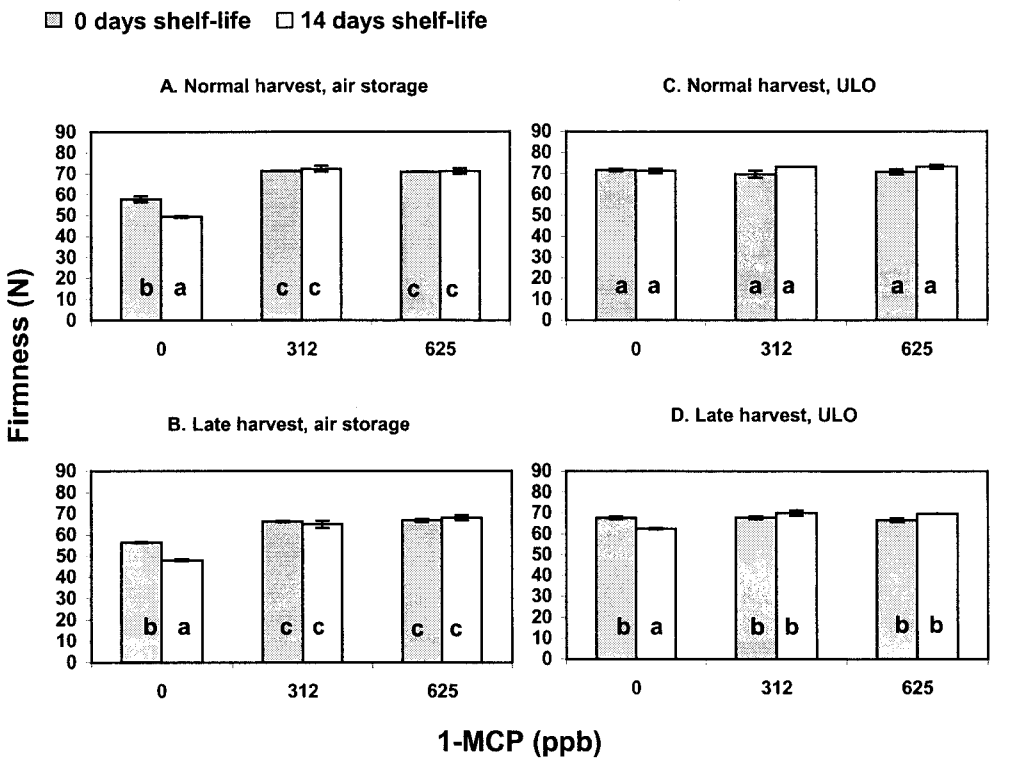

Fig. 24. Firmness of Tentation after 4 months of storage. Vertical bars indicate ± std of the mean of two replicates. Columns within a chart marked with a same letter are not statistically different (P=0.05).

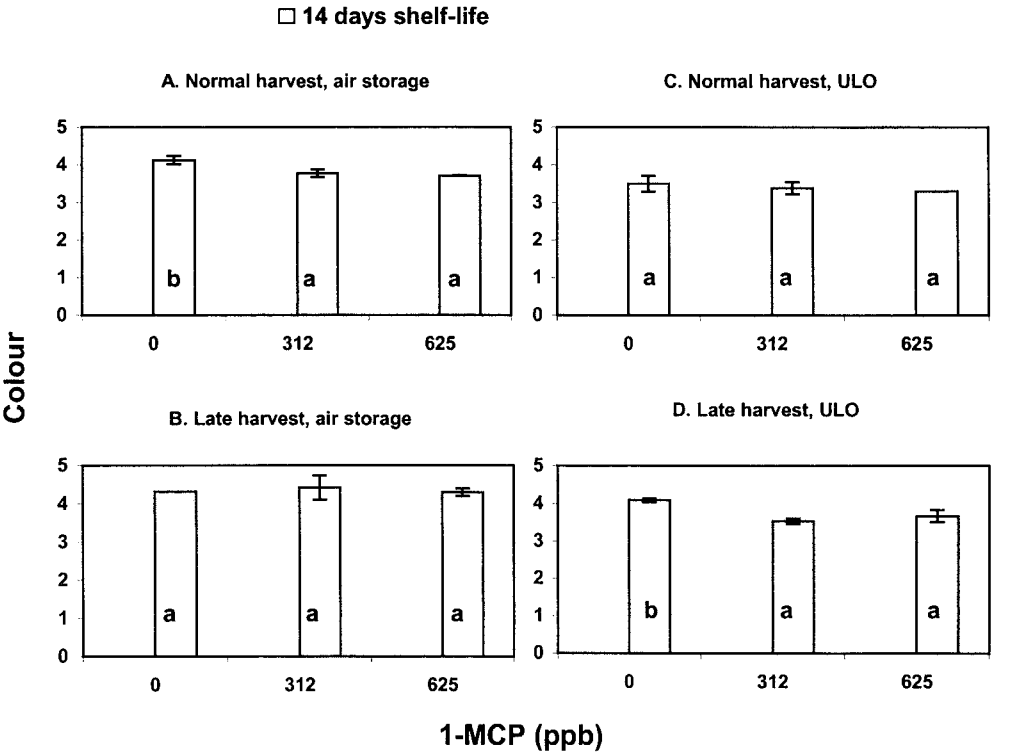

Fig. 25. Colour of Tentation after 4 months of storage. Vertical bars indicate ± std of the mean of two replicates. Columns within a chart marked with a same letter are not statistically different (P=0.05).

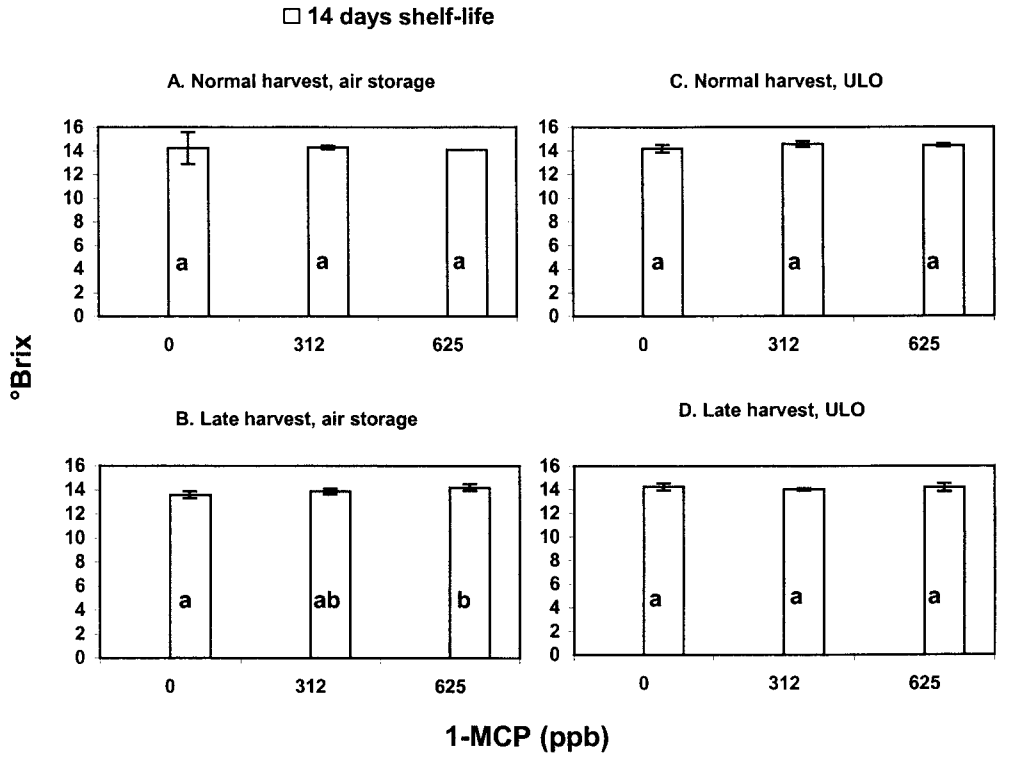

Fig. 26. Soluble solids content of Tentation after 4 months storage. Vertical bars indicate ± std of the mean of 2 replicates Columns within a chart marked with a same letter are not statistically different (P=0.05).

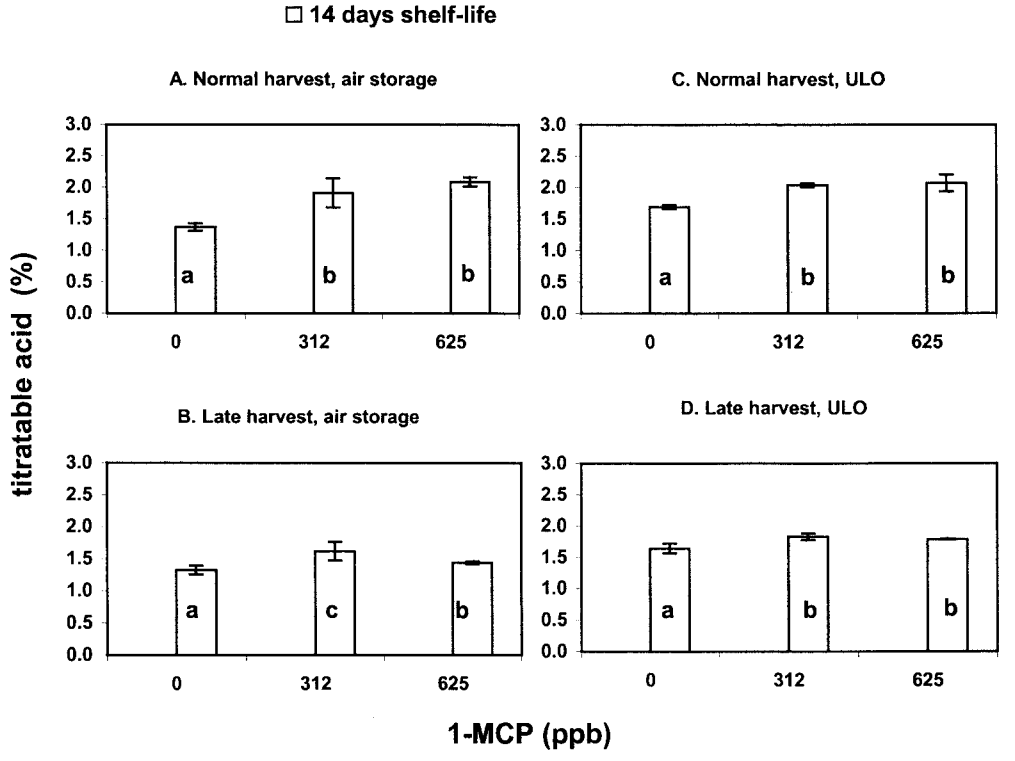

Fig. 27. Titratable acidity of Tentation after 4 months storage. Vertical bars indicate ± std of the mean of 2 replicates. Columns within a chart marked with a same letter are not statistically different (P=0.05).

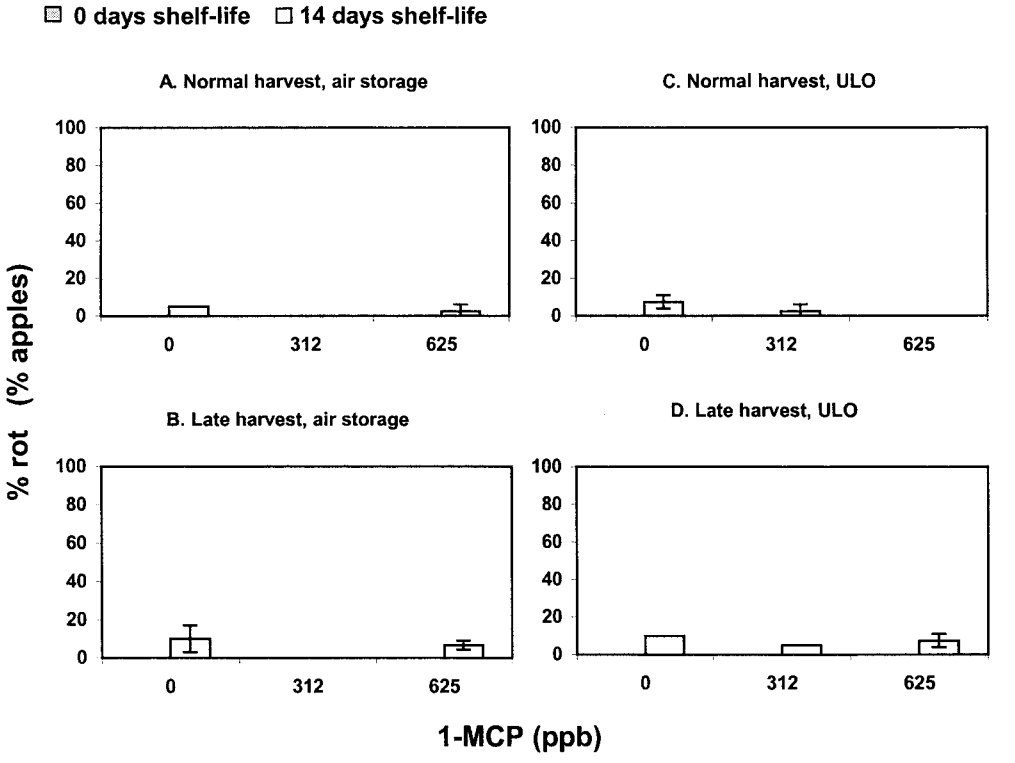

Fig. 28. % apples with rot of Tentation after 4 months storage. Vertical bars indicate ± std of the mean of 2 replicates.

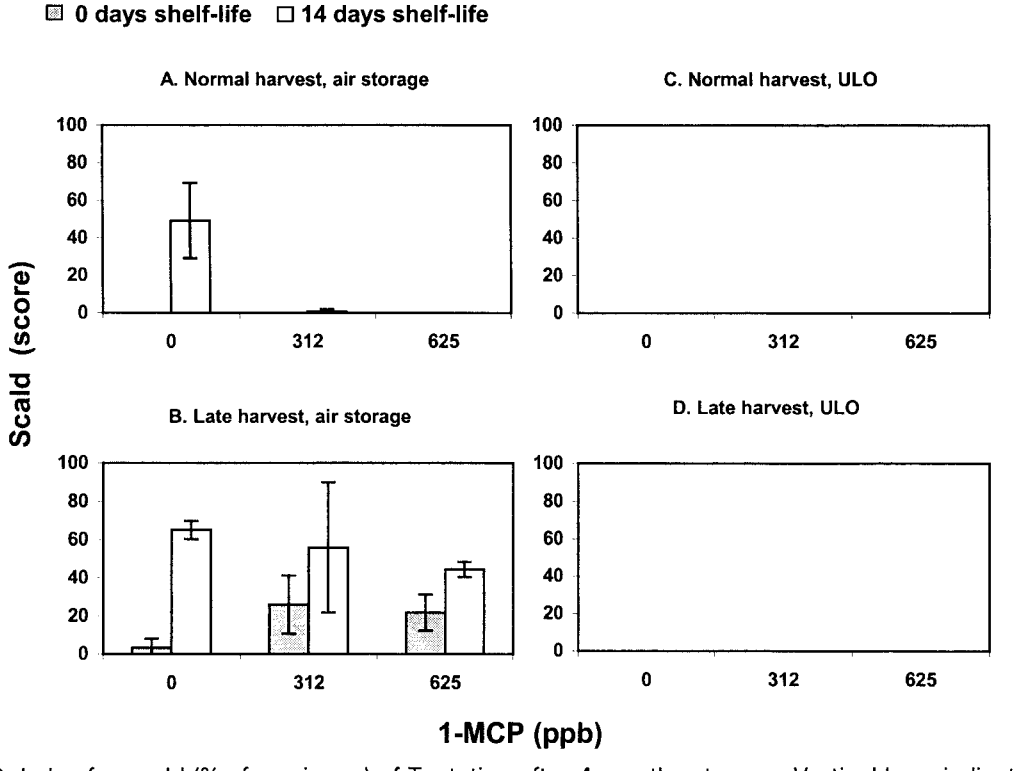

Fig. 29. Index for scald (% of maximum) of Tentation after 4 months storage. Vertical bars indicate ± std of the mean of 2 replicates.

6 Conclusions

Very positive effects of 1-MCP were found on firmness retention. Positive effects were also found on retention of colour, retention of titratable acids, inhibition of rot (during shelf-life after 6 months air storage of Elstar) and prevention of scald (normal harvest Tentation). There were no important effects of 1-MCP on soluble solids content.
For Tentation both 312 and 625 ppb 1-MCP was tested, but there were no important differences between these concentrations.

Conclusions on basis of the four objectives as formulated at the start of the experiments:

- ***1-MCP can improve CA (ULO) storage***
  For Elstar, firmness after ULO storage (4 and 6 months) was equal for control and 1-MCP treated apples. However, while control apples lost firmness during 14 days shelf-life, 1-MCP treated apples did not. This was the case both for normal and late harvest. 1-MCP inhibited yellowing of Elstar of normal harvest after 4 and 6 months ULO, and of late harvest after 4 months ULO. There were no important effects of 1-MCP on soluble solids content, acidity, % rot and skin spots.
  Firmness loss of Tentation apples during ULO storage (4 months) and subsequent shelf-life was small. An effect of 1-MCP on firmness retention was only found after 14 days shelf-life of late harvest. 1-MCP resulted in higher acidity both for normal and late harvest and inhibited yellowing of late harvest. There were no important effects of 1-MCP on soluble solids content or % rot. The disorder scald did not occur in ULO stored apples.
- ***1-MCP can be used to replace CA (ULO) under certain conditions***
  For Elstar, 1-MCP could be used to replace ULO during a 4 or 6 months storage period. The advantage of 1-MCP above ULO was firmness retention during shelf-life. This was the case both for normal and late harvest.
  For Tentation 1-MCP could be used to replace ULO during a 4 months storage period, but only for normal harvest. After storage + 14 days shelf-life, the firmness of 1-MCP treated apples from air storage was equal to the firmness of untreated apples from ULO. For the (extremely) late harvest, results obtained by ULO were better than for 1-MCP without ULO. This was due to the occurrence of scald which was prevented by ULO but not by 1-MCP.
- ***1-MCP facilitates the storage of apples harvested at a more mature stage***
  Air storage:
  After 2, 4 and 6 months storage plus shelf-life, firmness of 1-MCP treated Elstar of late harvest was still acceptable while firmness of control apples was not. In addition, titratable acids were higher after 1-MCP treatment.
  For Tentation, firmness of control apples of late harvest was still acceptable after 2 and 4 months storage plus shelf-life, but application of 1-MCP resulted in apples of even better firmness. However, 1-MCP could not prevent the development of scald.
  ULO storage:
  After 4 and 6 months storage plus shelf-life, firmness of 1-MCP treated Elstar of late harvest was still acceptable, while firmness of control Elstar was not.
  For Tentation, firmness of control apples of late harvest was still acceptable after 4 months storage plus shelf-life, but 1-MCP resulted in apples of even better firmness, greener colour and higher acidity.
- ***1-MCP improves the shelf-life of CA(ULO)-stored apples***
  In all cases, 1-MCP treatment (both normal and late harvest, all tested storage periods) prevented firmness loss of Elstar and Tentation during shelf-life following ULO storage.
- ***1-MCP inhibits development of scald in Tentation apples***
  Development of scald only occurred during air storage and especially during subsequent shelf-life. 1-MCP prevented development of scald in apples of normal harvest. 1-MCP could not prevent scald in (extremely) late harvested apples.