ATO

Registration of 1-MCP treatments on apples

Report of experiments storage season 2001-2002

Report B589

OPD 00/153/June 2002

Confidential

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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 'Jonagold' in the storage season 2001-2002.
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 7 days later at a more mature stage. Treatments with 1-MCP (312, 625 ppb) were performed shortly after harvest. Also a treatment with 625 ppb 1-MCP was performed at 10 days after harvest (only normal harvest). Subsequently apples were stored in normal air (cooling) or in ULO conditions (low O_2, high CO_2). Quality of apples was determined after 2, 4, and 6 months of air storage and after 4, 6, and 8 months of ULO storage. A shelf-life period of 14 days was simulated after each storage.

For Elstar, very good effects of 1-MCP were found on firmness retention. Also positive effects were found on colour (less yellowing of normal harvest) and on titratable acidity (often higher values). There were no important effects on sugar content and rot. The used Elstar apples appeared to be sensitive for skin pecks. The occurrence of skin pecks after 6 months storage was increased by 1-MCP.
Also for Jonagold very positive effects of 1-MCP were found on firmness retention in various storage regimes. Also positive effects were found on colour, titratable acidity, disorders (less rot) and greasiness (less grease).
For Elstar, there were no clear differences between 312 and 625 ppb 1-MCP applied shortly after harvest. For Jonagold, 625 ppb was sometimes more effective in inhibition of greasiness and disorders.
For Elstar, there was no important effect when treated at 10 days after harvest compared to treatment shortly after harvest. However, for Jonagold the treatment at 10 days after harvest was less effective especially regarding firmness retention.

1-MCP can be advantageous for ULO (CA) storage.
For Elstar, firmness of control apples (no 1-MCP) of normal harvest was maintained during 8 months ULO. Therefore no effect of 1-MCP was found on firmness directly after storage (0 days shelf-life). However, while control apples lost firmness during subsequent shelf-life, 1-MCP in all cases (normal and late harvest, all storage periods) prevented firmness loss. Also, 1-MCP inhibited yellowing during shelf-life of Elstar of normal harvest after 4, 6 and 8 months of ULO storage. It did not have an effect on yellowing of late harvest.
For Jonagold, firmness of control apples of both normal and late harvest decreased during 8 months ULO. Advantage of 1-MCP was inhibition of softening during ULO storage and inhibition of softening during shelf-life. Also, 1-MCP inhibited yellowing during shelf-life after ULO storage (4, 6 and 8 months).

For Elstar, 1-MCP could be used to replace ULO during a 4 months storage period. The main advantage of 1-MCP above ULO was firmness retention during subsequent shelf-life. At a longer storage period of 6 months, the firmness of 1-MCP treated apples from air storage was less than the firmness of untreated apples from ULO storage. However, firmness of 1-MCP treated apples was better after an additional shelf-life period of 14 days.
For Jonagold, 1-MCP could not replace the beneficial effect of 4 months ULO.

1-MCP can facilitate both air and ULO storage of apples that are harvested at a more mature stage. 1-MCP inhibited firmness loss of apples during all storage periods and thereby prolonged the storage life of late harvested apples. After 2, 4 and 6 months of air storage plus 14 days shelf-life, firmness of 1-MCP treated Elstar and Jonagold was still acceptable while firmness of control apples was not.

1-MCP treatment in most cases (both normal and late harvest, all tested storage periods) prevented firmness loss of Elstar during shelf-life following ULO storage. The same was true for Jonagold but with the exception of 1-MCP treatment at 10 days after harvest.

1 Introduction

1-Methylcyclopropene (1-MCP) is an effective inhibitor of ethylene responses. To test the efficacy of 1-MCP on apples, experiments were performed on apple cultivars 'Elstar' and 'Jonagold' in the storage season 2001-2002. These varieties are important in The Netherlands as well as in other countries.
Four 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?

To find an answer to these questions, apples were harvested at the optimum picking date and also 7 days later at a more mature stage. The treatments of 1-MCP were performed shortly after harvest but also one treatment was done at 10 days after harvest. Subsequently apples were stored in normal air (only cooling) or in ULO conditions (low O_2, high CO_2). Quality of apples was determined after 2, 4, 6 and 8 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 2001 apples were harvested. Apples were harvested at their optimal harvest date (commercial advice) and also 7 days after the optimal harvest date. Harvest of Elstar took place on September 19th and September 26th. Harvest of Jonagold took place on October 15th and October 22th. For Elstar, the 'Elshof' mutant was used. For Jonagold, the 'Jonica' mutant was used.
Harvests were within the window of commercial harvests (Advised starch index is 2-3 for Elstar, 5-6 for Jonagold). Both cultivars were from orchards in Randwijk, province Gelderland, The Netherlands (10 km from Wageningen).
After harvest, apples were placed in a temperature controlled room at 1.8 °C (Elstar) or 1.0 °C (Jonagold).

Pre-and other post-harvest treatments other than 1-MCP
Last pre-harvest treatments were done more than 1 month from harvest (August 29th and September 7th for both cultivars).
No post-harvest treatments other than 1-MCP were done.

Storage issues in commercial storage
Both cultivars are commercially stored in air up to 3 months and in ULO up to 8 months (Elstar) or 10 months (Jonagold).
Main problems of Jonagold are firmness loss during long-term storage and subsequent shelf-life (mealiness) and greasiness of ripe apples.
Main problems of Elstar are firmness loss during shelf-life and the occurrence of skin pecks in sensitive batches.

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 (Jonagold). Treatments were: 312 and 625 ppb starting one day after harvest, and 625 ppb 10 days after harvest. Treatment dates are given in table 1. Also control apples (0 ppm 1-MCP) were included in the experiments.

Table 1. Harvest dates, 1-MCP treatment dates and start of air/ULO storage for Elstar and Jonagold (all dates were in year 2001).

	Harvest date	Treatment date	Start air or ULO storage
Elstar normal harvest	Sept 19th	Sept 21th	Sept 25th
Elstar normal harvest, late treatment	Sept 19th	Oct 1th	Oct 4th
Elstar late harvest	Sept 26th	Sept 27th	Oct 4th
Jonagold normal harvest	Oct 15th	Oct 16th	Oct 22th
Jonagold normal harvest, late treatment	Oct 15th	Oct 25th	Oct 29th
Jonagold late harvest	Oct 22th	Oct 24th	Oct 29th

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 (1.16 m^3 free volume, 130-140 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. This lime does not absorb 1-MCP, which was tested. 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 1.16 m^3. The following solutions were made:

- 312 ppb 1-MCP: 0.58 g powder + 93 ml water (ratio product:water 160)
- 625 ppb 1-MCP: 1.16 g powder + 186 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 2 °C (Jonagold) for several 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 Jonagold : first month 1.2% O_2 and 4.0% CO_2
subsequently 1.0% O_2 and 4.0% 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 a few 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 Jonagold and Elstar directly after storage and after storage plus 14 days shelf-life.

Storage duration	Elstar cooling	Elstar ULO	Jonagold cooling	Jonagold ULO
2 months	Nov 19th 2001	Nov 19th 2001	Dec 6th 2001	Dec 6th 2001
2 months + 14 days	Dec 3th 2001	Dec 3th 2001	Dec 20th 2001	Dec 20th 2001
4 months	Jan 17th 2002	Jan 17th 2002	Feb 7th 2002	Feb 7th 2002
4 months + 14 days	Jan 31th 2002	Jan 31th 2002	Feb 21th 2002	Feb 21th 2002
6 months	March 19th 2002	March 19th 2002	April 5th 2002	April 5th 2002
6 months + 14 days	April 2nd 2002	April 2nd 2002	April 19th 2002	April 19th 2002
8 months	May 17th 2002	May 17th 2002	June 5th 2002	June 5th 2002
8 months + 14 days	May 31th 2002	May 31th 2002	June 19th 2002	June 19th 2002

Directly after storage, apples were measured only on firmness. 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 70-85% RH. Measurements were done on firmness (individual apples), colour (individual apples), content of soluble solids (sugars, mixed sample), titratable acidity (mixed sample), external and internal disorders, and greasiness (Jonagold). 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. Greasiness was measured visually using a scale where 0=no grease, 1=light grease, and 2=grease or very grease. Disorders included flesh browning, core browning, core fungus, rot, and stalk rot. The occurrence of skin pecks at Elstar apples was analysed separately. Skin pecks were scored after 10 days of shelf-life. Thereby two different judgements were made: one taking into account all skin pecks, and one taking into account only skin pecks that are commercially important (clearly visible).

Weight loss Jonagold

For normal harvest, weight loss of Jonagold apples was followed during ULO storage. Per treatment 2 replicates of 10 apples were used. Apples were measured individually in case of falling out of apples due to rot. Weight was measured before storage and after 4, 6 and 8 months ULO storage.

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, % apples with skin-pecks and greasiness, as residuals were not normally distributed.

Summary of experimental set-up

Apple varieties:	Jonagold ('Jonica'), Elstar ('Elshof')
Harvest dates:	optimal, late
Treatment:	24 h. at 1.0 °C (Jonagold) or 1.8 °C (Elstar)
1-MCP concentrations:	0, 312 ppb, 625 ppb within a few days after harvest 625 ppb 10 days after harvest (only normal harvest)
Storage gas conditions:	ambient air, CA
Storage temperature:	1.0 °C (Jonagold), 1.8 °C (Elstar)
Sampling dates:	2, 4, 6 months for air storage 4, 6, 8 months for CA
Measurement dates:	0, 14 (days after storage)
Measurements:	firmness, colour, sugars, acidity, external and internal disorders, greasiness (Jonagold)
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 59.3±0.3N (mean ± standard deviation) for normal harvest and 59.7±0.2 N for late harvest. The mean colour was 3.0±0.0 and 3.4±0.1 respectively. The mean content of soluble solids was 13.0±0.1 and 13.4±0.2 °brix respectively. The mean % titratable acidity was 0.94±0.06 and 0.90±0.03 respectively.

4.2 Elstar, 2 months storage

There was no significant firmness loss of normal harvested apples during 2 months air storage. Control apples showed severe firmness loss during subsequent shelf-life while 1-MCP treated apples did not (Fig 1A).
Firmness at harvest was 59.3±0.3 N, the firmness after 2 months air storage without 1-MCP was 58.7±0.2 N.

Firmness loss of late harvested apples during air storage was inhibited by 1-MCP (Fig. 1B). Again, control apples showed firmness loss during shelf-life while 1-MCP treated apples did not.
Firmness at harvest was 59.7±0.2 N, firmness after storage was 53.7±0.2 58.6±0.1 and 58.2±1.7 N for control, 0.312 ppm and 0.625 ppm 1-MCP respectively.

Yellowing was inhibited by 1-MCP for normal harvest (Fig. 2A) while no effect of 1-MCP was found for late harvest (Fig. 2B).

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

1-MCP treatments in all cases resulted in higher titratabe acidity (Fig. 4).

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

For all quality aspects, there were no differences between the two 1-MCP doses (0.312 and 0.625 ppm) or between the two application dates (0.625 ppm or 0.625 ppm 10 days after harvest).

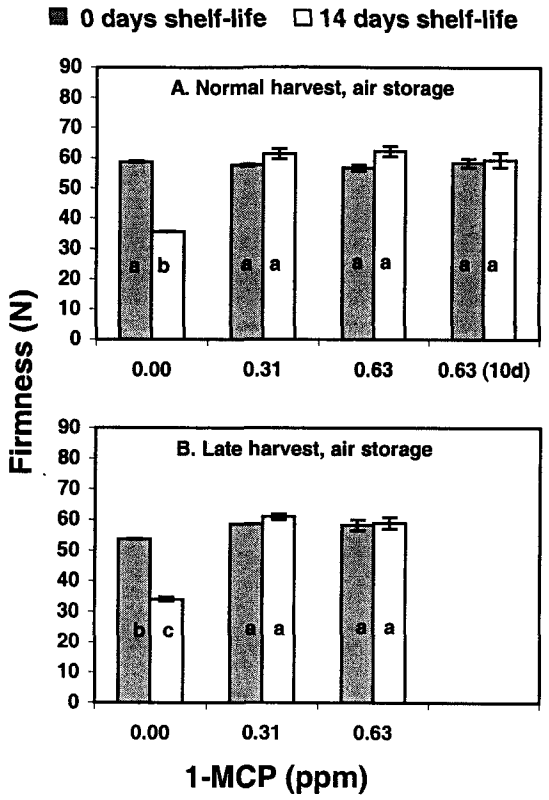

Fig. 1. Firmness of Elstar after 2 months of storage. Vertical bars indicate ± std of the mean of two replicates. Columns within a chart marked with a same letter are not statistically different (P=0.05).

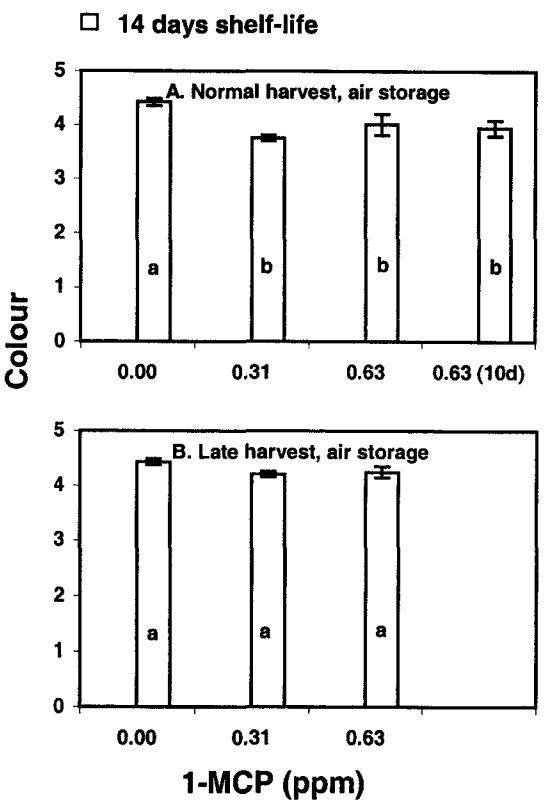

Fig. 2. Colour of Elstar after 2 months of storage. Vertical bars indicate ± std of the mean of two replicates. Columns within a chart marked with a same letter are not statistically different (P=0.05).

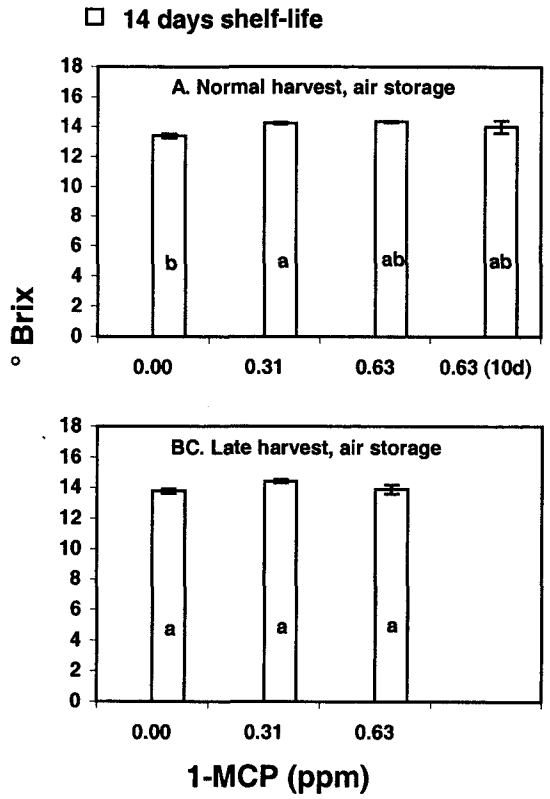

Fig. 3. Soluble solids content of Elstar after 2 months storage. Vertical bars indicate ± std of the mean of 2 replicates. Columns within a chart marked with a same letter are not statistically different (P=0.05).

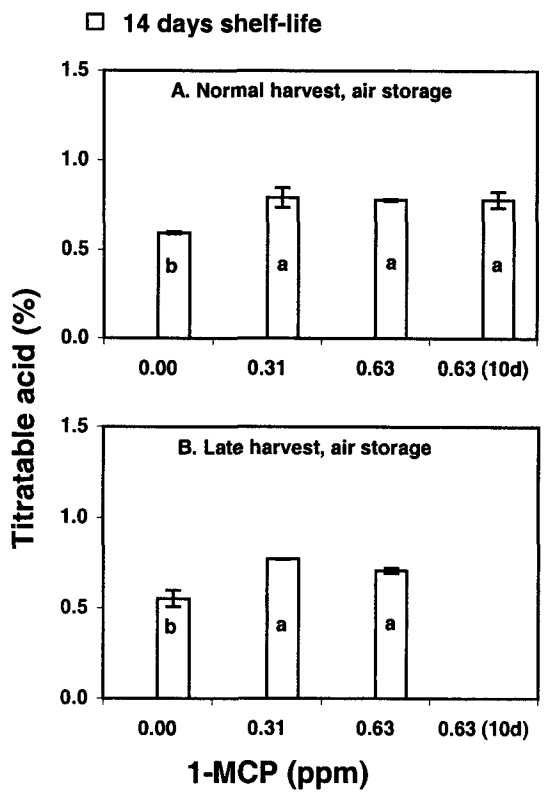

Fig. 4. Titratable acidity of Elstar after 2 months storage. Vertical bars indicate ± std of the mean of 2 replicates. Columns within a chart marked with a same letter are not statistically different (P=0.05).

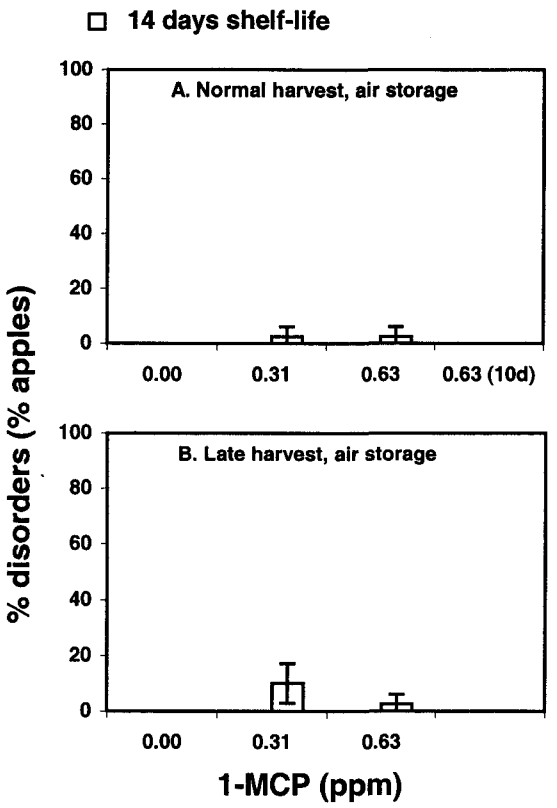

Fig. 5. % apples with disorders of Elstar after 2 months storage. Vertical bars indicate ± std of the mean of 2 replicates.

4.3 Elstar, 4 months storage

The firmness of control apples (0 ppm 1-MCP) of normal harvest after 4 months air storage was below the requirements for good quality (45-50 N) and even decreased further during shelf-life (Fig. 6A). 1-MCP completely prevented firmness loss during storage and during subsequent shelf-life. Firmness of 1-MCP treated apples after air storage + shelf-life was better than the firmness of untreated apples after ULO storage + shelf-life (Fig 6C).
Firmness at harvest was 59.3±0.3N, firmness after storage was 42.7±0.8, 59.3±1.6, 58.2±2.2 and 57.4±2.1 N for control, 0.312 ppm, 0.625 ppm and 0.625 ppm (10d) 1-MCP respectively.

For late harvest, 1-MCP strongly inhibited firmness loss during air storage (Fig 6B). After 14 days shelf-life, 1-MCP treated apples still had an acceptable firmness.

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) while no clear effect was found for late harvest (Fig 7B and 7D).

There was no important effect of 1-MCP on soluble solids content (Fig. 8).

For air storage of normal harvest, 1-MCP treatments resulted in higher acidity (Fig. 9A). For ULO storage of normal harvest, a decrease of acidity was found for 0.63 ppm 1-MCP (Fig. 9C). This result may be the consequence of a measurement fault, as it is not in line with other 1-MCP treatments and other tested storage durations. The titratable acidity of late harvest was not affected by 1-MCP (Fig. 9B and 9D).

No skin pecks were found. There was no clear effect of 1-MCP on other disorders (Fig. 10).

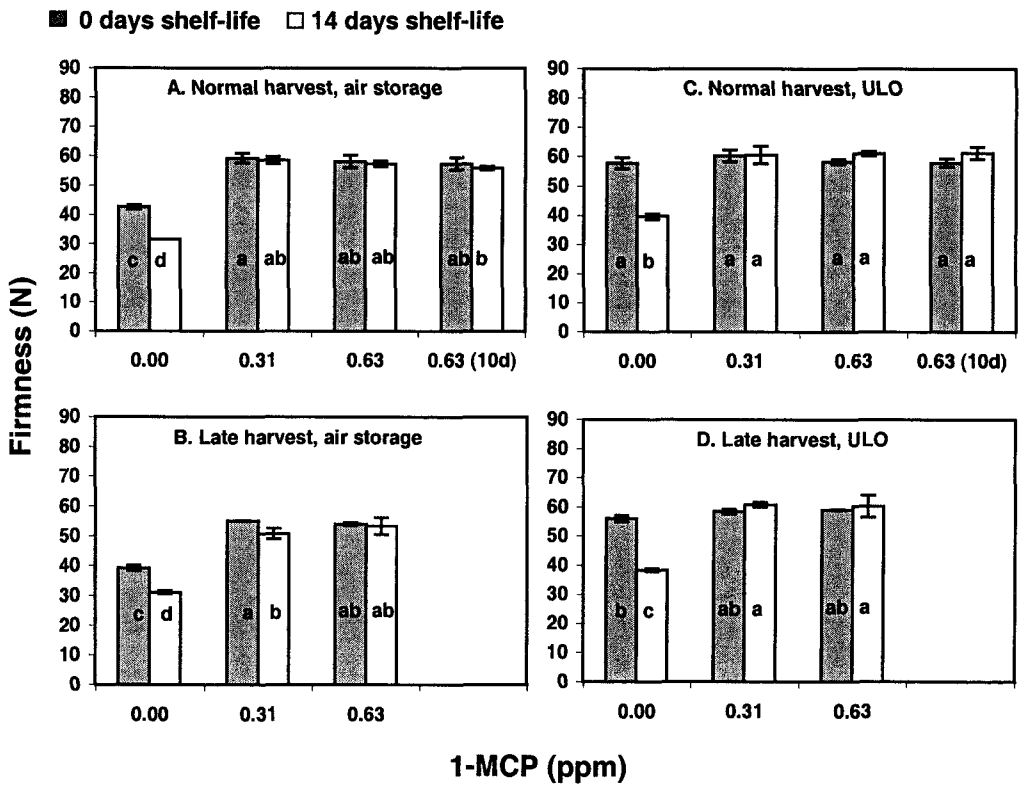

Fig. 6. Firmness of Elstar after 4 months of storage. Vertical bars indicate ± std of the mean of two replicates. Columns within a chart marked with a same letter are not statistically different (P=0.05).

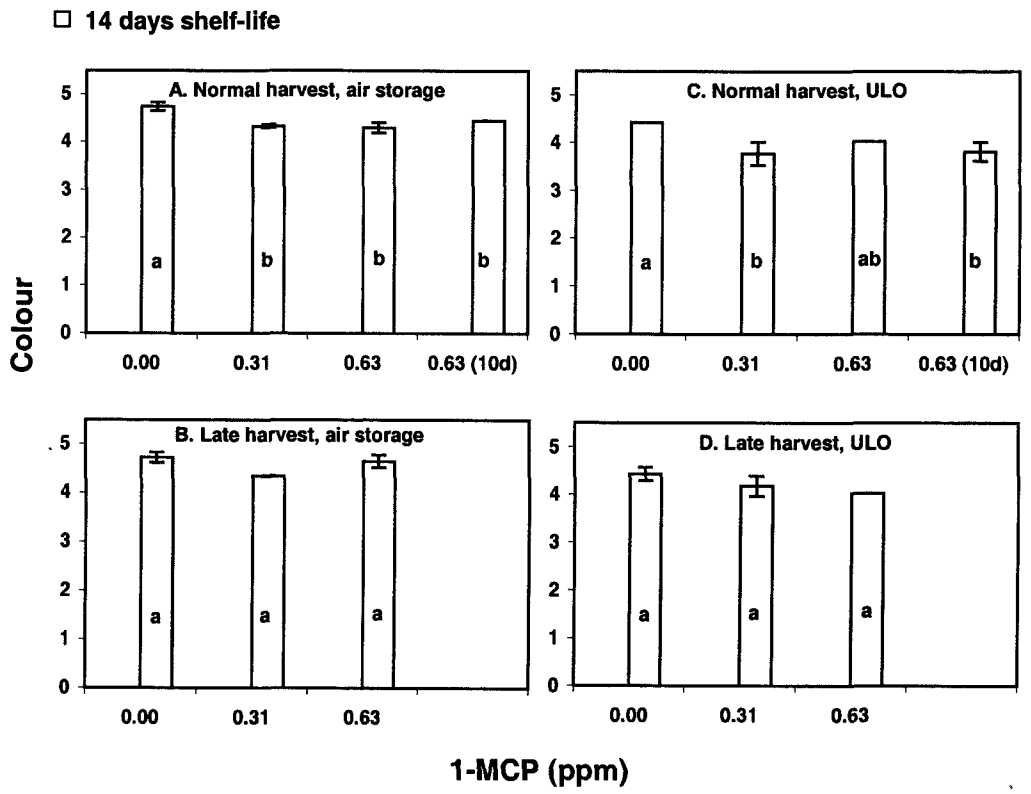

Fig. 7. Colour of Elstar after 4 months of storage. Vertical bars indicate ± std of the mean of two replicates. Columns within a chart marked with a same letter are not statistically different (P=0.05).

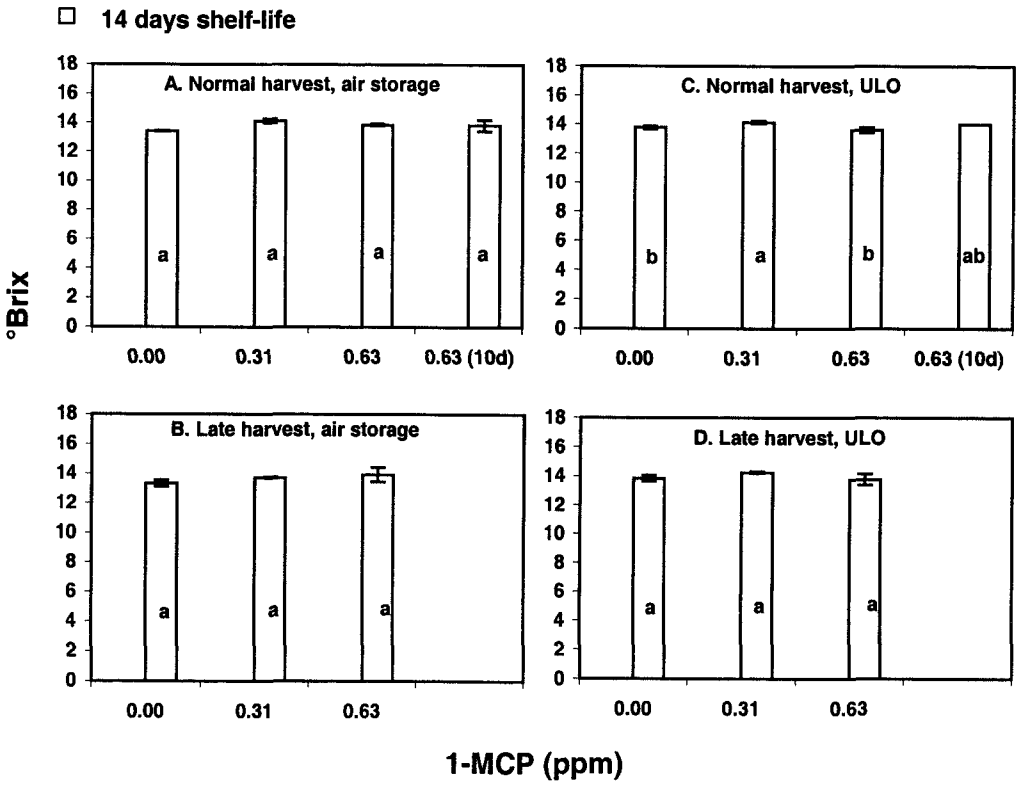

Fig. 8. Soluble solids content of Elstar after 4 months storage. Vertical bars indicate ± std of the mean of 2 replicates. Columns within a chart marked with a same letter are not statistically different (P=0.05).

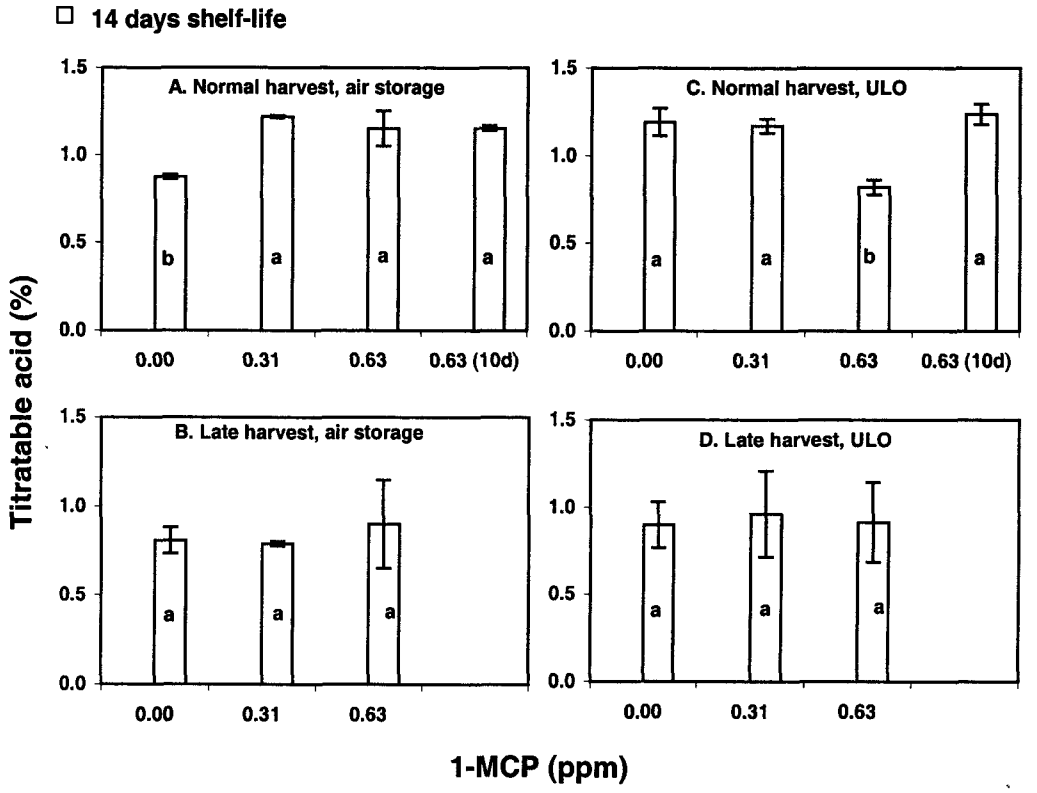

Fig. 9. Titratable acidity of Elstar after 4 months storage. Vertical bars indicate ± std of the mean of 2 replicates. Columns within a chart marked with a same letter are not statistically different (P=0.05).

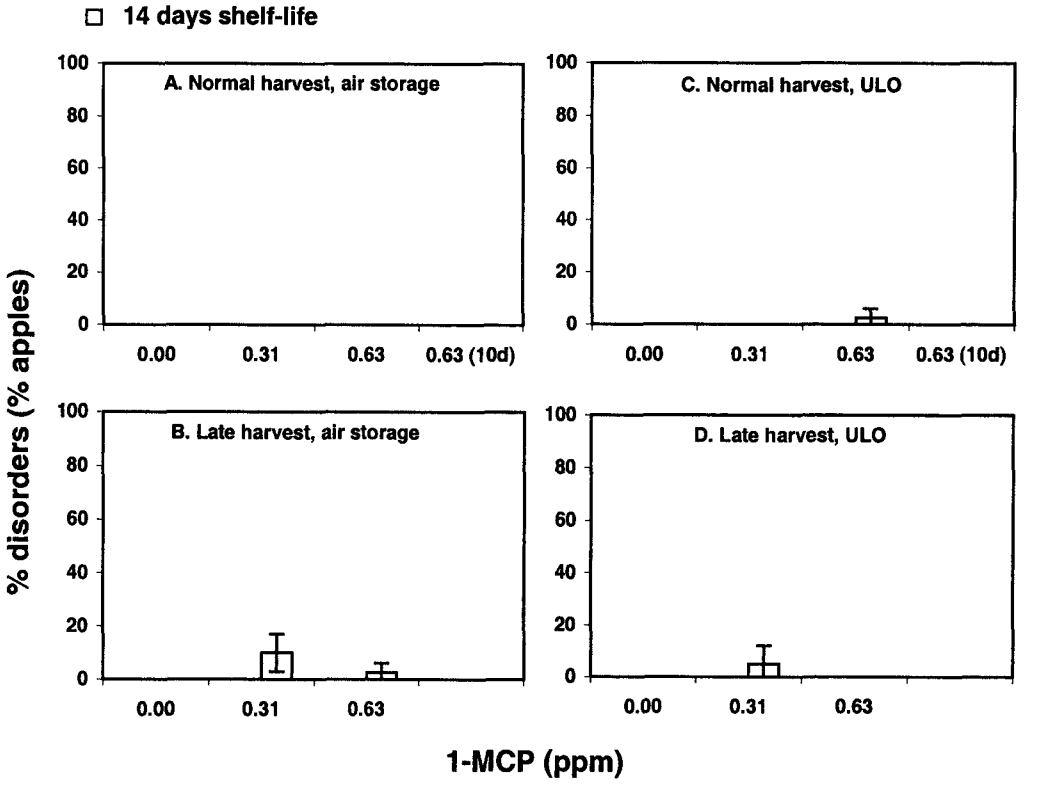

Fig. 10. % apples with disorders of Elstar after 4 months storage. Vertical bars indicate ± std of the mean of 2 replicates.

4.4 Elstar, 6 months storage

Firmness of control apples (0 ppm 1-MCP) of normal harvest was commercially unacceptable after 6 months air storage (Fig. 11A). Treatment with 1-MCP strongly inhibited firmness loss during storage and prevented firmness loss during shelf-life. Firmness after air storage + 1-MCP (0 days shelf-life) was lower than the firmness of ULO without 1-MCP (Fig. 11C). However after 14 days shelf-life, the contrary was true.

Apples of late harvest without 1-MCP severely lost firmness during 6 months air storage, resulting in a commercially unacceptable quality (Fig. 11B). 1-MCP inhibited firmness loss both during storage and during shelf-life which resulted in apples with still acceptable firmness.

Firmness of control apples of normal harvest was maintained during 6 months ULO (Fig. 11C). In this case, the advantage of 1-MCP was shown during shelf-life where 1-MCP prevented firmness loss.
Initial firmness was 59.7±0.2 N while firmness of control apples directly after storage was 60.6±1.6 N.

Also for ULO storage of late harvest, the advantage of 1-MCP was shown during shelf-life where 1-MCP prevented firmness loss (Fig. 11D).

In contrast to 2 and 4 months air storage of normal harvest, 1-MCP now did not have an effect on yellowing (Fig. 12A). However, again inhibition of yellowing was found for ULO (Fig. 12C). No effects were found for late harvest (Fig 12B and 12D).

There were no large effects of 1-MCP on soluble solids content (Fig. 13).

Except for ULO storage of normal harvest, 1-MCP treatments resulted in higher acidity (Fig. 14).

There were no clear effects of 1-MCP on disorders other than skin pecks (Fig. 15).

Control apples (0 ppm 1-MCP) showed a high % of apples with skin pecks (Fig. 16). This was the case with both judgements (total and commercial). Apparently, apples were from a sensitive origin. The % of apples with skin pecks increased by 1-MCP.

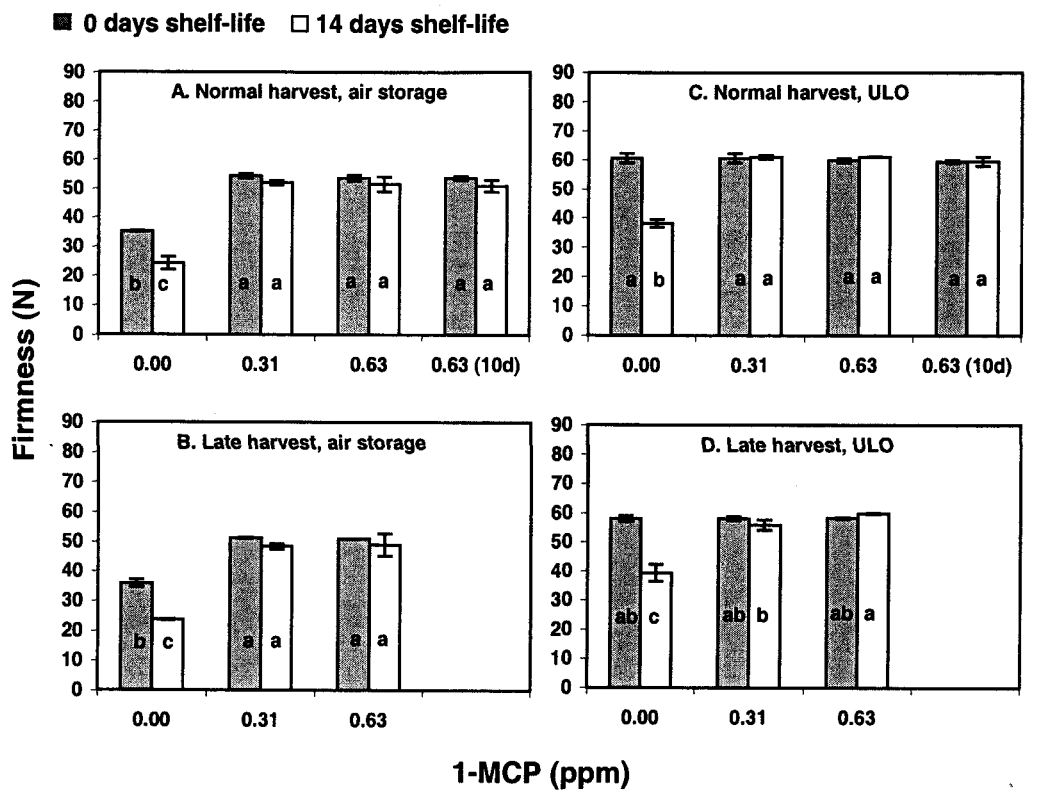

Fig. 11. Firmness of Elstar after 6 months of storage. Vertical bars indicate ± std of the mean of two replicates. Columns within a chart marked with a same letter are not statistically different (P=0.05).

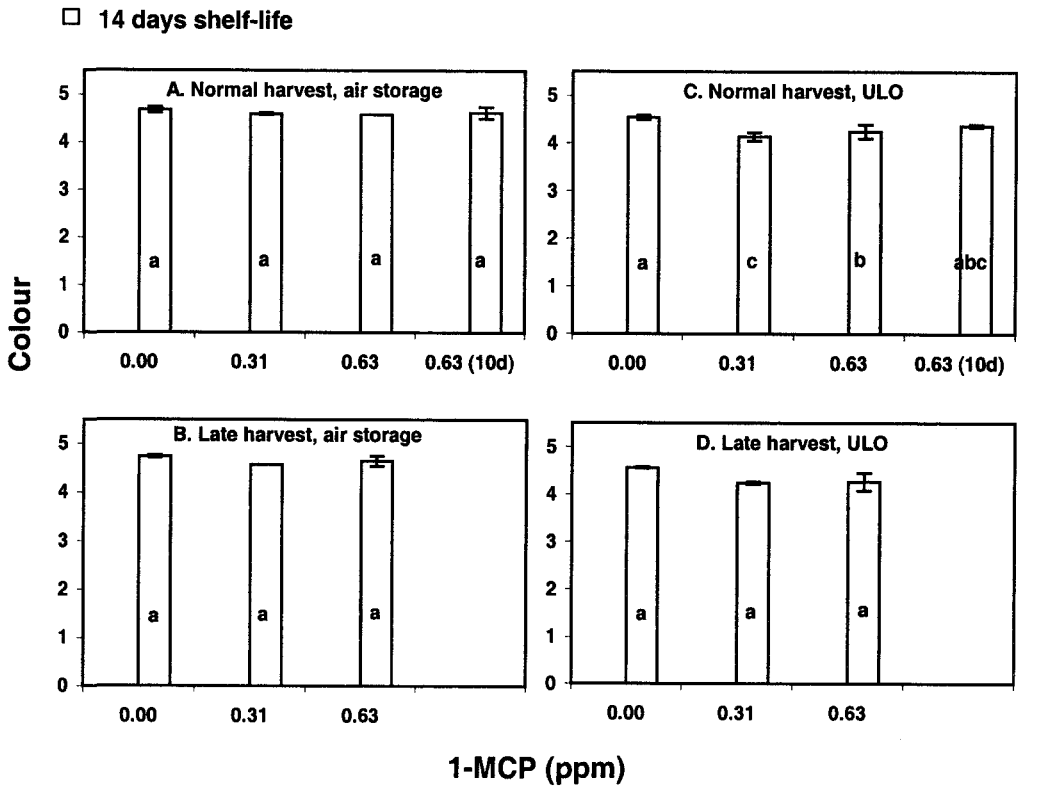

Fig. 12. Colour of Elstar after 6 months of storage. Vertical bars indicate ± std of the mean of two replicates. Columns within a chart marked with a same letter are not statistically different (P=0.05).

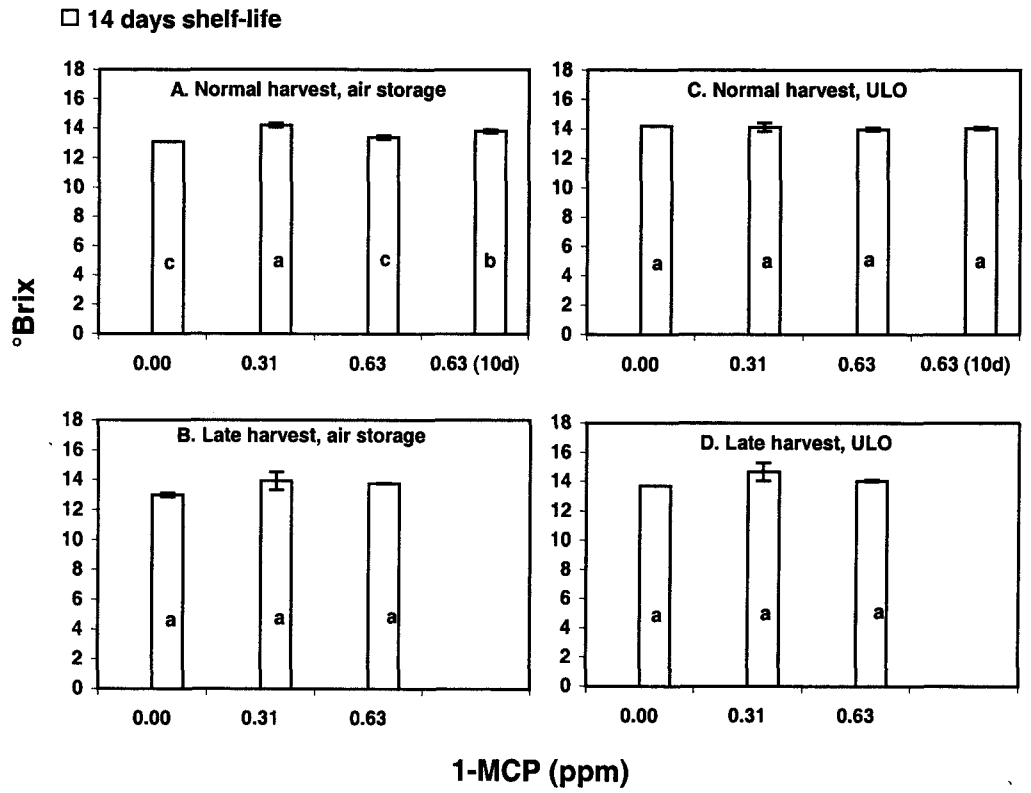

Fig. 13. Soluble solids content of Elstar after 6 months storage. Vertical bars indicate ± std of the mean of 2 replicates. Columns within a chart marked with a same letter are not statistically different (P=0.05).

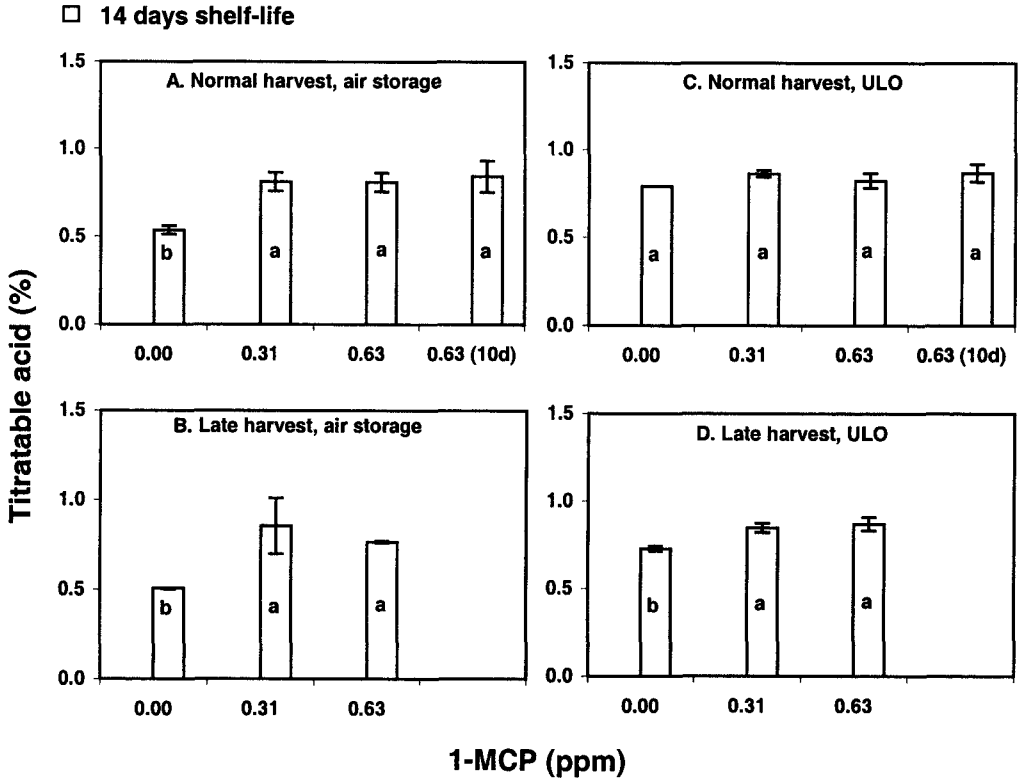

Fig. 14. Titratable acidity of Elstar after 6 months storage. Vertical bars indicate ± std of the mean of 2 replicates. Columns within a chart marked with a same letter are not statistically different (P=0.05).

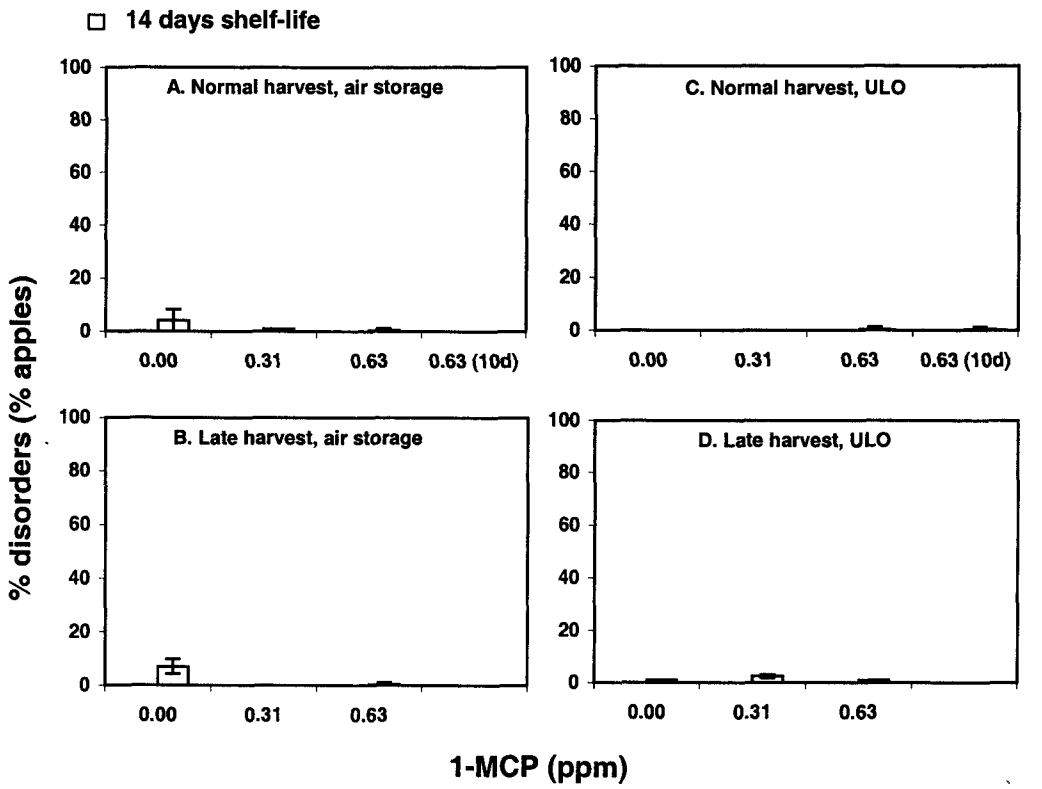

Fig. 15. % apples with disorders of Elstar after 6 months storage. Vertical bars indicate ± std of the mean of 2 replicates.

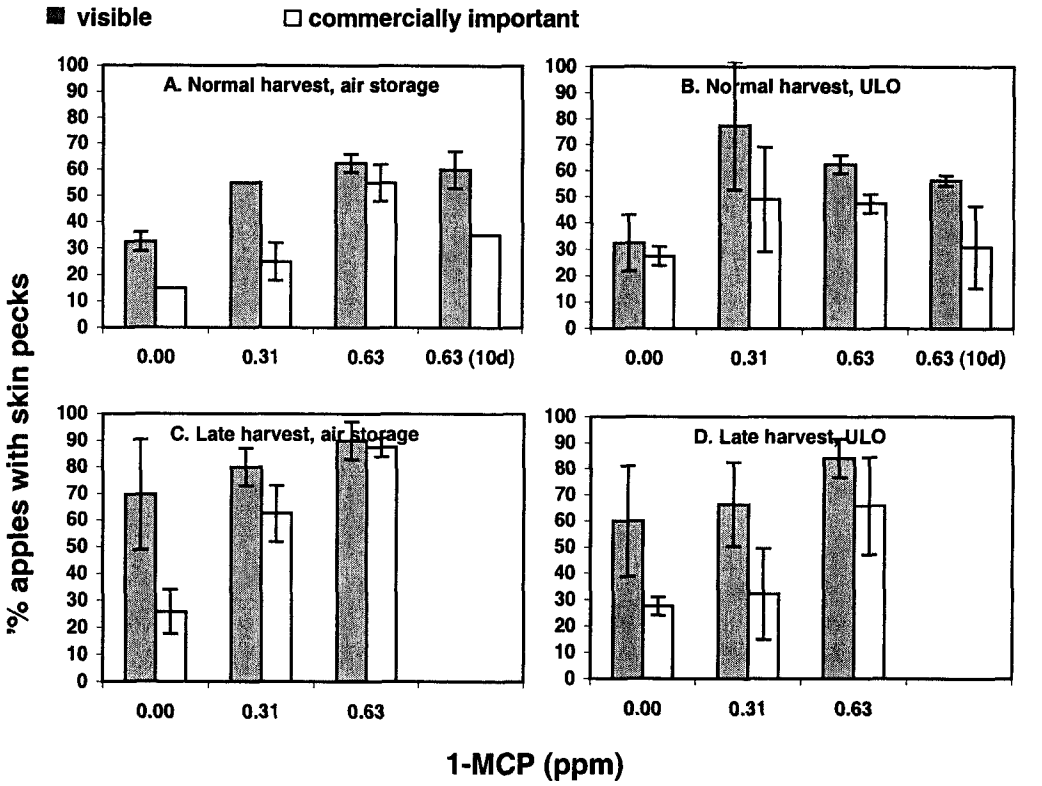

Fig. 16. % apples with skin pecks of Elstar after 6 months storage. Vertical bars indicate ± std of the mean of 2 replicates.

4.4 Elstar, 8 months storage

The firmness of control apples of both harvest dates was maintained during 8 months of ULO storage (Fig. 17A and 17B). However, firmness decreased during subsequent shelf-life to values below commercially acceptable. 1-MCP treatments prevented firmness loss during shelf-life which resulted in apples with good firmness. The apparent increase in firmness during shelf-life is probably the consequence of some dehydration of apples.
Initial firmness was 59.3±0.3 N while firmness of control apples directly after 8 months ULO was 59.7±0.0 N.

Inhibition of yellowing by 1-MCP was found for ULO storage of normal harvest (Fig. 18A) while no effects were found for late harvest (Fig 18B).

There were no effects of 1-MCP on soluble solids content (Fig. 19) and titratable acidity (Fig. 20).

There were no clear effects of 1-MCP on disorders other than skin pecks (Fig. 21).

Compared to 6 months storage, skin pecks had increased (Fig. 22). In general, no clear differences were found any more between control and 1-MCP treatments.

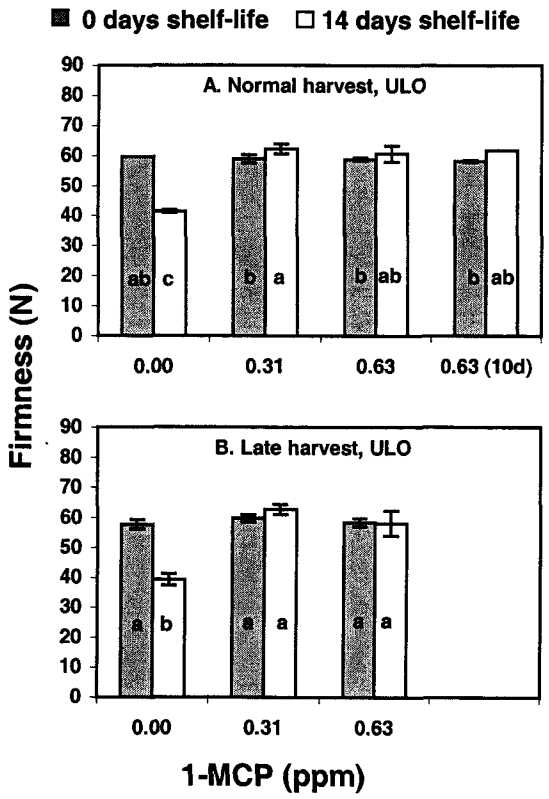

Fig. 17. Firmness of Elstar after 8 months storage. Vertical bars indicate ± std of the mean of two replicates. Columns within a chart marked with a same letter are not statistically different (P=0.05).

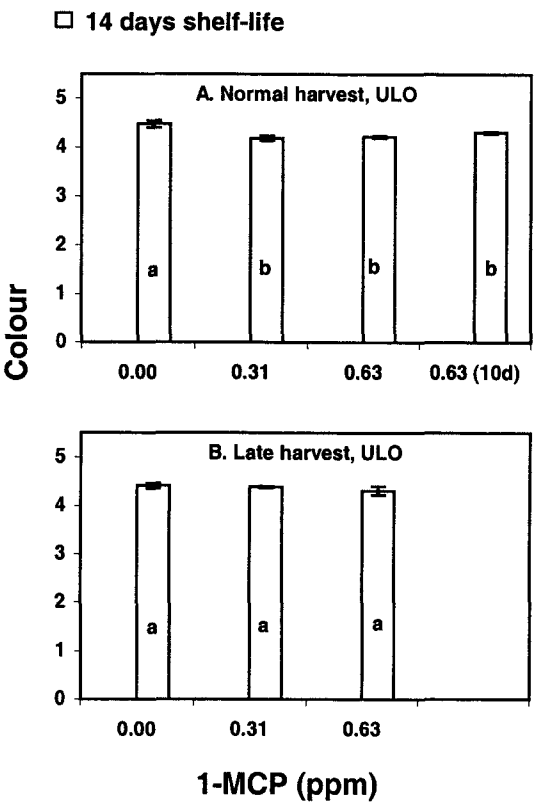

Fig. 18. Colour of Elstar after 8 months of storage. Vertical bars indicate ± std of the mean of two replicates. Columns within a chart marked with a same letter are not statistically different (P=0.05).

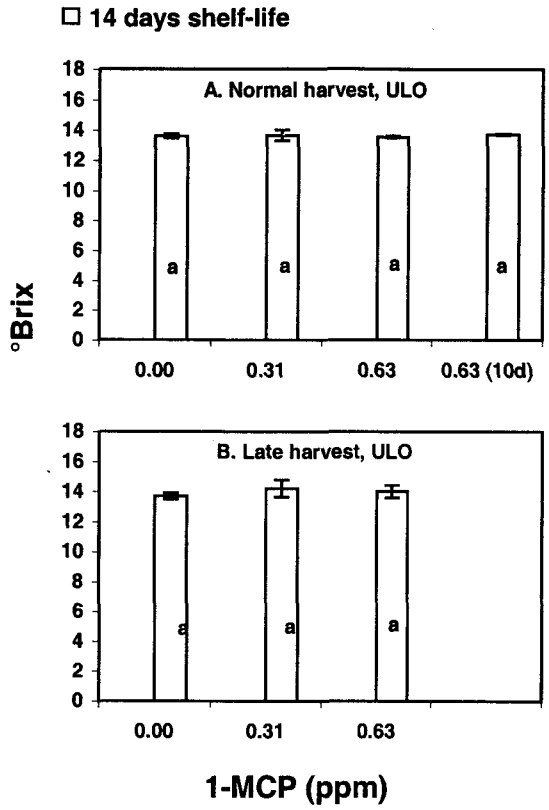

Fig. 19. Soluble solids content of Elstar after 8 months storage. Vertical bars indicate ± std of the mean of 2 replicates. Columns within a chart marked with a same letter are not statistically different (P=0.05).

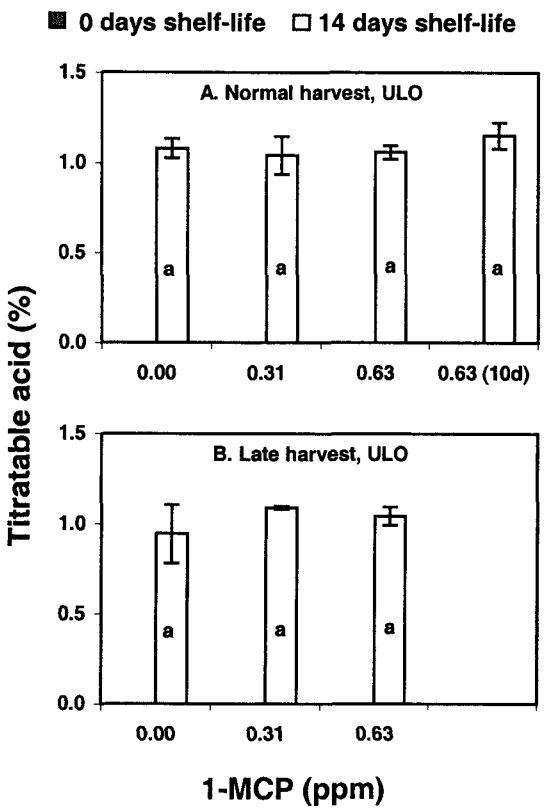

Fig. 20. Titratable acidity of Elstar after 8 months storage. Vertical bars indicate ± std of the mean of 2 replicates. Columns within a chart marked with a same letter are not statistically different (P=0.05).

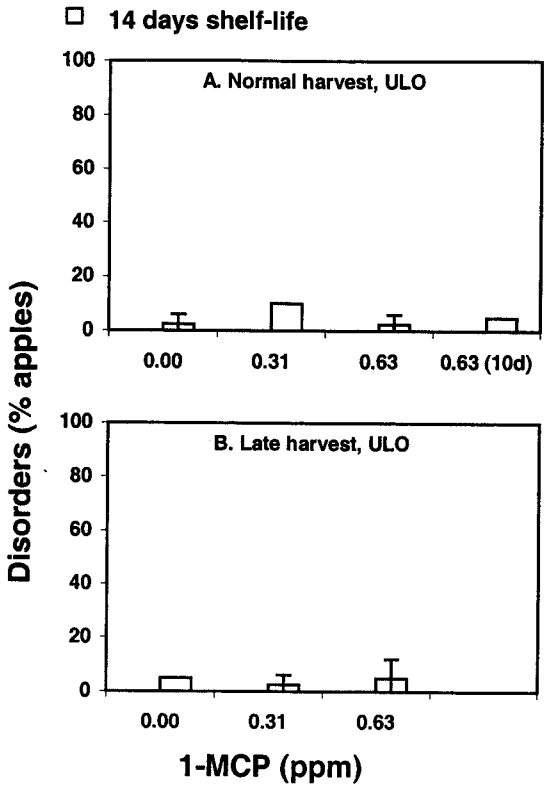

Fig. 21. % appels with disorders of Elstar after 8 months storage. Vertical bars indicate ± std of the mean of 2 replicates.

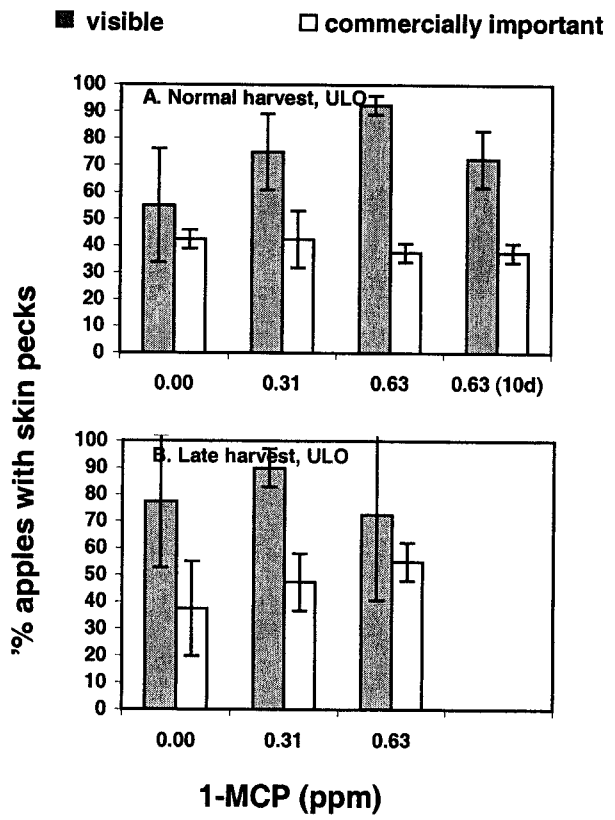

Fig. 22. % apples with skin pecks of Elstar after 8 months storage. Vertical bars indicate ± std of the mean of 2 replicates.

5. Results Jonagold

5.1 Jonagold, initial quality

The mean firmness of Jonagold at the start of the experiments was 69.3±0.1 N (mean ± standard deviation) for normal harvest and 69.4±1.4 N for late harvest. The mean colour was 3.2±0.0 and 4.1±0.2 respectively. The mean content of soluble solids was 13.4±0.2 and 13.8±0.2 °brix respectively. The mean % titratable acidity was 0.66±0.02 and 0.64±0.00 respectively.

5.2 Jonagold, 2 months storage

Firmness of control apples (0 ppm 1-MCP) of normal harvest had decreased during 2 months air storage (Fig. 23A). Treatment with 1-MCP shortly after harvest largely prevented this decrease and inhibited firmness loss during 14 days shelf-life. The treatment with 1-MCP at 10 days after harvest was less successful compared to treatment shortly after harvest.
While firmness at harvest was 69.3±0.1 N, the firmness after 2 months air was 52.7±2.3, 62.3±0.6, 64.7±0.6 and 57.3±2.0 N for control, 0.312 ppm, 0.625 ppm and 0.625 ppm (10d) 1-MCP respectively.

Also firmness loss of late harvested apples during air storage and subsequent shelf-life was inhibited by 1-MCP (Fig. 23B).
Firmness at harvest was 69.4±1.4 N, firmness after storage was 60.0±0.8, 67.4±2.2 and 63.9±0.6 N for control, 0.312 ppm and 0.625 ppm 1-MCP respectively.

Yellowing was inhibited by 1-MCP for both harvests (Fig. 24).

There were no clear effects of 1-MCP on soluble solids content (Fig. 25).

In all cases 1-MCP treatments resulted in higher titratable acidity (Fig. 26).

There were no clear effects of 1-MCP on disorders (Fig. 27).

Greasiness was inhibited by 0.625 ppm 1-MCP (Fig. 28).

Two months air storage + 14 days shelf-life resulted in apples of good quality if treated with 1-MCP shortly after harvest.

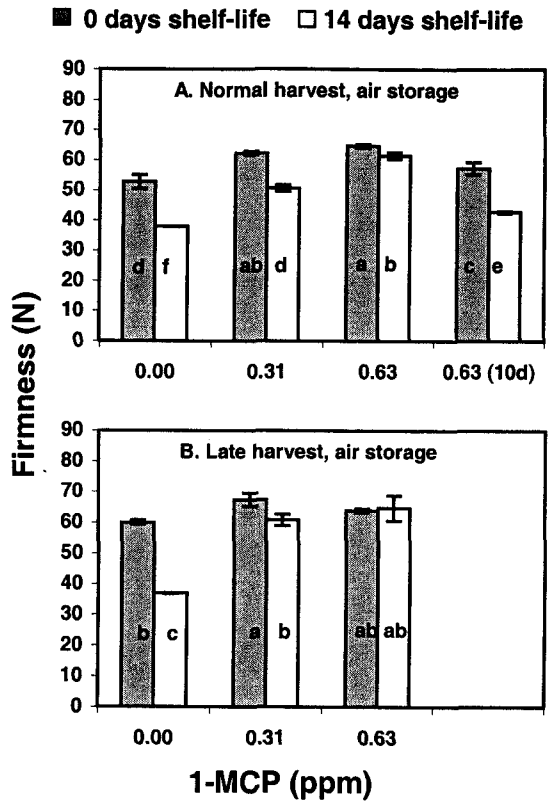

Fig. 23. Firmness of Jonagold after 2 months of storage. Vertical bars indicate ± std of the mean of two replicates. Columns within a chart marked with a same letter are not statistically different (P=0.05).

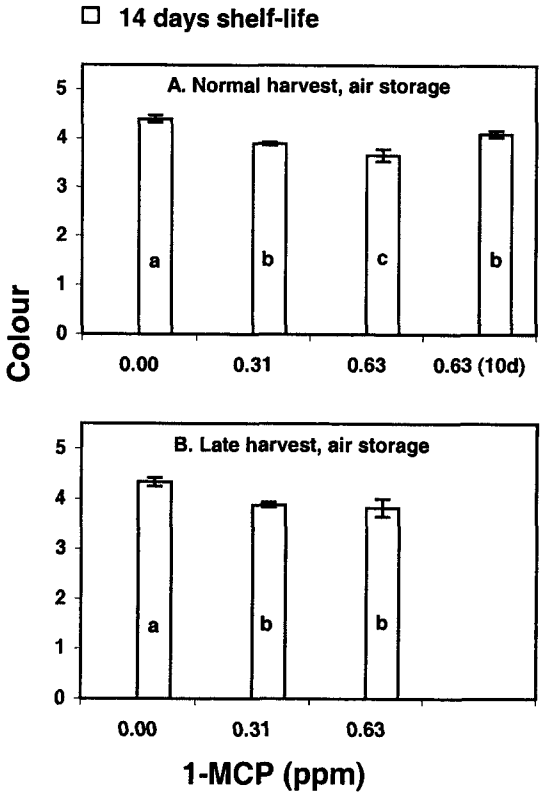

Fig. 24. Colour of Jonagold after 2 months of storage. Vertical bars indicate ± std of the mean of two replicates. Columns within a chart marked with a same letter are not statistically different (P=0.05).

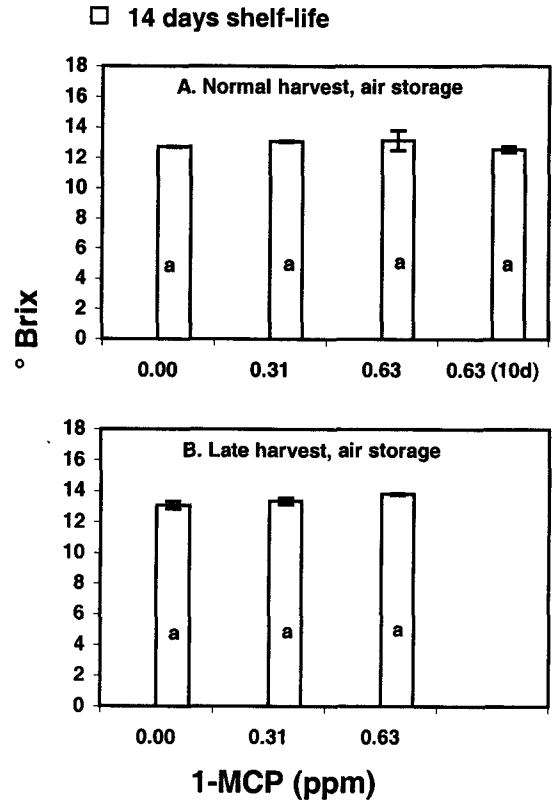

Fig. 25. Soluble solids content of Jonagold after 2 months storage. Vertical bars indicate ± std of the mean of 2 replicates. Columns within a chart marked with a same letter are not statistically different (P=0.05).

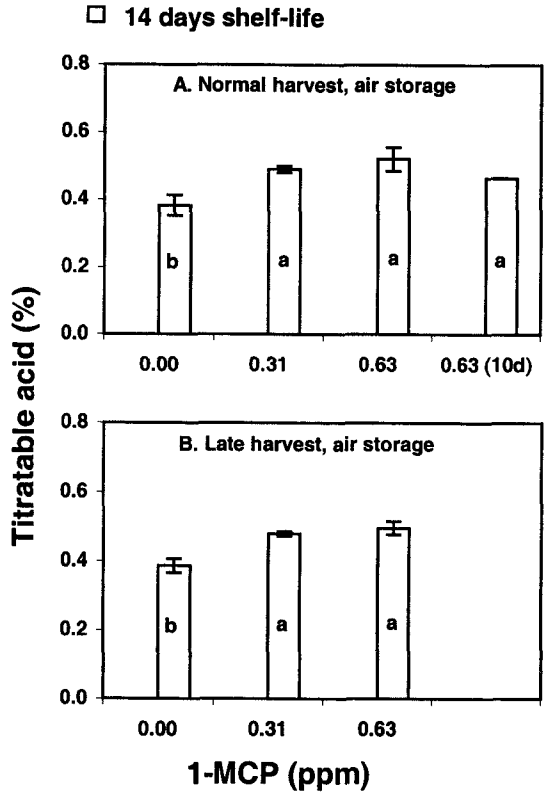

Fig. 26. Titratable acidity of Jonagold after 2 months storage. Vertical bars indicate ± std of the mean of 2 replicates. Columns within a chart marked with a same letter are not statistically different (P=0.05).

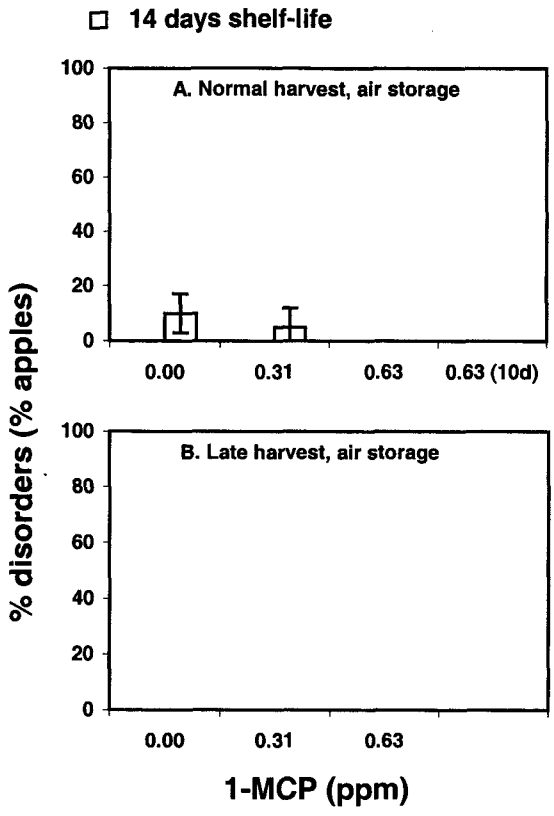

Fig. 27. % apples with disorders of Jonagold after 2 months storage. Vertical bars indicate ± std of the mean of 2 replicates.

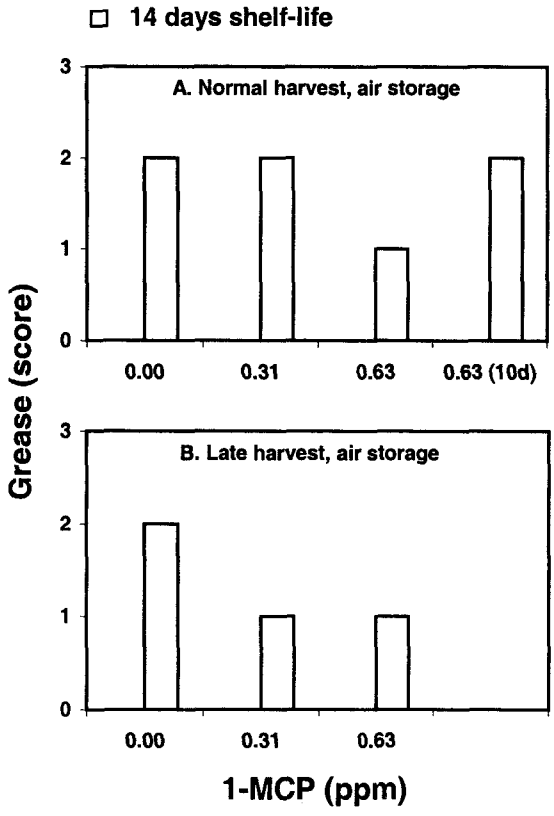

Fig. 28. Index for greasiness of Jonagold after 2 months storage. Vertical bars indicate ± std of the mean of 2 replicates.

5.3 Jonagold, 4 months storage

The firmness of control apples (0 ppm 1-MCP) of normal harvest after 4 months air storage was below the requirements for good quality (45-50 N) (Fig. 29A). Also with 1-MCP, apples were below or at the acceptable limit. Treatment with 1-MCP could not replace the beneficial effect of ULO. Both at 0 and at 14 days shelf-life, control apples from ULO (Fig. 29C) were firmer than 1-MCP treated apples from air storage.

Also the firmness of control apples of late harvest was below the requirements for good quality (Fig. 29B). With 1-MCP, firmness was still acceptable after 14 days shelf-life

The best results for ULO storage of normal harvest were found for 1-MCP treatments shortly after harvest (Fig. 29C). Advantage of these 1-MCP treatments was firmness retention during storage and during shelf-life.

Similar results were found for late harvested apples (Fig 29D). Advantage of 1-MCP was firmness retention during shelf-life.

Yellowing was inhibited by 1-MCP only in case of ULO storage (Fig. 30).

Only for air storage of late harvest, soluble solids content was little higher of 1-MCP treated apples than of control apples (Fig. 31).

In manyl cases 1-MCP treatments resulted in higher titratable acidity (Fig. 32).

For air storage of normal harvest, control apples showed a high percentage of apples with disorders (Fig. 33). This was also the case for the 1-MCP treatment at 10 days after harvest. The two 1-MCP treatments shortly after harvest inhibited the development of disorders.

In general, greasiness tended to decrease by 1-MCP treatments shortly after harvest (Fig. 34).

The best quality was found for the combination of ULO and 1-MCP treatments shortly after harvest.

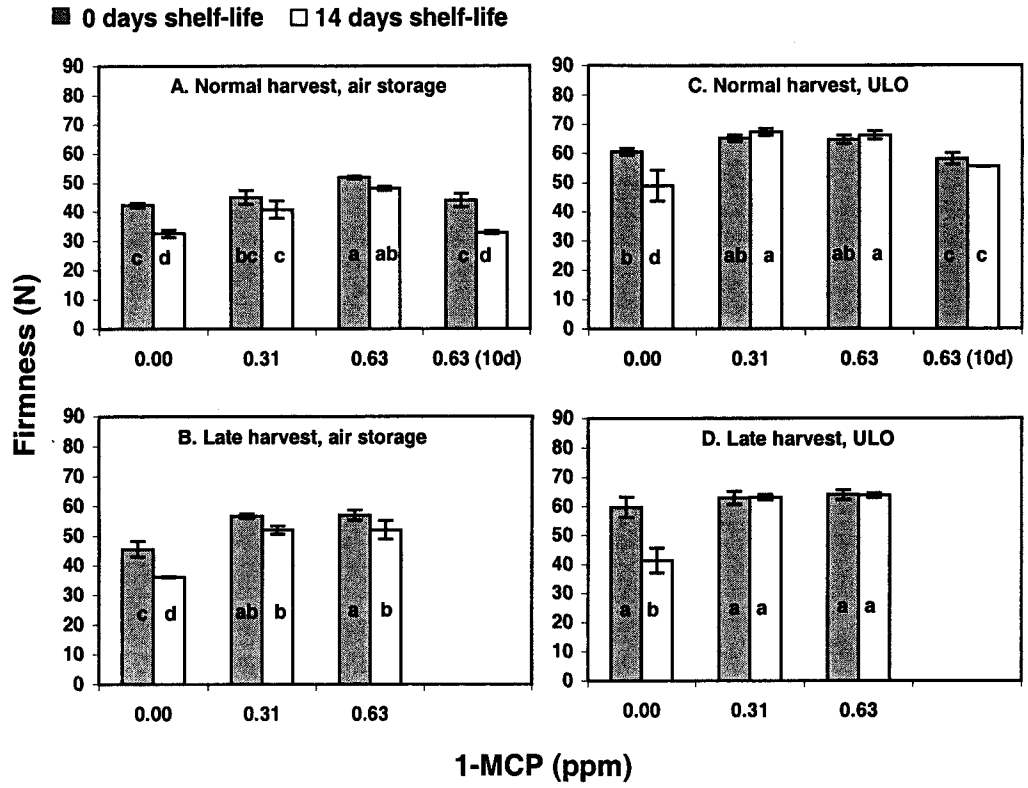

Fig. 29. Firmness of Jonagold after 4 months of storage. Vertical bars indicate ± std of the mean of two replicates. Columns within a chart marked with a same letter are not statistically different (P=0.05).

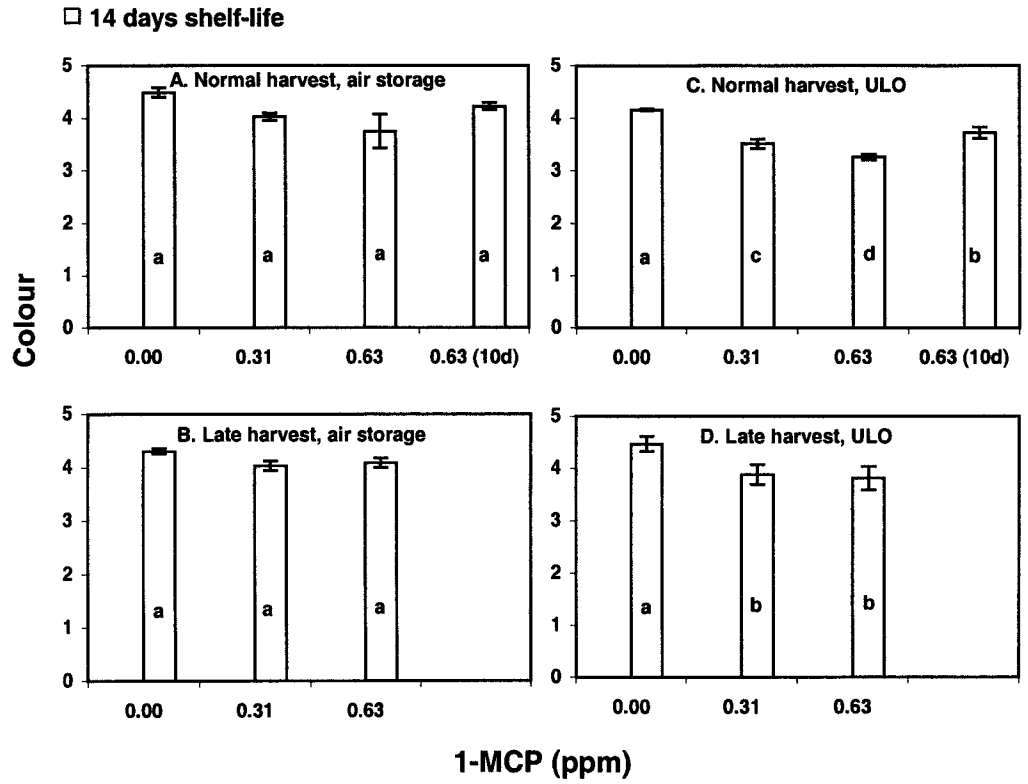

Fig. 30. Colour of Jonagold after 4 months of storage. Vertical bars indicate ± std of the mean of two replicates. Columns within a chart marked with a same letter are not statistically different (P=0.05).

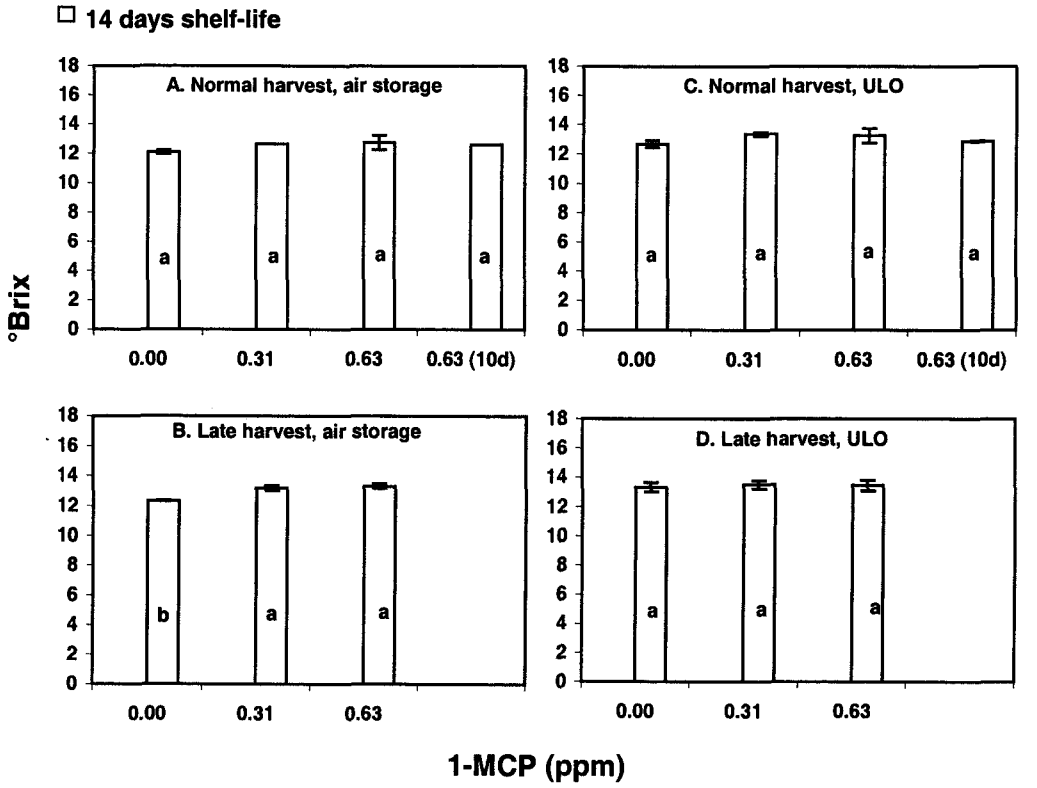

Fig. 31. Soluble solids content of Jonagold after 4 months storage. Vertical bars indicate ± std of the mean of 2 replicates Columns within a chart marked with a same letter are not statistically different (P=0.05).

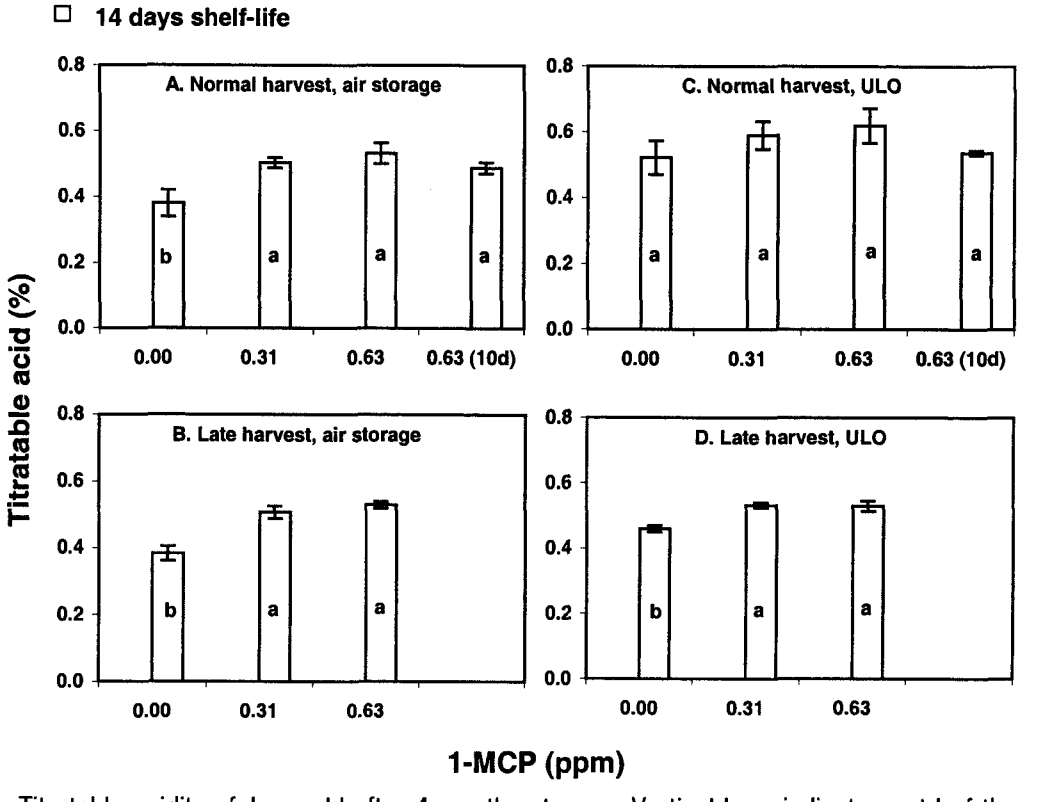

Fig. 32. Titratable acidity of Jonagold after 4 months storage. Vertical bars indicate ± std of the mean of 2 replicates. Columns within a chart marked with a same letter are not statistically different (P=0.05).

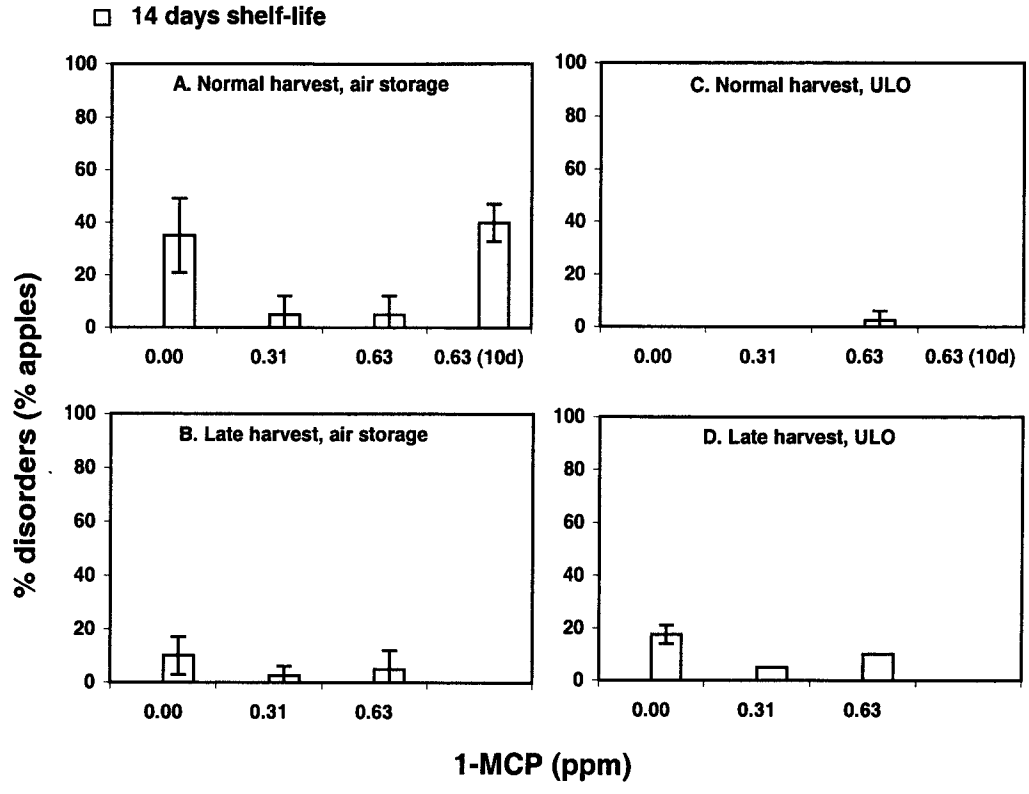

Fig. 33. % apples with disorders of Jonagold after 4 months storage. Vertical bars indicate ± std of the mean of 2 replicates.

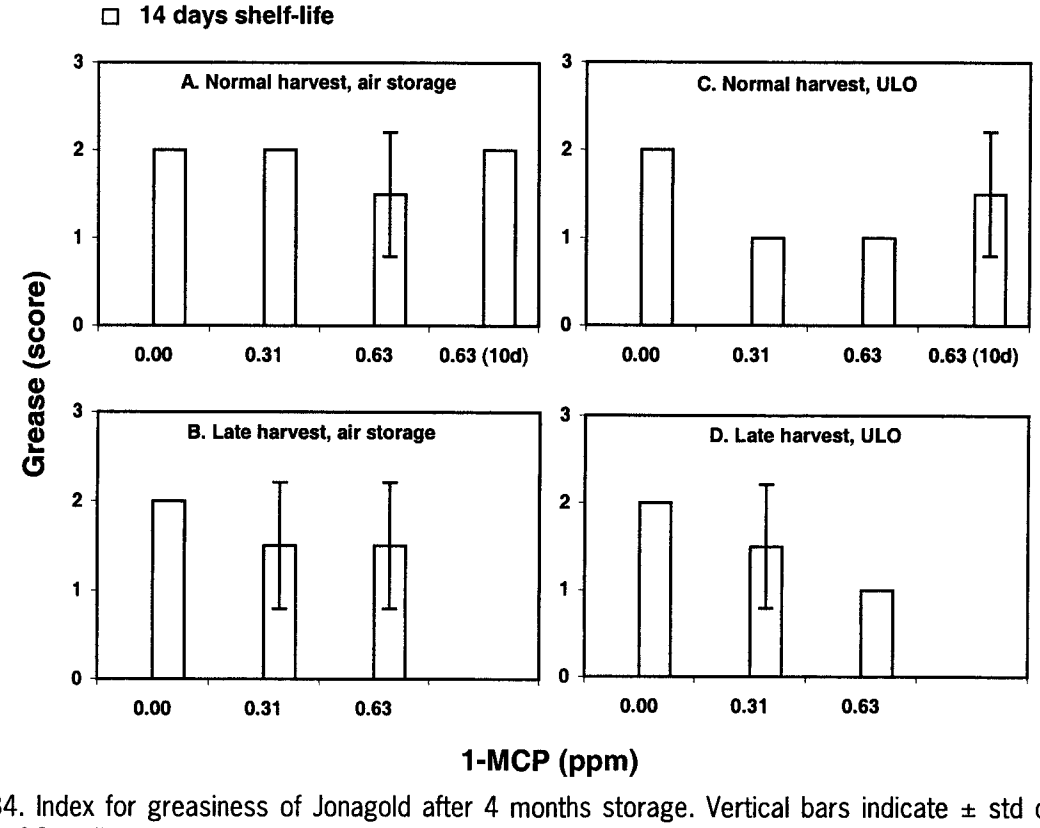

Fig. 34. Index for greasiness of Jonagold after 4 months storage. Vertical bars indicate ± std of the mean of 2 replicates.

5.4 Jonagold, 6 months storage

After 6 months air storage, firmness had decreased severely for all treatments. For normal harvest, firmness was only acceptable of apples treated with 0.625 ppm 1-MCP shortly after harvest (Fig. 35A). Treatment with 1-MCP could not replace the beneficial effect of ULO. Control apples from ULO storage (Fig 35C) were firmer than 1-MCP treated apples from air storage, both directly after storage and after shelf-life.

For late harvest, firmness after shelf-life was still acceptable after 1-MCP treatment (Fig. 35B). Firmness was similar to control apples from ULO (Fig 35D).

Firmness of normal harvest had decreased during ULO for all treatments (Fig 35C). No difference was found between control and 1-MCP treatment at 10 days after harvest. The 1-MCP treatments shortly after harvest were very effective. The apparent increase in firmness during shelf-life is probably the consequence of some dehydration of the apples.
Firmness at harvest was 69.3±0.1 N, firmness after storage was 60.2±0.1, 63.7±2.0, 64.2±0.8 and 58.6±0.7 N for control, 0.312 ppm, 0.625 ppm and 0.625 ppm (10 days) 1-MCP respectively.

Also for ULO storage of late harvest, 1-MCP treatments were advantageous for firmness retention (Fig 35D).

Especially for ULO, 1-MCP inhibited yellowing with best results if applied shortly after harvest (Fig. 36).

Effects on soluble solids content were similar to 4 months storage: Only for air storage of late harvest, soluble solids content was little higher for 1-MCP treated apples compared to control apples (Fig. 37).

For air storage, 1-MCP treatments resulted in higher titratable acidity (Fig. 38).

For air storage, the 0.625 ppm 1-MCP treatment shortly after harvest seemed to be most effective for inhibiting the development of disorders (Fig. 39).

For ULO, greasiness tended to decrease by 1-MCP treatments (Fig. 40).

Similar to 4 months storage, the best quality was found for the combination of ULO and 1-MCP treatments shortly after harvest.

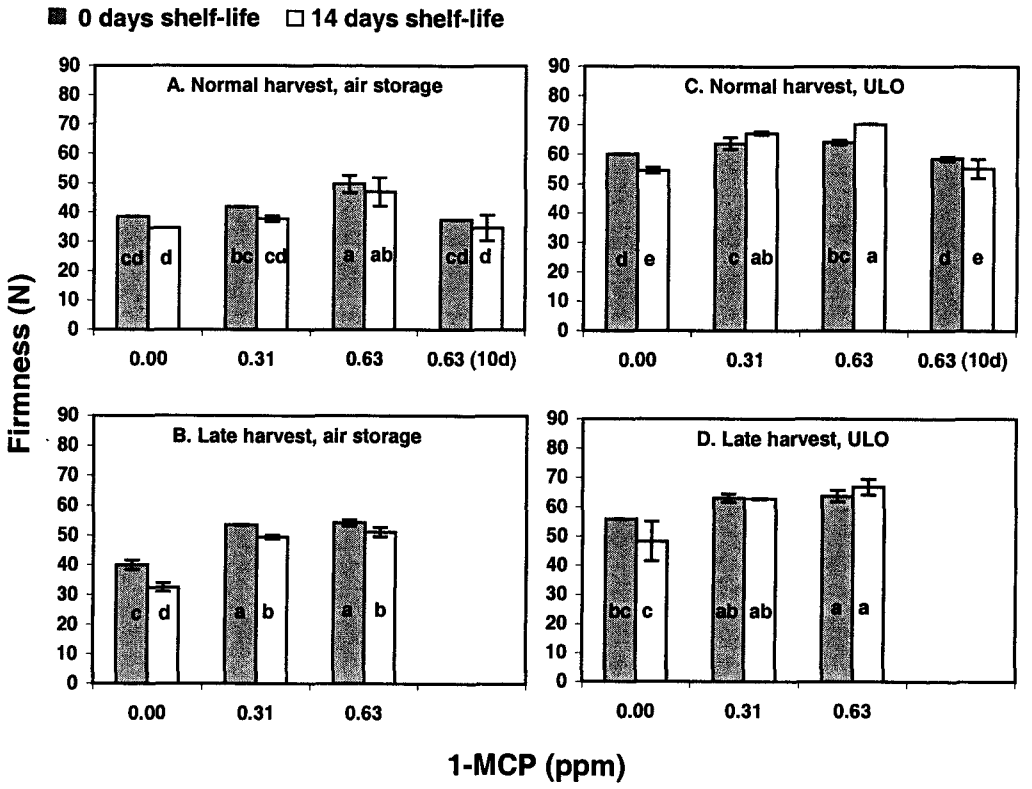

Fig. 35. Firmness of Jonagold after 6 months of storage. Vertical bars indicate ± std of the mean of two replicates. Columns within a chart marked with a same letter are not statistically different (P=0.05).

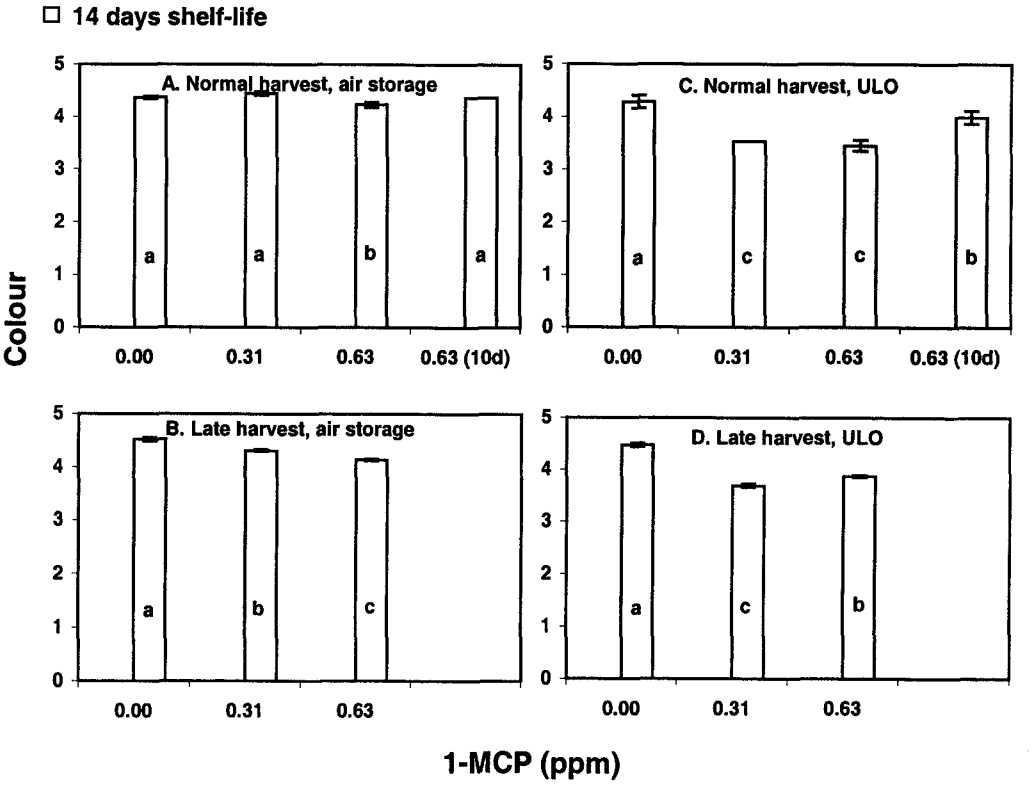

Fig. 36. Colour of Jonagold after 6 months of storage. Vertical bars indicate ± std of the mean of two replicates. Columns within a chart marked with a same letter are not statistically different (P=0.05).

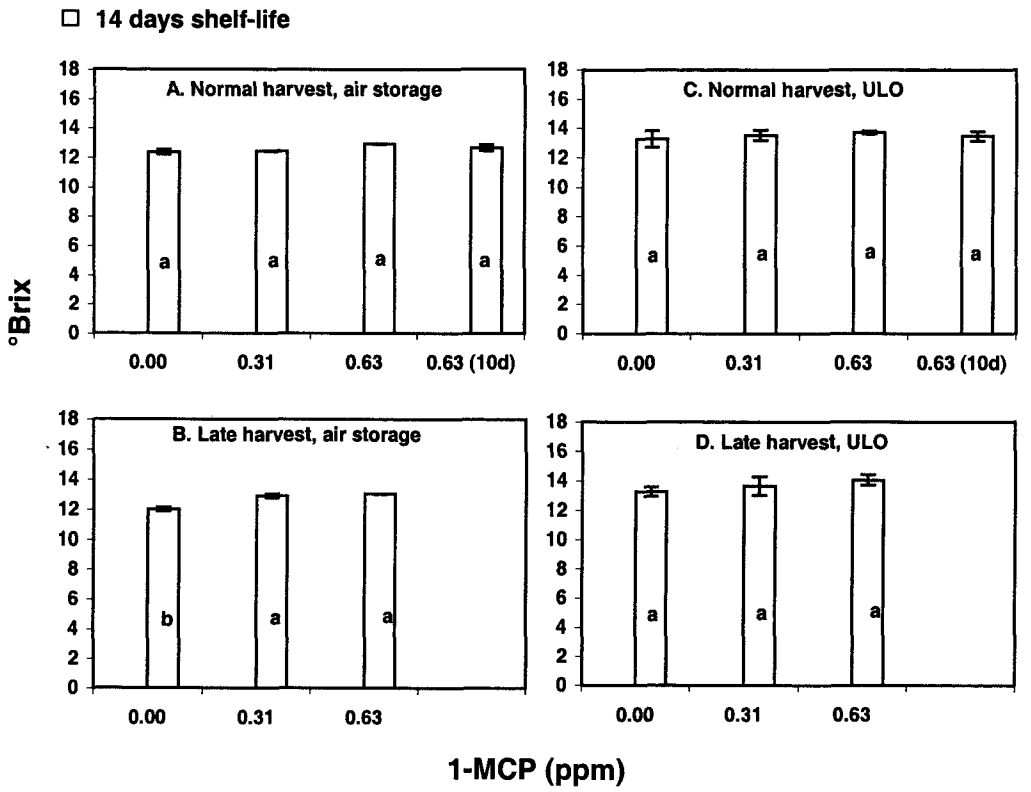

Fig. 37. Soluble solids content of Jonagold after 6 months storage. Vertical bars indicate ± std of the mean of 2 replicates. Columns within a chart marked with a same letter are not statistically different (P=0.05).

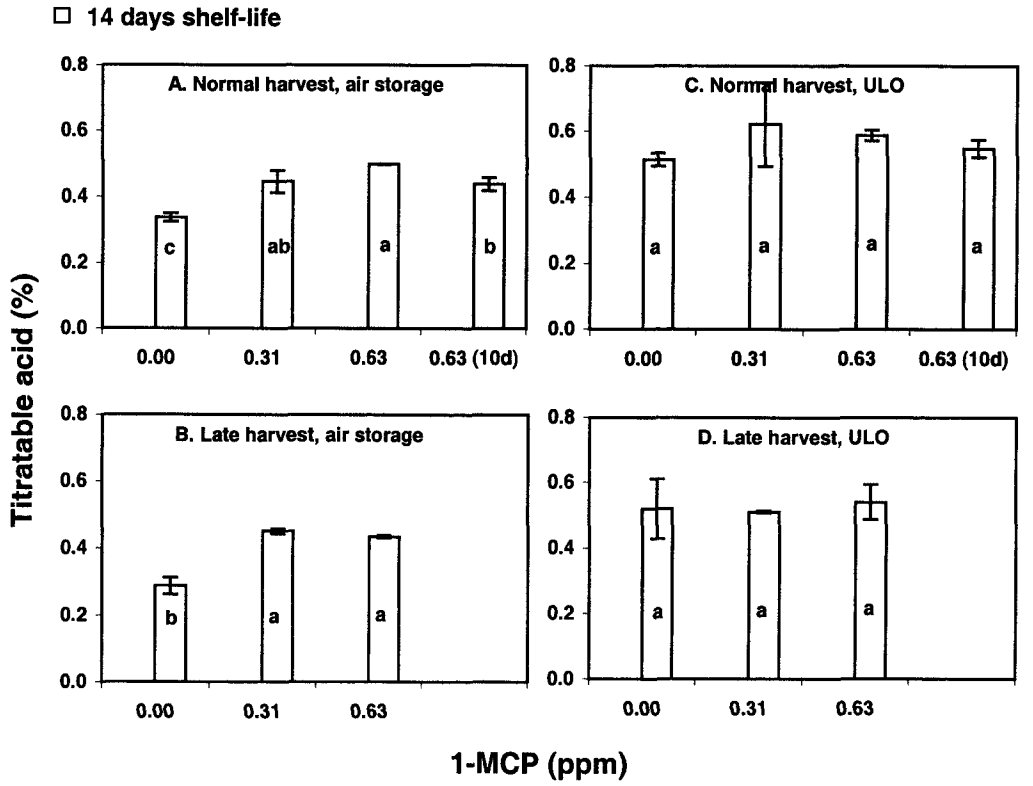

Fig. 38. Titratable acidity of Jonagold after 6 months storage. Vertical bars indicate ± std of the mean of 2 replicates. Columns within a chart marked with a same letter are not statistically different (P=0.05).

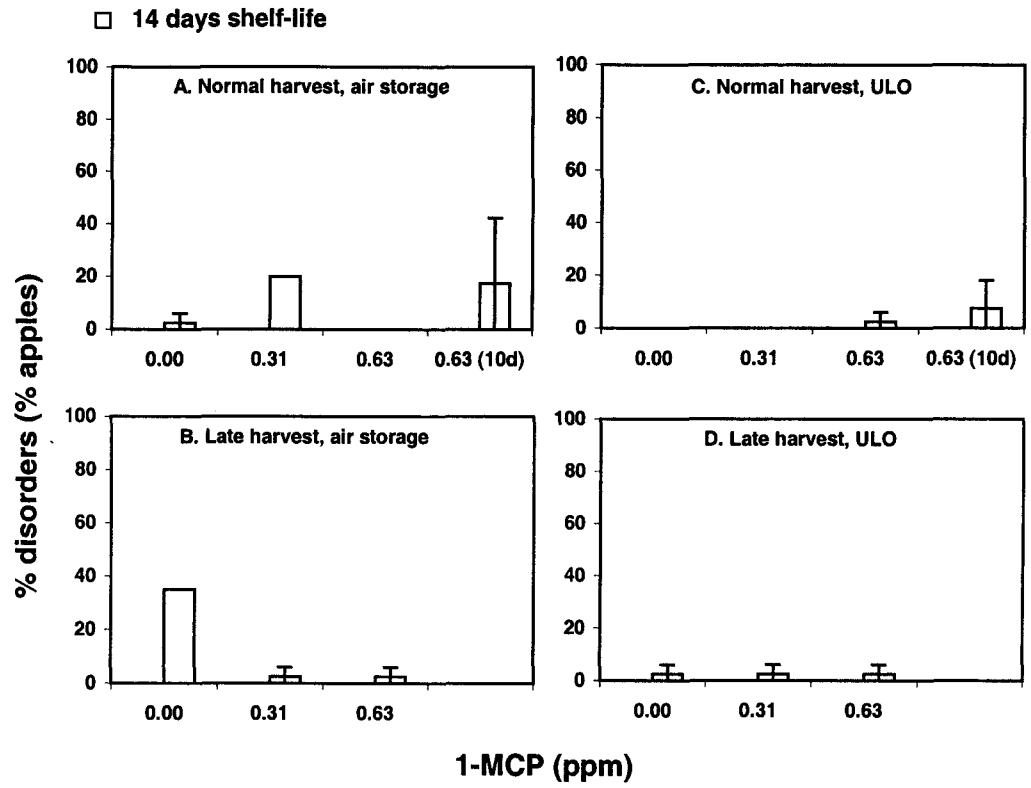

Fig. 39. % apples with disorders of Jonagold after 6 months storage. Vertical bars indicate ± std of the mean of 2 replicates.

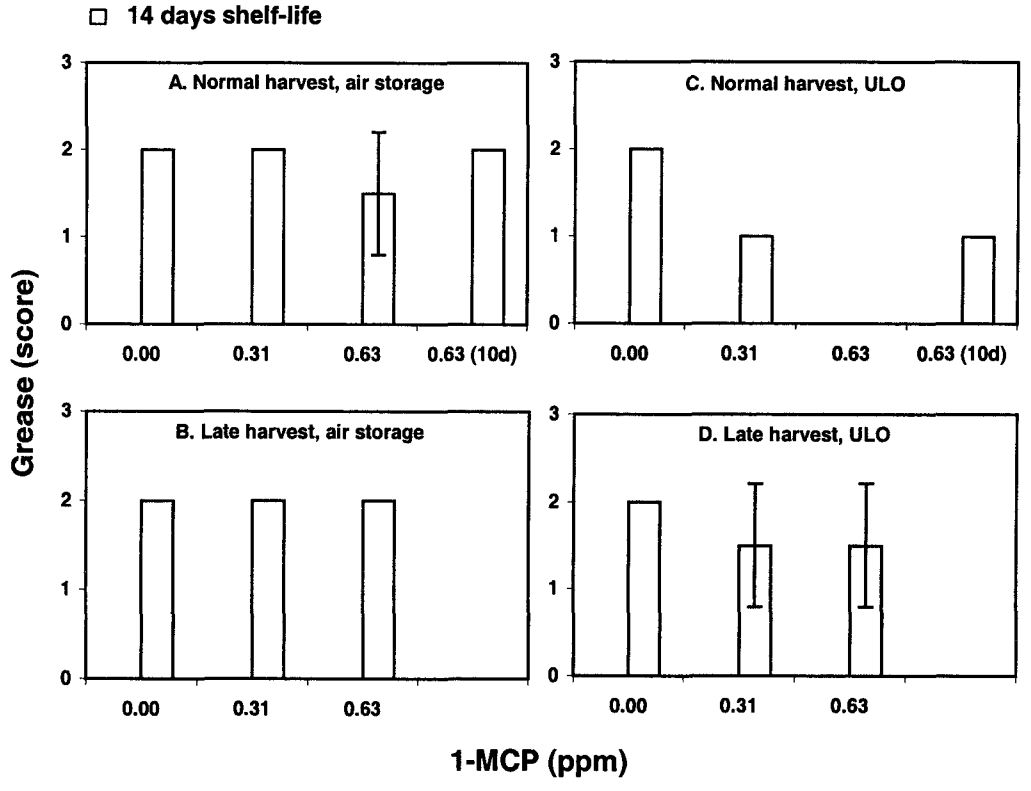

Fig. 40. Index for greasiness of Jonagold after 6 months storage. Vertical bars indicate ± std of the mean of 2 replicates.

5.5 Jonagold, 8 months storage

Firmness of control apples of normal harvest decreased during ULO storage and during shelf-life (Fig. 41A). No difference was found between control and 1-MCP treatment at 10 days after harvest. The 1-MCP treatments shortly after harvest were very effective with good firmness retention even after 14 days shelf-life.

For late harvest, 1-MCP treatments were advantageous for firmness retention during shelf-life (Fig 41B).

Although differences were not statistically significant, 1-MCP tended to inhibit yellowing if applied shortly after harvest (Fig. 42).

Effects on soluble solids content were small (Fig. 43).

There were no clear effects on titratable acidity (Fig. 44) and on disorders (Fig. 45).

Greasiness decreased by 1-MCP treatments, especially by 0.625 ppm shortly after harvest (Fig. 46).

The best quality was found for the combination of ULO and 1-MCP treatments shortly after harvest.

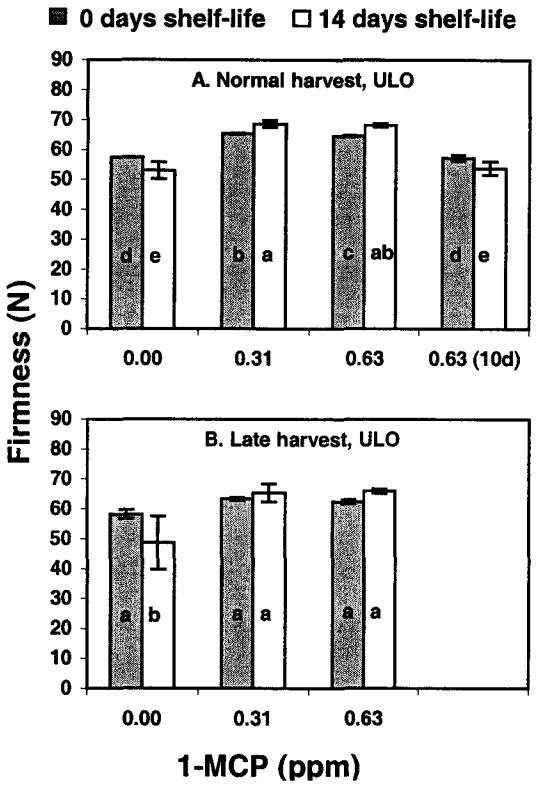

Fig. 41. Firmness of Jonagold after 8 months of storage. Vertical bars indicate ± std of the mean of two replicates. Columns within a chart marked with a same letter are not statistically different (P=0.05).

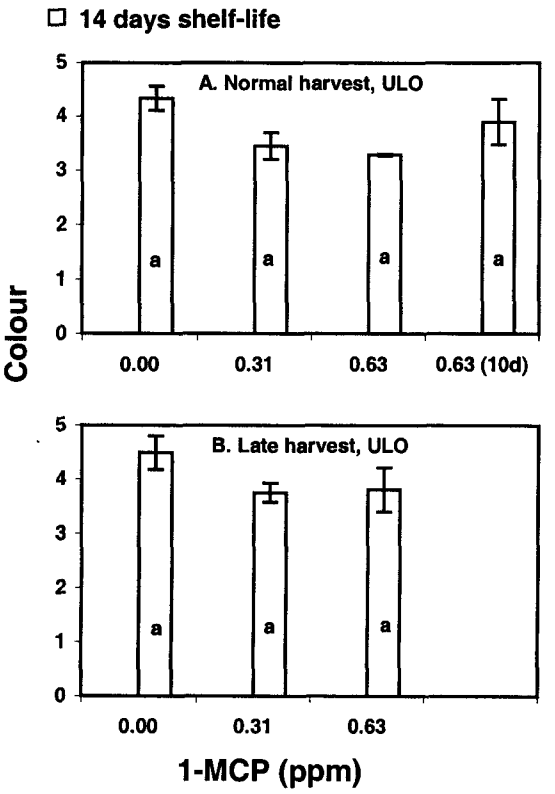

Fig. 42. Colour of Jonagold after 8 months of storage. Vertical bars indicate ± std of the mean of two replicates. Columns within a chart marked with a same letter are not statistically different (P=0.05).

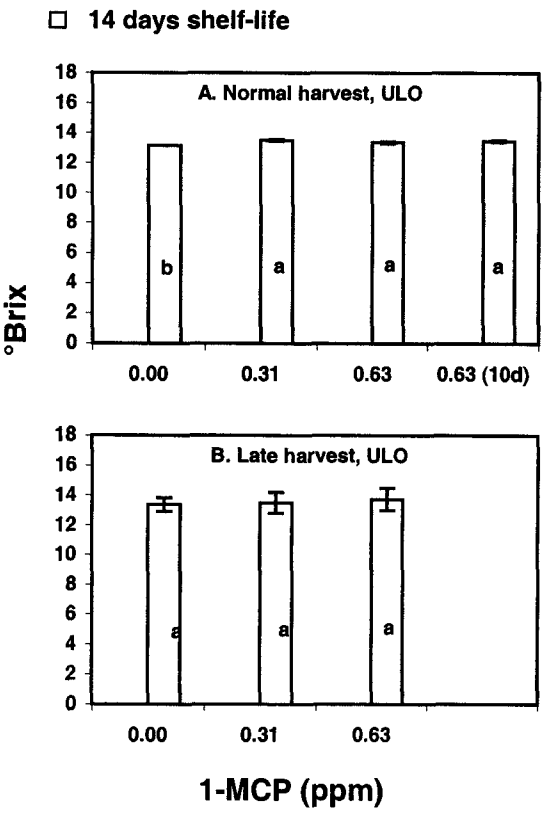

Fig. 43. Soluble solids content of Jonagold after 8 months storage. Vertical bars indicate ± std of the mean of 2 replicates. Columns within a chart marked with a same letter are not statistically different (P=0.05).

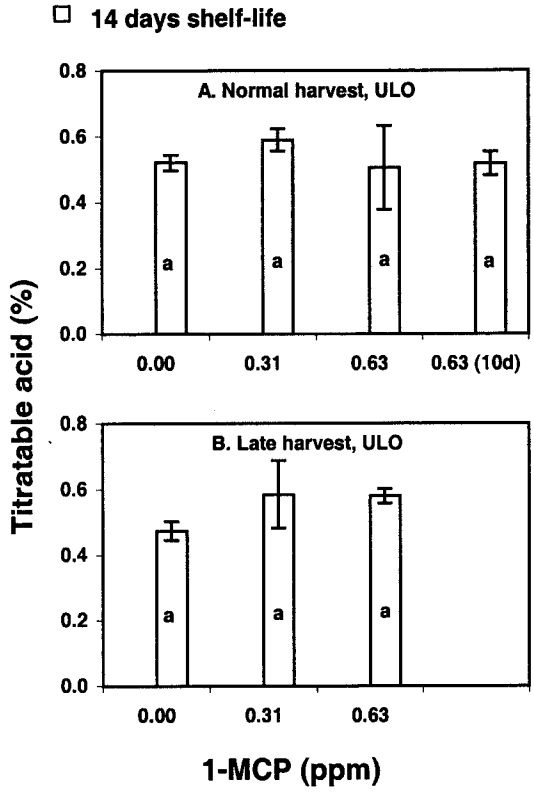

Fig. 44. Titratable acidity of Jonagold after 8 months storage. Vertical bars indicate ± std of the mean of 2 replicates. Columns within a chart marked with a same letter are not statistically different (P=0.05).

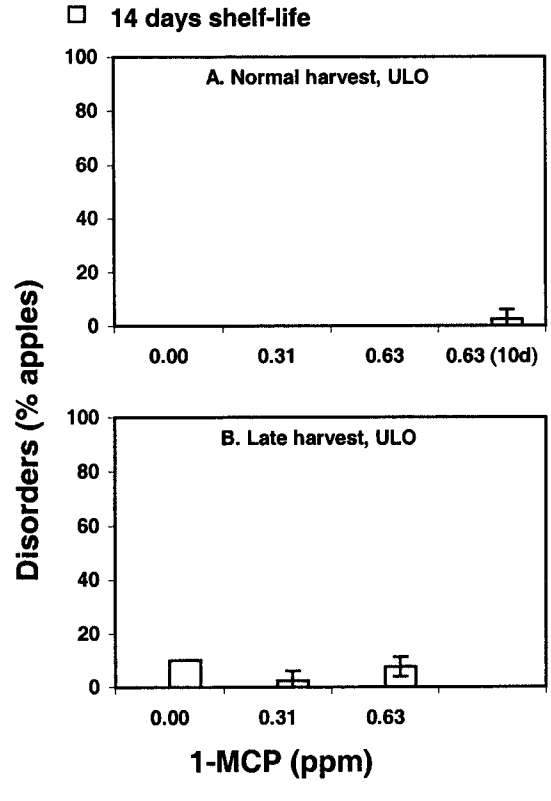

Fig. 45. % apples with disorders of Jonagold after 8 months storage. Vertical bars indicate ± std of the mean of 2 replicates.

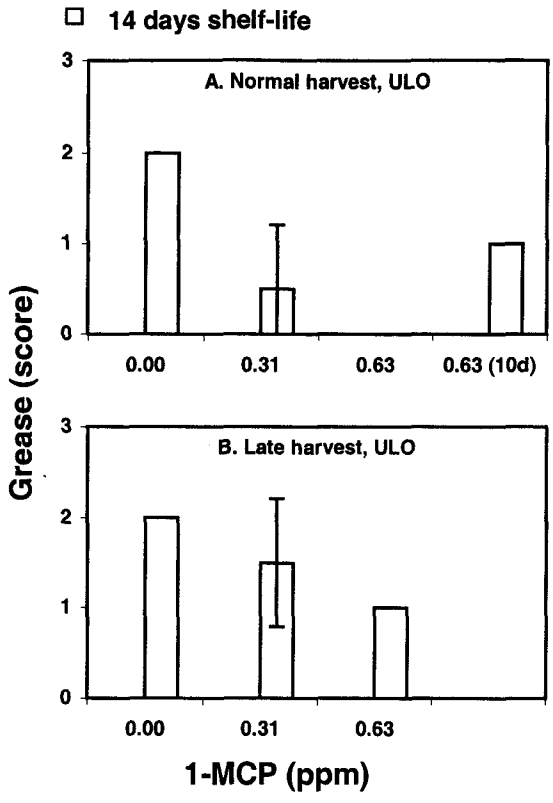

Fig. 46. Index for greasiness of Jonagold after 8 months storage. Vertical bars indicate ± std of the mean of 2 replicates.

5.6 Jonagold, weight loss

Although the 0.312 ppm 1-MCP treatment seemed to promote weight loss, the 0.625 ppm treatment did not (Table 3).

Table 3. Percentage weight loss (average ± standard deviation) on basis of fresh weight before storage.

1-MCP treatment	Weight loss month 1,2,3,4	Weight loss month 5 and 6	Weight loss month 7 and 8	Weight loss total
0 ppm	2.5 ± 0.3	1.2 ± 0.2	1.2 ± 0.2	4.9 ± 0.3
0.312 ppm	3.1 ± 0.1	1.5 ± 0.0	1.5 ± 0.4	6.1 ± 0.2
0.625 ppm	2.6 ± 0.1	1.3 ± 0.0	1.3 ± 0.4	5.2 ± 0.5

6 Conclusions

Very positive effects of 1-MCP were found on firmness retention. Positive effects were also found on colour, titratable acids, disorders (Jonagold) and greasiness (Jonagold). There were no important effects of 1-MCP on soluble solids content. The occurrence of skin pecks on Elstar was increased by 1-MCP in case of 6 months storage.
For Elstar, there were no clear differences between 312 and 625 ppb 1-MCP. For Jonagold, 625 ppb was sometimes more effective for inhibition of disorders and greasiness.
For Elstar, there was no important effect when treated at 10 days after harvest compared to treatment shortly after harvest. However, for Jonagold the treatment at 10 days after harvest was less effective especially regarding firmness retention.

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 of control apples of normal harvest was maintained during 8 months ULO. Therefore no effect of 1-MCP was found directly after storage (0 days shelf-life). However, while control apples lost firmness during 14 days shelf-life, 1-MCP treated apples did not. In general 1-MCP inhibited yellowing of Elstar of normal harvest after 4, 6 and 8 months of ULO storage.
  For Jonagold, firmness of control apples (normal and late harvest) decreased during 8 months ULO. Advantage of 1-MCP was both inhibition of softening during storage and during shelf-life. Also yellowing after ULO storage (4, 6 and 8 months) was inhibited by 1-MCP.
- ***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 months storage period. The main advantage of 1-MCP above ULO was firmness retention during shelf-life. After a storage period of 6 months (0 days shelf-life), the firmness of 1-MCP treated apples from air storage was less than the firmness of untreated apples from ULO. However after shelf-life, firmness of 1-MCP treated apples from air storage was better than firmness of untreated apples from ULO.
  For Jonagold, 1-MCP could not replace the beneficial effect of 4 months ULO.
- ***1-MCP facilitates the storage of apples harvested at a more mature stage***
  Treatment with 1-MCP strongly inhibited firmness loss of late harvested Elstar during shelf-life and of late harvested Jonagold during storage and shelf-life.
  Air storage:
  After 2, 4, and 6 months storage plus shelf-life, firmness of 1-MCP treated Elstar and Jonagold was still acceptable, while firmness of control apples was not. In addition for Elstar, titratable acids were higher after 1-MCP treatment. For Jonagold, 1-MCP inhibited yellowing (after 2 and 6 months air storage) and inhibited the decrease of acidity (after 2, 4 and 6 months air storage).
  ULO storage:
  After 4, 6 and 8 months storage plus shelf-life, firmness of 1-MCP treated Elstar was still acceptable, while firmness of control Elstar was not.
  For Jonagold, firmness of control apples was still acceptable after 8 months storage plus shelf-life. However with 1-MCP firmness was retained better. In addition there were sometimes positive effects on colour (less yellowing), acidity (higher) and greasiness (less grease).
- ***1-MCP improves the shelf-life of CA(ULO)-stored apples***
  In most cases, 1-MCP treatment (both normal and late harvest, all tested storage periods) prevented firmness loss of Elstar and Jonagold during shelf-life following ULO storage. The 1-MCP treatment of Jonagold at 10 days after harvest could not totally prevent firmness loss during shelf-life (after 6 and 8 months ULO storage).