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Effects of ethylene and 1-MCP on the quality and storage life of strawberries

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Abstract

Strawberry quality declines rapidly after harvest. Deterioration may be accelerated by ethylene and is potentially increased, decreased or unaffected by the ethylene inhibitor 1-MCP (1-methylcyclopropene). We have examined the effects of 0.01, 0.05, 0.1 and 1 μl l^{-1} of ethylene and 0.01, 0.1, and 1.0 μl l^{-1} 1-MCP on the quality attributes and respiration rates of strawberries stored at 0 or 5 °C. Ethylene did not affect the rate of rot development. However, calyx quality was significantly reduced by exposure to 0.1 or 1.0 μl l^{-1} ethylene. Treatment with 1 μl l^{-1} 1-MCP protected the calyx tissue from these effects. Exposure of strawberries to 0.01, 0.1 or 1.0 μl l^{-1} 1-MCP did not affect overall fruit acceptability but did slightly increase the rate of rot development. 1-MCP treatment reduced ethylene production by the fruit. Increased production of CO_2 by 1-MCP treated fruit was associated with the earlier onset of rots. Although the results suggest that blocking ethylene perception interferes with disease resistance in strawberries, there was only a small effect on total storage life. It was concluded that neither the removal of low levels of ethylene from the storage environment nor the treatment with 1-MCP are likely to be cost effective methods of extending strawberry storage life. It was concluded that neither removing low levels of ethylene from the storage environment nor treating with 1-MCP are likely to be cost-effective methods of extending storage life.

Keywords: 1-Methylcyclopropene; Respiration; Decay; Non-climacteric; Ethylene

1. Introduction

Strawberries are both high in value and highly perishable. Storage life may be less than a week even under ideal conditions at 0 °C (Wills, 1998). Loss of quality is frequently due to the onset of rots, often caused by *Botrytis cinerea* (Terry and Joyce, 2000). When combined with water loss, softening and bruising during handling and transport, greater than 40% may be wasted before the fruit reaches consumers (Wright and Billeter, 1975).

Ethylene exposure could be one factor increasing strawberry deterioration during marketing. Wills and Kim (1995) reported that 0.01 μl l^{-1} ethylene increased softening and reduced the

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storage life of strawberries at 0 °C. This is significant as concentrations of up to 0.36 μl l^{-1} were found in strawberry punnets at wholesale markets (Wills and Kim, 1995). A subsequent study found a linear relationship between storage life of fruit and log ethylene concentration at 20 °C (Kim and Wills, 1998). Tian et al. (2000) found that ethylene concentrations between 0.5 and 100 μl l^{-1} significantly reduced firmness of strawberries after 3 days at 20 °C.

However, other studies have found little or no effect of ethylene on strawberries. Up to 100 μl l^{-1} of ethylene did not affect sensory quality or colour development and had only a delayed or transient effect on strawberry respiration at 0.6 and 20 °C (El-Kazzaz et al., 1983; Tian et al., 2000). Siriphanich (1980) found no differences between fruit held in air and those in 10 or 100 μl l^{-1} ethylene. The discrepancy among the published data is intriguing.

Although treatment with 1-MCP has been shown to significantly increase the storage life of a range of climacteric fruit, benefits for non-climacteric fruit are uncertain (Porat et al., 1999; Mullins et al., 2000). Jiang et al. (2001) found that although exposure of strawberries to 0.01–1.0 μl l^{-1} 1-MCP slowed loss of firmness and colour changes, >2.5 μl l^{-1} 1-MCP slightly increased the rate of rot development at 20 °C. Ku et al. (1999) reported that treatment of strawberries with 0.005–0.015 μl l^{-1} 1-MCP was beneficial, but $\geq$ 0.05 μl l^{-1} 1-MCP significantly reduced storage life. Tian et al. (2000) also reported mixed effects, in that 2 μl l^{-1} of 1-MCP reduced softening, colour changes, and respiration rates of early harvested strawberries, but had less effect on late harvested fruit. The effects of 1-MCP on strawberries may vary according to fruit maturity and variety as well as the storage environment.

We decided to repeat the previous work on the effects of low ethylene concentrations on strawberries using Californian fruit. In addition, we treated a number of fruit with 1-MCP at a range of concentrations, and then stored the fruit in either air or air containing 1 μl l^{-1} ethylene. The results are discussed in the context of the potential economic benefits of using this technology.

2. Materials and methods

2.1. Plant materials

Strawberry fruit were obtained from local commercial sources and transported to the laboratory at the University of California, Davis. The fruit were sorted so as to select only well formed, rot free, unblemished fruit with intact calyxes. Units of 12 fruit were selected from three replicate groups. Each treatment unit was placed in a vented 'clamshell' type strawberry punnet and secured with an elastic band.

2.2. Treatments

Eighteen treatment units were placed inside sealed containers and treated with 0.01, 0.1 or 1.0 μl l^{-1} 1-MCP for 24 h at 5 °C. The remaining strawberries were stored overnight under similar conditions in air. The following day, half of the punnets treated with 1-MCP were placed in containers ventilated with air containing 1 μl l^{-1} ethylene, the remainder being ventilated with air alone.

The untreated punnets were stored at either 0 or 5 °C. Each set of three replicate treatment units was ventilated with air containing 0, 0.01, 0.05, 0.1, or 1.0 μl l^{-1} ethylene. Ethylene and CO_2 concentrations in the streams entering and exiting each container were analysed every 2–3 days by gas chromatography (Model AGC Series 400, Hach-Carle Co., USA) or rapid gas analysis (VIA510, Horiba, Japan) to verify that the composition of each gas mixture remained stable.

An extra quantity of strawberries was used for measurements of respiration and ethylene production. After exposure to 0, 0.01, 0.1 or 1.0 μl l^{-1} of 1-MCP, 12 treatment units were placed individually in glass jars at 5 °C. The jars were sealed for 1 h each day and the concentrations of CO_2 and ethylene inside the vessels determined by gas chromatography.

2.3. Quality assessment

Strawberry quality is highly subjective, so berry attributes were assessed in a number of different

ways. The condition of the fruit inside each punnet was evaluated every 2 days by the same individual using rating scales from 1 to 5 for calyx colour, gloss, colour, and overall acceptability. In each case 1 represented the best quality, and 5 the worst.

Each punnet was sorted to characterise the stage of rot development of individual berries. In this case the scores were from 0 (no rots) to 4 (soft deep lesions affecting $>30\%$ of berry). The sum of these scores was used to give each punnet an overall disease rating. Therefore, the minimum score by a punnet was 0, and the maximum was 48 (12×4).

2.4. Calculations

Differences between the treatments were analysed by comparing the rates of change in the measured quality attributes. Regression equations could then be used to estimate the number of days taken to reach a threshold value. In the case of rot development, this was represented by an average grade of 2 (total score of 24 for each punnet of 12 fruit), while grade 3 was used as the cut-off for calyx quality and overall acceptability. Values for the various treatments were compared using SAS statistical software (SAS Institute, USA) to conduct analysis of variation (ANOVA) on the treatments.

Rates of ethylene and CO_2 production were calculated as mol kg^{-1} h^{-1} at standard atmospheric pressure. Means were compared according to Duncans Multiple Range Test ($\alpha = 0.05$).

3. Results

3.1. Changes during storage

Gloss decreased and red colour increased during storage. The rate of change in these attributes was approximately linear over time, but did not vary among the treatments (data not shown). There was greater variation among the other attributes recorded, and these were analysed by regression. Changes over time in calyx colour and loss of overall acceptability for each punnet were analysed by linear regression, resulting in R^2 values >0.85 and >0.9, respectively. The rate of disease development, however, was not linear over time, but increased with length of storage. This data was, therefore, better described by polynomial regression equations ($R^2 > 0.97$). These equations were used to estimate the days until calyx quality, acceptability and the total score for rots reached their predetermined limits.

3.2. Effect of ethylene on fruit quality

Ethylene in the storage environment caused premature browning and shrivelling of the calyx (Fig. 1a). Exposure to 1.0 or 0.1 μl l^{-1} ethylene at either 0 or 5 °C reduced calyx quality compared with lower ethylene concentrations and air alone ($P < 0.001$). As a result, the number of days that strawberries remained acceptable was decreased by exposure to 1.0 μl l^{-1} ethylene at 5 °C and by 1.0, 0.1 and 0.05 μl l^{-1} ethylene at 0 °C ($P < 0.0017$) (Fig. 1c) Lower ethylene concentrations had no effect.

In contrast, ethylene did not affect the rate of rot development. The time taken for soft lesions to develop on the fruit at each temperature only varied by 1 day ($\pm 1/2$), regardless of ethylene concentration (Fig. 1b).

3.3. Effect of 1-MCP on fruit quality

Calyx quality and overall acceptability were similar among the different 1-MCP concentrations in ethylene free air (Fig. 2a and c). However, in air containing 1.0 μl l^{-1} ethylene, previous exposure to 1 μl l^{-1} 1-MCP significantly improved both of these attributes compared with the control ($P < 0.05$). Therefore, 1-MCP protected fruit from the effects of ethylene, thereby having a positive effect on fruit quality.

Treatment with 1-MCP also had negative effects on fruit quality. Rot development progressed more quickly in all 1-MCP treated fruit than the untreated controls (Fig. 2b). This occurred both when ethylene was present ($P = 0.0131$) and when fruit were stored in ethylene free air ($P = 0.0251$) (Fig. 2b).

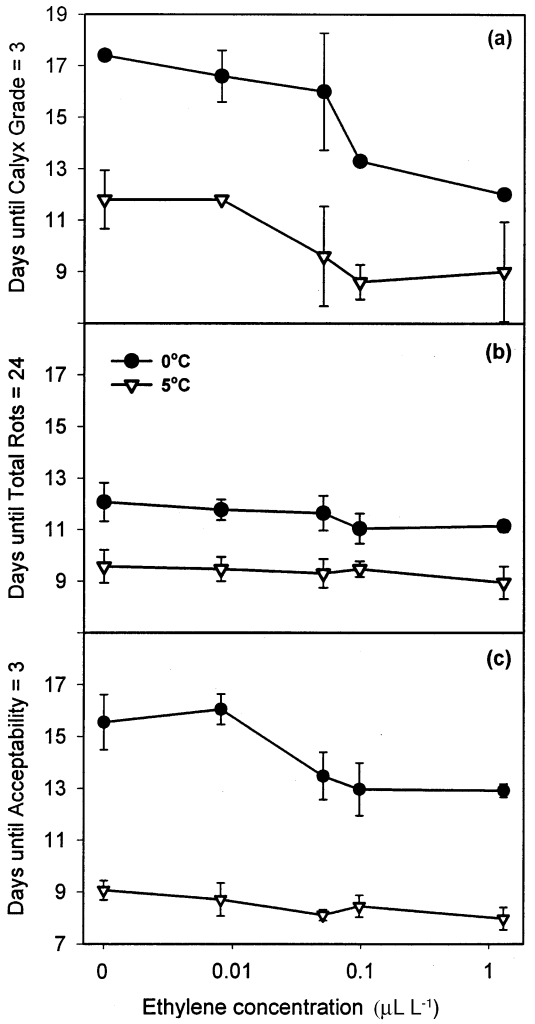

Fig. 1. Effect of ethylene in the storage atmosphere on the number of days until calyx quality (a), rots (b) and overall acceptability (c) of strawberries stored at 0 or 5 °C reached unacceptable levels; error bars indicate the standard deviation of each mean value ($n = 3$ punnets each containing 12 fruit).

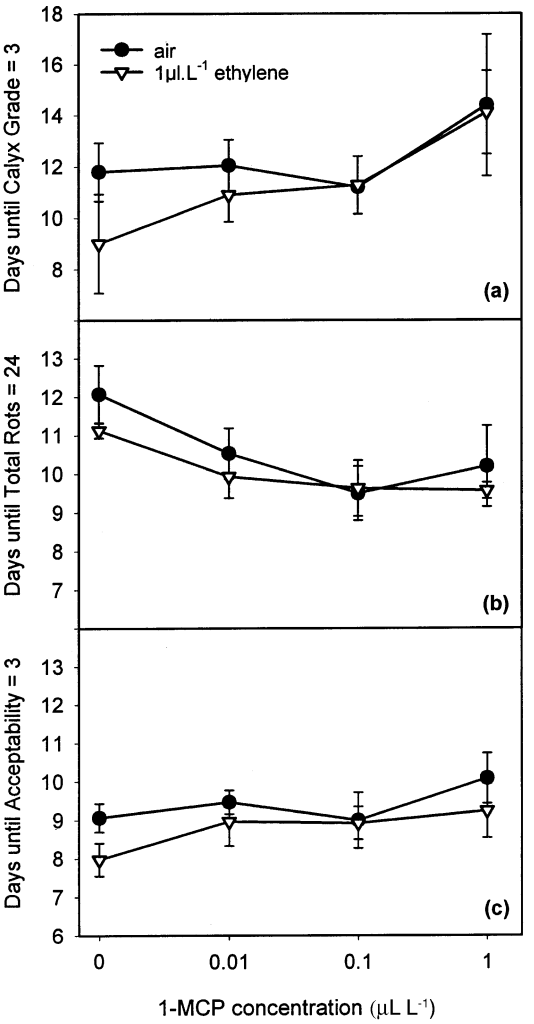

Fig. 2. Effect of exposure to different concentrations of 1-MCP on the number of days until calyx quality (a), rots (b) and overall acceptability (c) of strawberries stored at 0 or 5 °C reached unacceptable levels; error bars indicate the standard deviation of each mean value ($n = 3$ punnets each containing 12 fruit).

3.4. Effect of 1-MCP on gas exchange

The rates of both CO_2 and ethylene production of all fruit increased sharply on the second day of storage at 5 °C. Although untreated fruit returned to initial values, higher CO_2 production rates continued in the 1-MCP treated strawberries (Fig. 3a). The mean rate of CO_2 production during 8 days storage at 5 °C was, therefore, increased in fruit treated with 1 μl l^{-1} 1-MCP compared with the controls ($P < 0.001$). Differences between the controls and lower 1-MCP application levels were not significant.

In contrast, mean ethylene production during 8 days at 5 °C was lower for all of the 1-MCP treated fruit ($P < 0.001$) (Fig. 3b). For the sake of clarity, CO_2 and ethylene production are shown

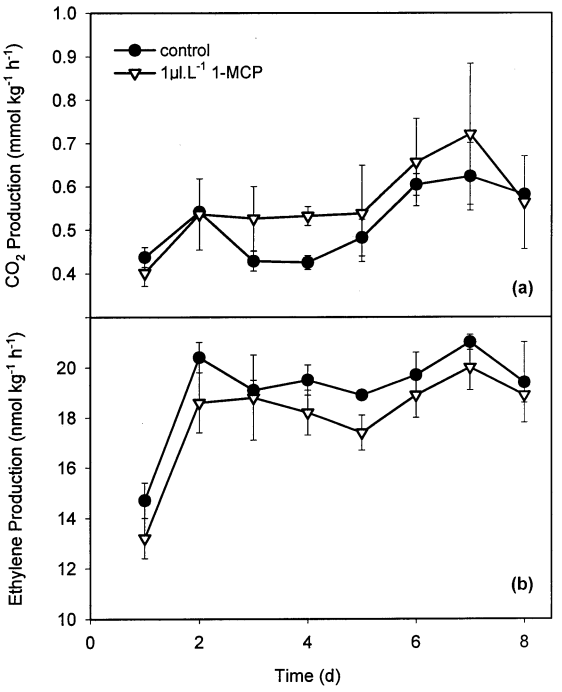

Fig. 3. Rates of production of CO_2 (a) and ethylene (b) by strawberries treated with 0 or 1 µl l^{-1} of 1-MCP during 8 days storage at 5 °C in air; error bars indicate the standard deviation of each mean value ($n = 3$ punnets each containing 12 fruit).

only for the control and the 1 µl l^{-1} 1-MCP treated fruit.

4. Discussion

Examination of previous publications suggests that the effects of ethylene on strawberry fruit are not well defined. Exposure to ethylene increases softening and colour development in some cases, although results may be affected by cultivar, maturity and storage time (Siriphanich, 1980; El-Kazzaz et al., 1983; Picon et al., 1993; Tian et al., 2000). Growth of *B. cinerea* was stimulated on strawberries inoculated with the pathogen and exposed to 20 µl l^{-1} ethylene (El-Kazzaz et al., 1983). The fungus itself produces ethylene, so rotting of one fruit could increase decay of other fruit nearby (Hislop et al., 1971; Qadir et al., 1997). Several reports have stated that removing ethylene from the storage environment reduces rot development (De la Plaza and Merodio, 1989; Wills and Kim, 1995; Kim and Wills, 1998).

In this trial ethylene concentrations of up to 1 µl l^{-1} did not affect the rate of disease development at either 0 or 5 °C. In this case the main effect of ethylene was browning of the calyx. Siriphanich (1980) also found no differences between strawberry fruit treated with 0.6 and 0.02 µl l^{-1} ethylene, or between fruit held in air and those in 10 or 100 µl l^{-1} ethylene.

There are several possible explanations for these differences between results. Many studies on strawberries and ethylene have been conducted at 20 °C. Changes under these conditions are likely to be different to changes during normal storage, as ethylene has less effect at low temperatures. Also, some of the observed effects of ethylene may relate to levels of latent infection by *Botrytis*. Rates of infection in the hot, dry climate of California could be relatively low compared with more humid growing areas. This suggests that stimulation of spore germination by ethylene may have been less significant in the current study than in studies done in more humid climates. Thirdly, cultivar differences and growing conditions could account for some of the variations in published data.

1-MCP application had mixed effects on strawberry quality. We did not find the same effects as Ku et al. (1999), who reported that 1-MCP concentrations > 0.01 µl l^{-1} decreased strawberry storage life by up to 60%. In our experiments, 1-MCP had little effect on fruits stored in air, and protected strawberry fruit from the effects of ethylene. This increased acceptable storage life under high ethylene storage conditions. However, 1-MCP applications also accelerated rot development, reducing the time until rots became severe by up to 20%. This supports the results reported by Jiang et al. (2001), who found that the onset of disease occurred sooner in fruit treated with 0.5 or 1.0 µl l^{-1} 1-MCP, even though rots were decreased by lower 1-MCP concentrations. This suggests that blocking ethylene perception may negatively affect disease resistance in strawberries. In this study other quality attributes did not appear to be

affected by 1-MCP application unless high levels of ethylene were also present.

Ethylene production was reduced by treatment with 1-MCP. It had been thought that the loss of feedback inhibition of ethylene synthesis could lead to an increase in ethylene production. This effect has been observed in 1-MCP treated pineapples (Selvarajah et al., 2001) and strawberries exposed to DCP, another inhibitor of ethylene action (Tian et al., 1997). Decreased ethylene production following 1-MCP exposure is consistent with results reported for many climacteric fruit, as well as strawberries (Jiang et al., 2001).

It might be expected that a treatment that reduces the production and perception of ethylene would be associated with a lower respiration rate. However, the opposite result was observed in the current trial, respiration being increased in the 1-MCP treated fruit. Tian et al. (2000) found that ethylene increased respiration rates of young or immature strawberry fruit, older berries being unaffected. Other reports have described an initial stimulation of respiration when fruit were exposed to ethylene (Siriphanich, 1980; Atta-Aly et al., 2000), that a week of ethylene treatment was necessary before any increase in respiration (El-Kazzaz et al., 1983), or that removal of ethylene from the storage environment may even increase respiration (De la Plaza and Merodio, 1989). Such a wide range of results is intriguing. Tian et al. (2000) has suggested that non-climacteric fruit such as strawberries may have different ethylene receptors than climacteric fruit, or that the ethylene receptors in these fruit may serve different functions.

Increases in respiration during storage may have been due to fungal growth, even though obvious decay was not visible. Similar results have been found for grapes, in which increases in respiration rate preceded the appearance of rots (Bower, 2001). As treatment with 1-MCP was associated with increased decay, this could explain the observed effects on respiration. Certainly, it would seem that the effect of ethylene on CO_2 production by strawberries is not straightforward.

Changes in strawberry quality may be subtle, and measurements are often necessarily subjective. This may account for some of the differences between these results and those previously published. For example, the effect of ethylene on the calyx is unsurprising, the consequences to leafy green tissues of ethylene exposure having been well documented (Reid, 1992). However, the extent to which consumers judge the 'freshness' of strawberries by the calyx quality is open to interpretation. If rots are the main reason that consumers discard strawberries, then rot development is a better indicator of storage life than overall appearance. It should also be noted that while the difference in acceptable storage time was statistically significant in this trial, it represented only a single day of extra life at 5 °C and less than 3 days at 0 °C. Such a difference may have less practical value.

In conclusion, treatments that either remove ethylene from the storage environment or reduce produce sensitivity must be cost effective. Reducing ethylene to very low levels not only requires expensive equipment but could also decrease humidity, potentially increasing weight loss (Dover, 1989). Furthermore, the levels of ethylene found inside strawberry punnets or storage lifee at low temperatures (Wills and Kim, 1995) are not likely to affect strawberry quality. This suggests that both ethylene removal and 1-MCP treatments are unlikely to be useful storage techniques for Californian strawberry fruit.

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