

1-Methyl cyclopropene (1-MCP): An alternative for controlled atmosphere storage of South African export avocados

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ABSTRACT

In the past, the firmness of export avocados was maintained by reducing the storage temperature during transport. More recently, controlled atmosphere (CA) has been added to further reduce ripening during storage. This has certainly improved the chances of landing a hard fruit in Europe, but certain physiological and monetary concerns remain. During the last two years we have been evaluating the effectiveness of 1-methyl cyclopropene (1-MCP), an ethylene inhibitor presently used in the cut-flower industry, on avocados. The trials were done with all the major export cultivars and covered aspects such as storage potential, respiration rate and fruit quality upon ripening. The results were extremely positive and the manufacturer (Rohm & Haas, USA) has subsequently filed for registration of the product. Static container trials are planned for the 2002 season and it is envisaged that 1-MCP will become available to the South African avocado export industry during the 2003 season.

INTRODUCTION

During the last two years, we have been evaluating the effectiveness of 1-methyl cyclopropene (1-MCP), an ethylene inhibitor that have been formulated to block the cellular receptor sites for this hormone. During 2000, trials were conducted with all the major export cultivars in order to establish the efficacy of 1-MCP in terms of the inhibition of ripening. The positive results warranted further research and the study was continued during the 2001 season. The most important aim of the latest trials was to compare the ripening inhibition efficacy of 1-MCP with that of controlled atmosphere (CA) storage.

TRIALS CONDUCTED DURING THE 2000 SEASON

The aim of the initial set of trials was to establish the efficacy of 1-MCP in terms of the inhibition of ripening during export simulations.

Fruit from five different cultivars, namely Pinkerton, Hass, Edranol, Fuerte and Ryan, was obtained from a packhouse in the Burgers-

hall area of the Mpumalanga Province of South Africa. The fruit was treated in the packhouse using the standard postharvest regime. This included a roller wash with a 0.5% commercial calcium hypochlorite formulation and the application of a carnauba / shellac natural wax. All the avocados used in the trial originated from export consignments and complied with present SAAGA export maturity specifications.

Count 14 fruit were used for the 'Fuerte', 'Pinkerton', 'Edranol' and 'Ryan' trials and count 22 fruit for the 'Hass' trial. A set of 14 single fruit repetitions were used per treatment, except in the case of Hass where 22 fruit were treated, stored and comprehensively evaluated. A second set of 14 / 22 fruit was treated, stored and superficially evaluated.

1-MCP was administered in three concentrations, namely 0, 225, 500 and 1000 ppb for 12 hours at 5°C and 10°C. After administering the MCP, the avocados were stored at 6°C for 25 days, except for 'Pinkerton' which was stored for 30 days. Hereafter, the fruit was ripened on the shelf at the prevailing room

temperature.

The fruits were thoroughly evaluated as they ripened. Moderate finger pressure was applied on a daily basis to establish when the fruit reach the 'ready to eat stage'. Densimeter readings were taken at time of evaluation to ensure that the fruit were evaluated within similar firmness ranges. Fruit ripening was expressed as the mean number of days until the 'ready to eat stage' was reached and a longitudinal ripening profile was composed.

The following recordings were made upon ripening:

- Black cold damage was scored and expressed as the percentage of the skin surface of each fruit that showed this chilling injury symptom.
- Dusky browning was scored and expressed as the percentage of the skin surface of each fruit that showed the symptom.
- Lenticel damage was scored and expressed as the percentage of the skin surface of each fruit exhibiting injured lenticels.
- Anthracnose was scored and expressed as the percentage of the skin surface of each fruit that showed symptoms of infection.
- Grey pulp was scored and expressed as the percentage of the pulp volume of each fruit that showed symptoms.
- Vascular browning was scored and expressed as the percentage of the pulp volume of each fruit that showed symptoms.
- Stem-end rot was scored and expressed as the percentage of the pulp volume of each fruit that showed symptoms.

The results are summarised in Figs. 1 to 6.

The mean number of days required for ripening at ambient temperature is displayed in Fig. 1. From the results it is clear that 1-MCP lengthened the ripening period of all cultivars. In the case of 'Fuerte' and 'Hass', the period from removal out of cold storage until ripening, was effectively doubled. With 'Edranol' and 'Pinkerton' it was tripled while in

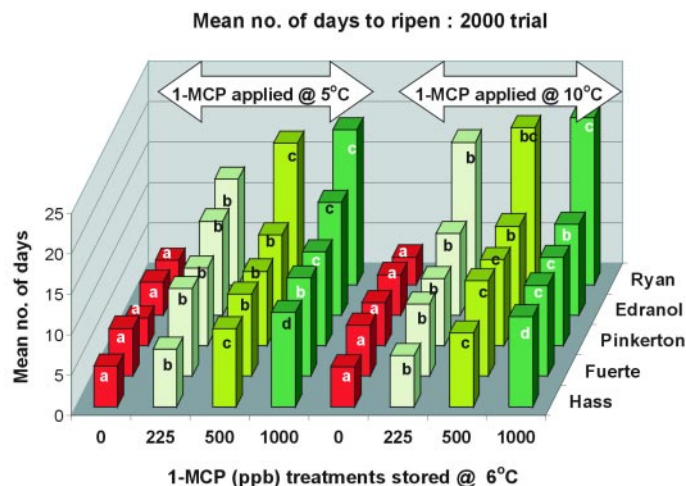


Fig 1. Mean number of days required to ripen the fruit of five different avocado cultivars under ambient conditions. The fruit were treated with different concentrations of 1-MCP (0, 225, 500 and 1000 ppb) applied at two temperatures (5°C and 10°C), before being stored at 6°C for 30 days. Bars marked with the same symbol are not significantly different. The statistics apply separately for each cultivar do not allow for statistical comparison between cultivars (Student t-test, $P > 0.05$).

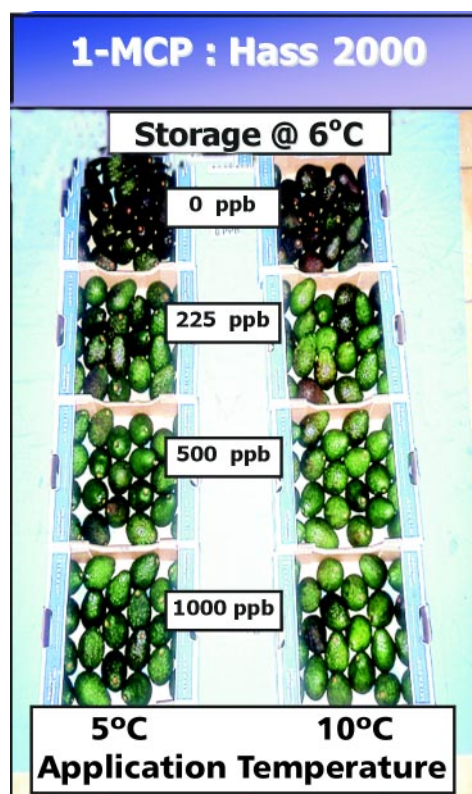


Fig 2. The visual appearance of 'Hass' fruit treated with four concentrations of 1-MCP at application temperatures of 5°C and 10°C.

'Ryan' the shelf life period was lengthened by four to six times.

No major difference in ripening rate was observed between the 5°C or 10°C applications. It would therefore be possible to apply the compound at the storage temperature at

which the fruit are exported. In South Africa, this temperature is usually between the two temperatures used in the present study.

In general, there was not a distinct differentiation between the different application rates. Taking all variables into account, we recommend that a 500 ppb dosage be used during semi-commercial trials.

In the case of 'Hass', the lengthening of the shelf life period did not seem to offset the synchronisation between pulp softening and skin darkening (Fig. 2).

The incidence of grey pulp is shown in Fig. 3. Interestingly, the 5°C 1-MCP treated 'Pinkerton', 'Edranol' and 'Ryan' fruit developed significantly less grey pulp than the control. This was also true for Edranol fruit treated at 10°C.

Although grey pulp appears during the ripening of cool stored fruit, it is not a chilling injury, but an indication of over-maturity. 1-MCP may possibly have a role to play in reducing the incidence of grey pulp. However, the epidemiology of the disorder is such that a number of seasons of commercial statistics are required to substantiate the claim.

In the cases of 'Ryan', 'Edranol' and 'Fuerte', the incidence of anthracnose and stem-end rot (Figs. 4 and 5) was significantly higher in 1-MCP treated than in control fruit. This is to be expected, as it is known in avocados, the lengthening of the storage period (by the use of colder temperatures, CA, MA or 1-MCP) increases the incidence of pathological disorders upon ripening.

The epidemiology of pulp spot, black cold injury, dusky browning and lenticel damage is usually difficult to interpret and the present study was no exception (data not shown). The incidence of the disorders

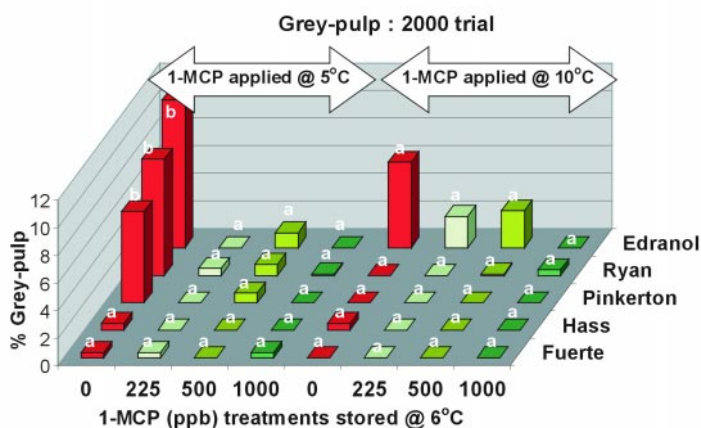


Fig 3. Percentage grey-pulp recorded in five different avocado cultivars, after ripening at ambient conditions. The fruit were treated with different concentrations of 1-MCP (0, 225, 500 and 1000 ppb) applied at two temperatures (5°C and 10°C), before being stored at 6°C for 30 days. Bars marked with the same symbol are not significantly different. The statistics apply separately for each cultivar do not allow for statistical comparison between cultivars (Student t-test, $P>0.05$).

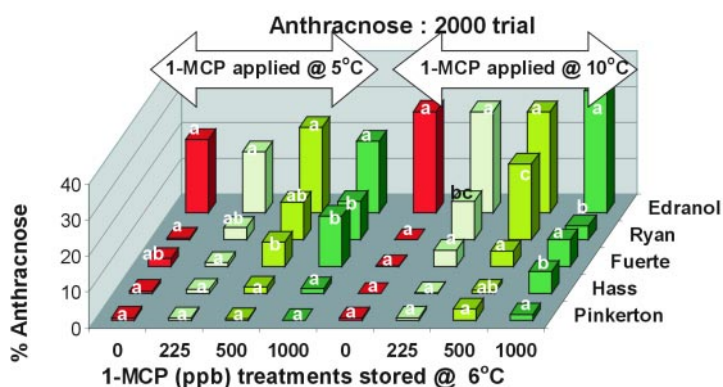


Fig 4. Percentage anthracnose recorded in five different avocado cultivars, after ripening at ambient conditions. The fruit were treated with different concentrations of 1-MCP (0, 225, 500 and 1000 ppb) applied at two temperatures (5°C and 10°C), before being stored at 6°C for 30 days. Bars marked with the same symbol are not significantly different. The statistics apply separately for each cultivar do not allow for statistical comparison between cultivars (Student t-test, $P>0.05$).

was found to be low and the results did not indicate 1-MCP that significantly influences the manifestation of these symptoms.

TRIALS CONDUCTED DURING THE 2001 SEASON

During the last number of seasons, the

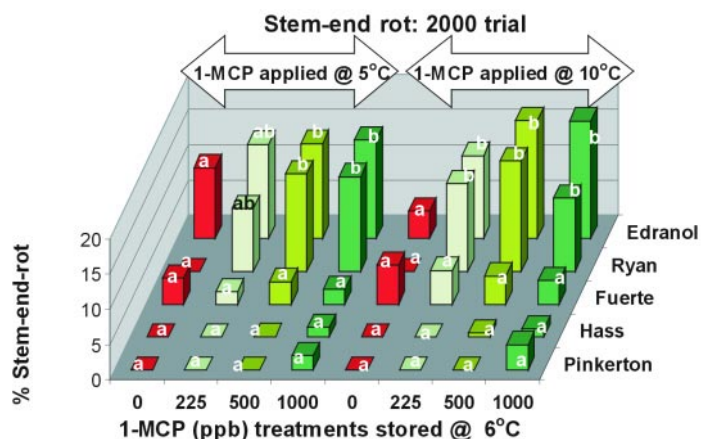


Fig 5. Percentage stem-end rot recorded in five different avocado cultivars, after ripening at ambient conditions. The fruit were treated with different concentrations of 1-MCP (0, 225, 500 and 1000 ppb) applied at two temperatures (5°C and 10°C), before being stored at 6°C for 30 days. Bars marked with the same symbol are not significantly different. The statistics apply separately for each cultivar do not allow for statistical comparison between cultivars (Student t-test, $P>0.05$).

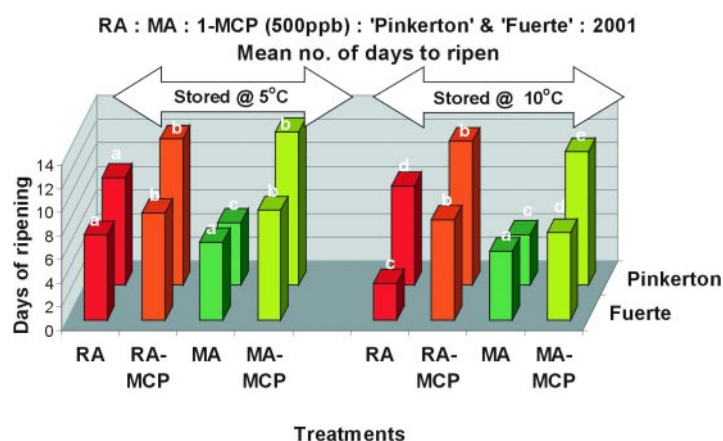


Fig 6. Mean number of days required to ripen 'Fuerte' and 'Pinkerton' fruit under ambient conditions. The fruit were treated with 500 ppb 1-MCP at 5°C, before stored at either 5°C and 10°C under RA and MA conditions for 30 days. Bars marked with the same symbol are not significantly different. The statistics apply separately for each cultivar do not allow for statistical comparison between cultivars (Student t-test, $P>0.05$).

use of CA and specific variations of modified atmosphere (MA) storage reduced the incidence of fruit arriving soft in Europe. As the primary effect of 1-MCP also concerns the inhibition of ripening, 1-MCP was compared with CA and MA during the 2001 season. Furthermore, the above techniques were used in combination with 1-MCP. This was done to establish whether the fruit can be exported at higher temperatures that will reduce the risk of black cold injury.

During 2001, three trials – one each with 'Fuerte', 'Pinkerton' and 'Edranol' – were conducted. In the 'Fuerte' and 'Pinkerton' trials, the avocados were either treated with 500 ppb 1-MCP or not and stored in regular atmosphere (RA) or MA (Xtend @ Stepak, Israel) at 5°C and 10°C for 25 days.

In the 'Edranol' trial, MA was replaced with CA (6% O₂; 4% CO₂). During this trial, the respiration rate of the fruit was also determined. In the case of the RA treatments, this was done with eight fruit throughout the storage period. As CA storage has to be uninterrupted, the respiration rate of the CA treatments was only determined on day 25 when CA storage was terminated and on day 30 when all the fruit were removed from cold storage. Upon ripening, the fruit were evaluated using the set of quality parameters mentioned above.

The results of the 'Fuerte' and 'Pinkerton' experiments are shown in Figs. 6 to 10. The 1-MCP treated Fuerte and 'Pinkerton' fruit took longer to reach the 'ready to eat' stage than the RA and MA treatments at both the 6°C and 10°C storage temperatures (Fig. 6). The poor performance of the MA treatment was unexpected. However, the densimeter readings indicated the MA treatments to be firmer at the time of inspection. The results should therefore be interpreted taking into

account that the experimental procedure may have unfairly advantaged the RA treatments (the MA treatments were, however, advantaged in terms of fungal infection). Nevertheless, the substantial effect of 1-MCP is obvious when comparing the RA treatment with the

RA 1-MCP treatment and the MA treatment with the MA 1-MCP treatment.

The incidence of grey pulp is shown in Fig. 8. As was the case with the 2000 trial, treatment with 1-MCP resulted in a reduction in the incidence of grey pulp in Fuerte and Pinkerton at both the 5°C and 10°C storage temperatures. The explanation provided above regarding the factors that govern the expression of grey pulp also apply here.

The incidence of the pathological disorders, anthracnose and stem-end rot are shown in Tables 8 and 9. With the exception of the 'Pinkerton' stem-end rot results, the increase in pathological disorders associated with the lengthening of the storage period, was not as obvious as in the previous season.

The black cold injury results are shown in Fig. 10. There seemed to be no obvious difference between the 1-MCP treated and untreated fruit kept at the same temperature. However, the fruit kept at 10°C had significantly less black cold injury than those kept at 5°C. This is an extremely important observation. If 1-MCP will allow the storage of South African export avocados at higher temperatures, the incidence of black cold injury will significantly decrease. This will reduce the need for costly repacking in Europe.

The results of the Edranol experiment are shown in Figs. 11 to 19.

During this experiment, extreme care was taken to ensure that the fruit were of similar firmness at the time of inspection. As a result of this, the differences between the ripening rates of the 5°C and 10°C treatments (Fig. 11) came out more clearly than in the preceding experiments. The trial again clearly demonstrated the efficacy of 1-MCP. Interestingly, 1-MCP was found to be statistically significantly more

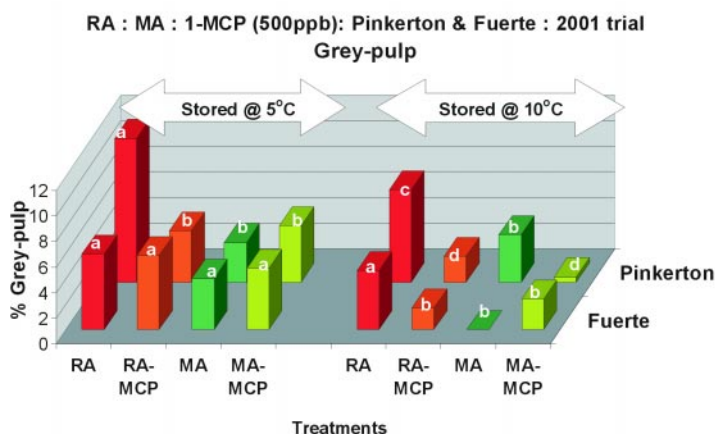


Fig 7. Percentage grey-pulp recorded in 'Fuerte' and 'Pinkerton' fruit when ripened under ambient conditions. The fruit were treated with 500 ppb 1-MCP at 5°C, before stored at either 5°C and 10°C under RA and MA conditions for 30 days. Bars marked with the same symbol are not significantly different. The statistics apply separately for each cultivar do not allow for statistical comparison between cultivars (Student t-test, $P>0.05$).

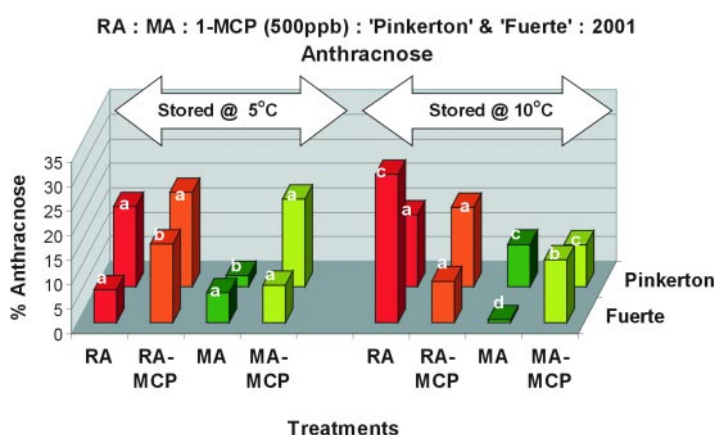


Fig 8. Percentage anthracnose recorded in 'Fuerte' and 'Pinkerton' fruit when ripened under ambient conditions. The fruit were treated with 500 ppb 1-MCP at 5°C, before stored at either 5°C and 10°C under RA and MA conditions for 30 days. Bars marked with the same symbol are not significantly different. The statistics apply separately for each cultivar do not allow for statistical comparison between cultivars (Student t-test, $P>0.05$).

effective than CA at the inhibition of ripening (Table 1). Furthermore, CA and 1-MCP would seem to have had a mild synergistic effect.

Table 1. Individual and combined effect of three variables on the storage potential of Edranol fruit.

Temperature (°C)	Variable		Mean no. of days to ripen	SD	T group
	Atmosphere	[1-MCP] (ppb)			
10	RA	0	0.4	0.97	A
6	RA	0	7.3	1.3	B
10	CA	0	7.5	1.2	B
10	RA	500	9.5	1.5	C
6	CA	0	9.7	1.6	C
6	RA	500	12.2	1.1	D
10	CA	500	12.4	1.6	D
6	CA	500	15.8	1.4	E

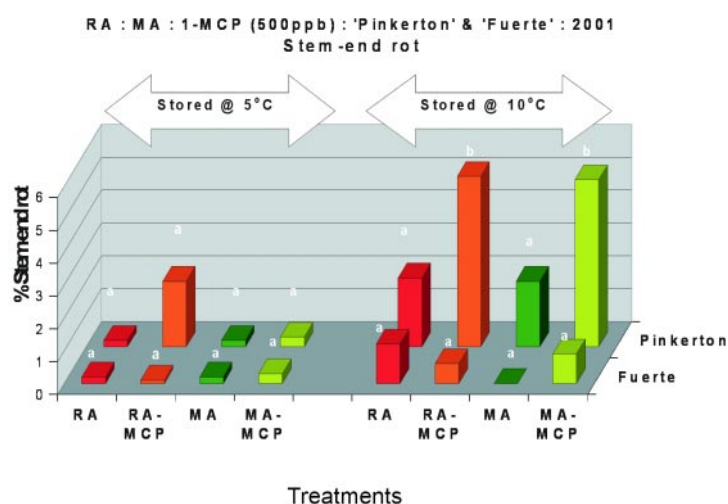


Fig 9. Percentage stem-end rot recorded in 'Fuerte' and 'Pinkerton' fruit when ripened under ambient conditions. The fruit were treated with 500 ppb 1-MCP at 5°C, before stored at either 5°C and 10°C under RA and MA conditions for 30 days. Bars marked with the same symbol are not significantly different. The statistics apply separately for each cultivar do not allow for statistical comparison between cultivars (Student t-test, $P>0.05$).

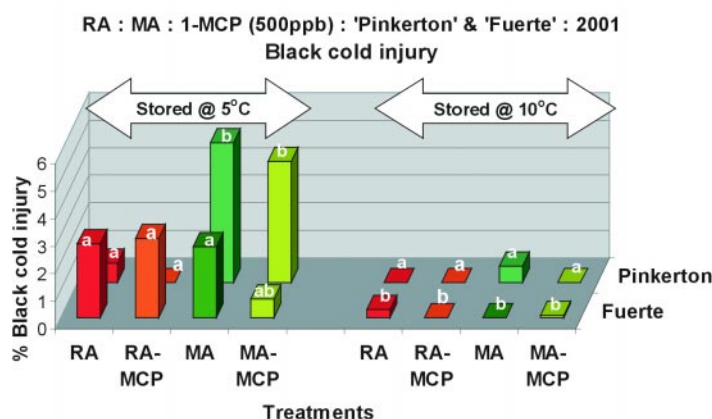


Fig 10. Percentage black cold injury in 'Fuerte' and 'Pinkerton' fruit when removed from cold storage. The fruit were treated with 500 ppb 1-MCP at 5°C, before stored at either 5°C and 10°C under RA and MA conditions for 30 days. Bars marked with the same symbol are not significantly different. The statistics apply separately for each cultivar do not allow for statistical comparison between cultivars (Student t-test, $P>0.05$).

The incidence of grey pulp recorded in the 'Edranol' fruit is shown in Fig. 12. The RA treatments again showed more grey pulp than the RA-MCP fruit. The CA fruit was also found to show very little grey pulp. However, in practice, the incidence of grey pulp recorded by the industry has not decreased since the introduction of CA. This reiterates our previous statement regarding the relationship between grey pulp and maturity and the strict regulation of the latter by SAAGA. We therefore recommend Rohm and Haas not to place the grey pulp reduction claim on the label as yet.

The anthracnose and stem-end rot results are shown in Figs. 13 and 14. The extended storage induced higher infection rate relationship was again evident, especially when the ripening period of fruit stored at 10°C was significantly lengthened.

The black cold injury statistics are shown in Fig. 15. The effect of storage temperature was more evident in the RA treatments than in the CA treatments. However, in practice, CA did not reduce the incidence of black cold injury during the last five years. It should, nevertheless, be noted that the experimental setup might have influenced the results as the experimental CA drums may reduce the magnitude of the temperature changes induced by the refrigeration cycle.

The 1-MCP treatments did not directly influence the incidence of black cold injury either. As mentioned above, 1-MCP will, nevertheless, play an important secondary role with regard to black cold injury by enabling the industry to export at higher temperatures.

The external appearance of the fruit stored

under RA is shown in Fig. 16 while fruit stored under CA is shown in Fig. 17. The combined effect of the CU and 1-MCP treatment is summarized by the photos. The benefit derived from the 1-MCP treatment is clear, especially in terms of the lighter coloured, less senescent skin, of the 1-MCP treated fruit.

The respiration rates of the different treatments are shown in Figs. 18 and 19. From the graphs it is clear that 1-MCP suppresses the respiration rate of the fruit to a far greater extent than does CA.

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

During the 2000 and 2001 seasons, a range of trials were conducted aimed at establishing the efficacy of 1-MCP in terms of the inhibition of ripening during export simulations with South African avocados.

Commercially packed count 22 'Hass' and count 14 'Fuerte', 'Pinkerton', 'Edranol' and 'Ryan' fruit from a pack house in the Burgershall area of Mpumalanga were used for the trials.

During 2000, 1-MCP was administered in three concentrations, namely, 0, 225, 500 and 1000 ppb for 12 hours at 5°C and 10°C. After administering the 1-MCP, the avocados were stored at 6°C for 25 days followed by ripening on the shelf at the prevailing room temperature.

During 2001, the ripening inhibition effect of 500 ppb 1-MCP was compared with that attained by means of controlled atmosphere (CA) and modified atmosphere (MA) storage. The synergistic effect between CA / MA on the one hand and 1-MCP on the other was also studied using the 'Fuerte', 'Pinkerton' and 'Edranol' cultivars.

Post-storage evaluation included establishing the mean number of days until ripening as well as recording the incidences of black cold injury, dusky brown-

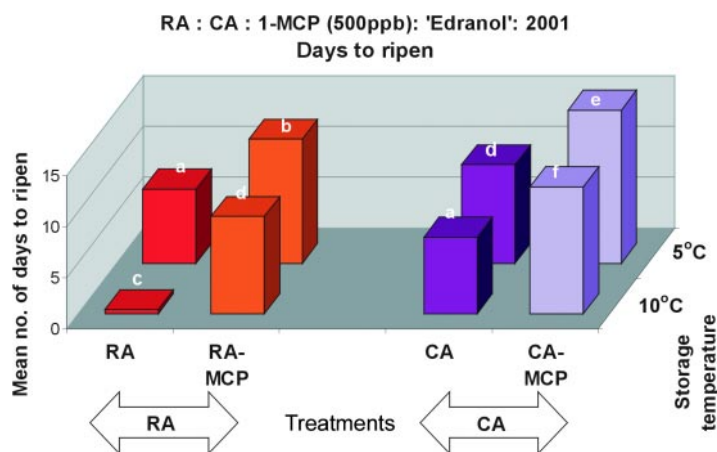


Fig 11. Mean number of days required to ripen 'Edranol' fruit under ambient conditions. The fruit were treated with 500 ppb 1-MCP at 5°C, before being stored under RA and CA conditions for 30 days at 5 and 10°C. Bars marked with the same symbol are not significantly different. The statistics apply separately for each cultivar do not allow for statistical comparison between cultivars (Student t-test, $P>0.05$).

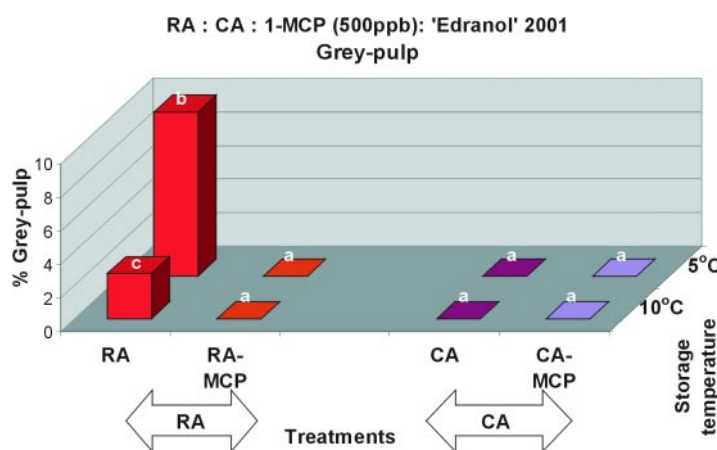


Fig 12. Percentage grey-pulp recorded in 'Edranol' fruit after ripening under ambient conditions. The fruit were treated with 500 ppb 1-MCP at 5°C, before being stored with control fruit under RA and CA conditions for 30 days at 5 and 10°C. Bars marked with the same symbol are not significantly different. The statistics apply separately for each cultivar do not allow for statistical comparison between cultivars (Student t-test, $P>0.05$).

ing, lenticel damage, pulp spot, anthracnose, grey pulp, vascular browning and stem-end rot.

The results indicated no major difference between the 5°C and 10°C application temperatures. It is therefore possible to apply the com-

pound at the storage temperature at which the fruit are stored (usually between 5°C and 10°C).

The results indicated 1-MCP lengthened the shelf life of South African avocados when stored under export simulation conditions. In 'Fuerte' and 'Hass', the period from removal out of cold storage until ripening was effectively doubled. In 'Edranol' and 'Pinkerton' it was tripled while in 'Ryan' the shelf life period was lengthened by four to six times.

The use of 1-MCP did not seem to affect the synchronization between pulp softening and skin darkening in 'Hass' fruit.

The manifestation patterns of black cold injury, dusky browning and lenticel damage indicated the incidence of these physiological disorders not to be effected by the 1-MCP treatment.

In certain trials, the 1-MCP treated fruit developed significantly less grey pulp than the control samples. It is therefore possible that the application of 1-MCP may contribute towards the reduction of grey pulp during export. We, however, do not advise that this claim be included on the label as yet. Although this physiological disorder manifests itself during storage, it is associated with advanced maturity and controlled by adherence to strict maturity regulations prescribed by the South African Avocado Growers' Association.

In certain of the experiments, the incidence of anthracnose and stem-end rot increased in 1-MCP treated fruit. The observed higher incidences of these microbial related disorders can not be attributed to 1-MCP *per se* but to the longer storage period induced by the 1-MCP treatment. It is well known that prolonged storage of avocados causes increased fungal infection upon ripening.

In general, 1-MCP would seem to be as effective, if not more effective than controlled

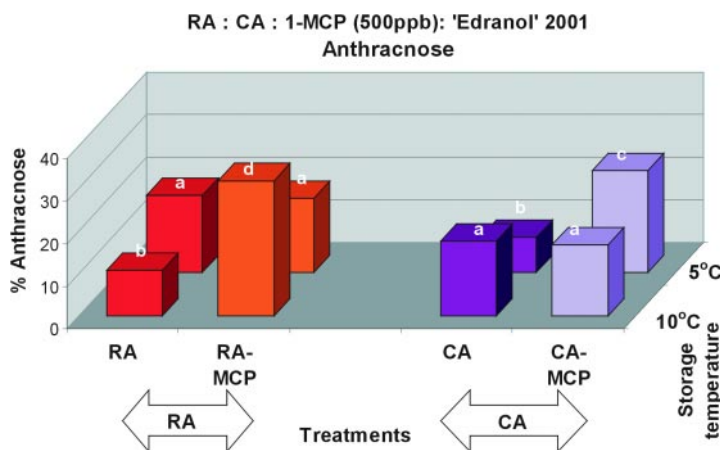


Fig 13. Percentage anthracnose recorded in 'Edranol' fruit after ripening under ambient conditions. The fruit were treated with 500 ppb 1-MCP at 5°C, before being stored with control fruit under RA and CA conditions for 30 days at 5 and 10°C. Bars marked with the same symbol are not significantly different. The statistics apply separately for each cultivar do not allow for statistical comparison between cultivars (Student t-test, $P>0.05$).

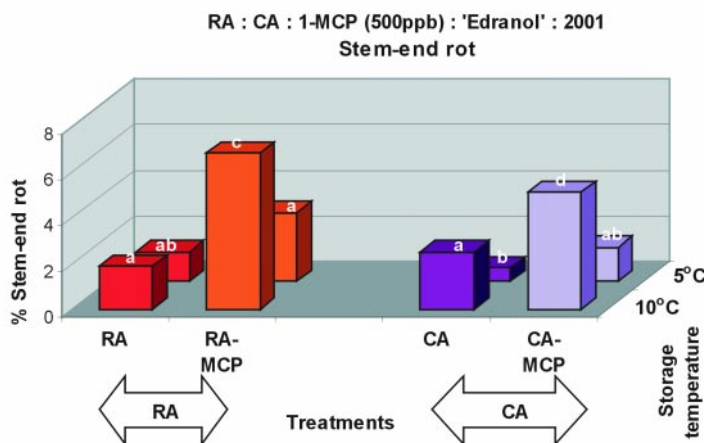


Fig 14. Percentage stem-end rot recorded in 'Edranol' fruit after ripening under ambient conditions. The fruit were treated with 500 ppb 1-MCP at 5°C, before being stored with control fruit under RA and CA conditions for 30 days at 5 and 10°C. Bars marked with the same symbol are not significantly different. The statistics apply separately for each cultivar do not allow for statistical comparison between cultivars (Student t-test, $P>0.05$).

atmosphere (CA) or modified atmosphere (MA) storage. When used in combination with CA, it would appear that in certain cases, there was a significant synergism between CA and 1-MCP while in others, the effect was not that clear.

The respiration rate studies revealed 1-MCP to restrain the climacteric ripening process to a greater extent than did CA storage.

At this stage, it is recommended that 1-MCP be applied at a dosage of 500 ppb at the temperature the fruit is to be exported.

It is recommended that further laboratory studies should include repeat trials aimed at further refining the dosage and exposure period as well as determining the effect of delays that may occur between harvest and 1-MCP

treatment. Trials aimed at reducing black cold injury by storing the fruit at higher temperatures, should also be conducted. Although sensory tests performed by the authors revealed no off-tastes, a formal taste panel evaluation should be performed.

Semi-commercial static trials must be conducted. It is recommended that the 1-MCP be applied in shipping containers as well as under pallet covers in regular cold rooms.

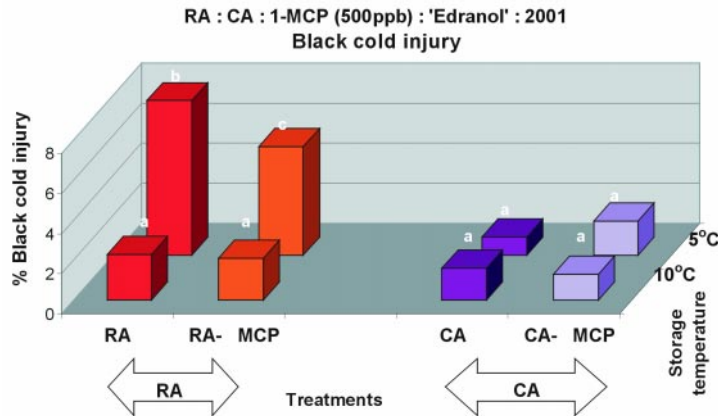


Fig 15. Percentage black cold injury recorded in 'Edranol' fruit after removal from cold storage. The fruit were treated with 500 ppb 1-MCP at 5°C, before being stored with control fruit under RA and CA conditions for 30 days at 5 and 10°C. Bars marked with the same symbol are not significantly different. The statistics apply separately for each cultivar do not allow for statistical comparison between cultivars (Student t-test, P>0.05).

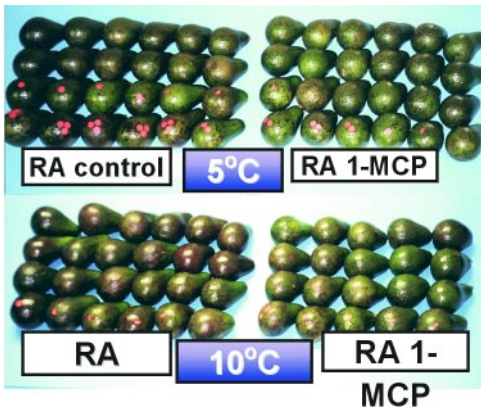


Fig 16. The visual appearance of 1-MCP treated Edranol fruit in comparison with the untreated control.

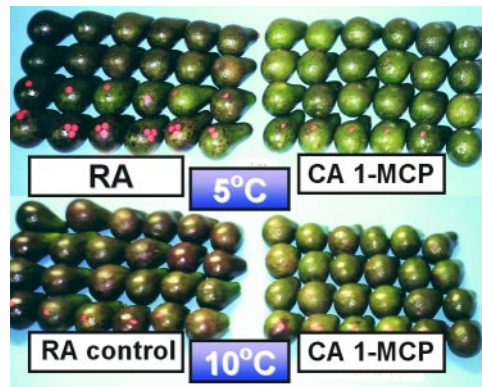


Fig 17. The visual appearance of 1-MCP/CA treated Edranol fruit in comparison with the untreated control.

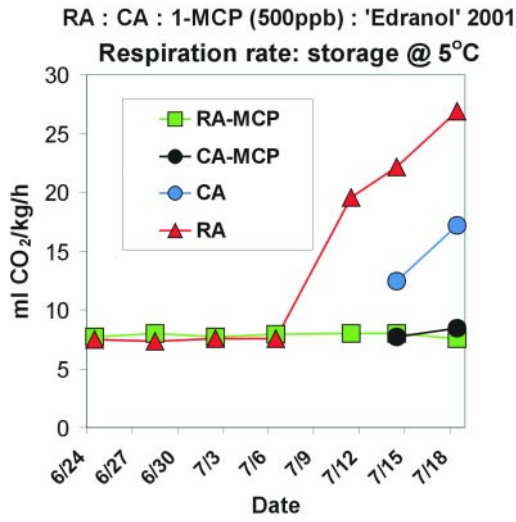


Fig 18. The respiration rate of control and 1-MCP treated 'Edranol' fruit stored under RA and CA conditions at 5°C

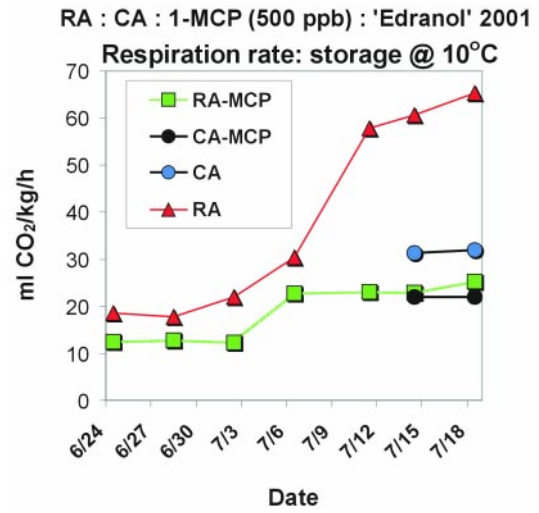


Fig 19. The respiration rate of control and 1-MCP treated 'Edranol' fruit stored under RA and CA conditions at 10°C.