Original Article

Application of 1-methylcyclopropene reduces wound responses and maintains quality in fresh-cut apple

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The objective of this study was to investigate the effects of 1-methylcyclopropene (1-MCP) treatment before cutting on respiration rate, ethylene production, electrolyte leakage, firmness, and color in fresh-cut apple fruit. Fresh-cut apple without 1-MCP treatment had a shelf life of 10 days at 2℃ and became browning and decay after pro-long storage. However, fresh-cut apple remained fresh-looking even after 14 days at 2℃ when fruit were exposed to 1-MCP before cutting. 1-MCP treatment significantly reduced wound-activated respiration rate and ethylene production, maintained firmness during storage. Visible changes in apple skin color do not occur, however,.*L* and whiteness index (WI) of flesh in intact and fresh-cut apple applied with 1-MCP were higher than those without 1-MCP treatment. Fresh-cut and intact fruit had little changes in electrolyte leakage after 2 days of storage when 1-MCP was pre-applied. The present study indicated that treatment with 1 μL/L 1-MCP for 10 h at 20℃ prior to cutting can significantly reduce wound-active responses in fresh-cut apple.

Key Words: 1-methylcyclopropene, fresh-cut, apple, wound response, quality

Introduction

Marketing of fresh-cut produce has increased rapidly due to increased consumer demand for fresh and convenient foods.[1] The USDA recommends that adults consume two to three servings of fruit per day, young children (ages 2–6) should have two servings of fruit.[2] Apple is a popular and commercially important fruit served as a fresh-cut item.[3] However fresh-cut produce may deteriorate rapidly because of the physical damage caused by cutting, slicing, peeling, and other mechanical injuries during processing.[4] Development of treatments or procedures to alleviate wound-induced degradative changes would enhance its quality and safety, and therefore would allow to be more widely marketed.

Apple is a typical climacteric fruit and is highly sensitive to ethylene. 1-MCP was found to prevent ethylene-dependent responses and fruit ripening.[5,6], and to decrease ethylene production in 'Empire', 'Fuji', 'Gala', 'Ginger Gold', 'Granny Smith', 'Jonagold', 'Law Rome', 'McIntosh', and 'Redchief Delicious' apples.[7] Application of 0.5 μL/L 1-MCP in Gala apple significantly inhibits respiration and ethylene production, slows down the decrease in the flesh firmness and titratable acids.[8] 1-MCP can probably reduce the dependence on low temperature and condition of atmosphere during storage in apples. [9] Fan et al. (1999) demonstrated that 1-MCP inhibits ethylene production, respiration, softening and loss of titratable acidity in five apple cultivars.[10] In recent years, production of fresh-cut apples has increased dramatically, and further growth can be anticipated.[11] Fresh-cut apple does not store well because of browning, susceptibility to microbial infection and rapid breakdown. However, at present, there is very little information about effects of 1-MCP on fresh-cut apple. Applying 1-MCP to intact fruit before fresh-cut processing should be much easier and more convenient than after processing.

The objective of this study was to determine the effects of 1-MCP treatment before cutting on physiological responses, as well as quality maintenance of fresh-cut apple fruit.

Material and methods

Design

Apples *(Malus sylvestris* L. cv. Fuji) were carefully sorted to eliminate damaged or defective ones and selected for uniformity of size, color. The fruit were then dipped in 200 μL/L sodium hypochlorite for 10 min and rinsed with deionized water, air-dried and then placed in six 55-L polystyrene containers at 20℃. Three containers of fruit were treated with 1 μL/L 1-MCP for 10 h at 20℃. Gas of 1-MCP was released by adding a buffering agent to calculated amount of SmartFresh powder (a.i. 0.14%, Rohm & Hass) in a 0.25-L vial. A calculated volume of 1-MCP gas was injected through a port inserted in the wall of the container. Other three containers of fruit were not injected with 1-MCP. After treatment, half of 1-MCP treated and untreated fruit were cut longitudinally in halves with a blade. Fresh-cut and intact fruit were placed on plastic

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trays with two fruit each, covered with 40 μm-thick polyethylene film and stored at 2℃. At the indicated intervals, intact and fresh-cut fruit were removed from storage and analyzed.

Ethylene production and respiration rate

Each 4 fruit per replicate (three replicates) were weighted and placed in a 1.4-L glass jar at 2℃. Jars were sealed for 1 h with a cap and a rubber septum, and then 1 mL of head-space gas was removed with a syringe and injected into a gas chromatograph (SP6800A, Lunan Ruihong Chemical Engineering Instruments Co., Ltd., Shandong, China) to determine ethylene. The oven and detector temperatures were 80 and 120℃, respectively, with nitrogen as the carrier gas. CO_2 evolution was determined with an infrared gas analyzer (GXH-305, Junfang Science & Technology Institute of Physical and Chemical Research, Beijing, China) and respiration rate was calculated as CO_2 mL/kg/ h.

Firmness

Firmness was measured as the puncture force in outer cortex using a Texture Analyzer (TA–XT2i, Godalming, UK) fitted with a probe of 5 mm in diameter and a penetrating depth of 10 mm.

Color intensity of the cut-surface

The color of the cut surface was determined using a colorimeter (WCS-S, Precision scientific Instrument Co., Ltd., Shanghai, China). A standard white calibration plate was employed to calibrate the equipment. Three readings of *L* (lightness), *a* (greeness) and *b* (yellowness) were taken around the mid point area between endocarp and skin. Observations were recorded for each of four halved fruit per replicate at each time interval. A decrease in *L* value indicates a loss of whiteness, a more positive *a* value means progressive browning and a more positive *b* value indicates more yellowing. The whiteness index [WI = 100-(100-*L*) ^{2}+a^2+b^2)$^{1/2}$] was calculated as described by Bolin and Huxsoll.[12]

Electrolyte leakage

Cylinders of apple flesh tissue were excised with a 10-mm diameter stainless steel cork borer. Two pieces of 4-mm thickness were cut from each cylinder. After being rinsed 3 times (2–3 min) with deionized water, ten pieces were put into 50 mL of deionzed water and shaken at 100 cycles per min at room temperature. The electrolyte leakage in the solution was measured after 5 h using a Conductance Bridge (DDS-11A, Yamei Electron Instrument Factory, Hangzhou, China). Total conductivity was obtained after keeping the flasks in an oven (90℃) for 2 h. Results were expressed as percentage of total conductivity.

Statistical analysis

The experimental design was a Randomized Complete Block Design (RCBD), triplicated. Statistical analysis was conducted on data using a factorial ANOVA with SAS 8.2 (GLM) PC software package for windows. Differences between means were determined by the Tukey's test. Statistical significance was considered at $p \leq 0.05$.

Results and discussion

Browning and shelf-life of fresh-cut apple

In this study, color was assessed by the *L* and WI values, the responses of both factors were similar. The lightest flesh color (highest *L* and WI values) occurred in freshly prepared halved fruit (Fig 1, 2). Cutting resulted in enzymatic browning as indicated by lower *L* and WI values in fresh-cut fruit than in intact fruit. However, this wound-induced color change was reduced by the application of 1-MCP before cutting (Fig 1, 2). 1-MCP can retarded browning indicated by the higher level of *L* and WI values in 1-MCP pre-applied apples, comparing with untreated fruit.

In this research, *L* values were lowest at day 4 in all storage periods. This was similar to the results obtained in previous studies. Lightness of 'Red Delicious' apple rings decreased sharply during 48 h at 1℃.[13] All twelve cultivars of apples showed a rapid decrease in *L* values.[14] Apples slices packaged with air and 90%N_2, 5%CO_2 modified atmosphere had lowest WI values at the fourth day of storage period at 4℃, and that 65%N_2O, 25%Ar, 5%CO_2, 5%O_2 increased WI value and brightened after 8 days of

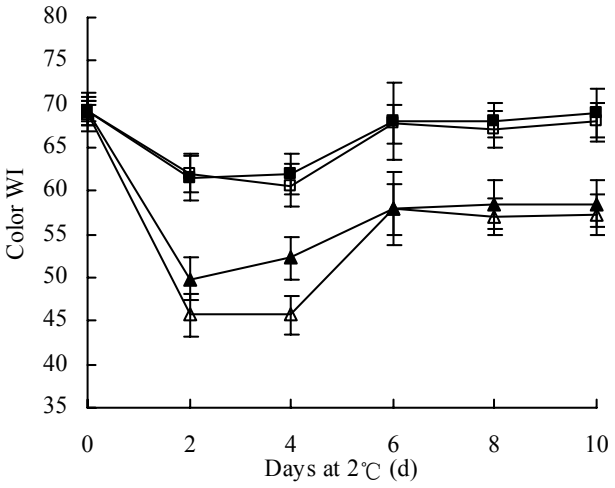

Figure 1. Changes of color WI value in fresh-cut and intact apples during storage at 2℃. Intact fruit were treated with 1 μL/L 1-MCP for 10 h (■) and then cut in halves (▲). Intact fruit without the treatment of 1-MCP (□) and cut in halves (Δ).

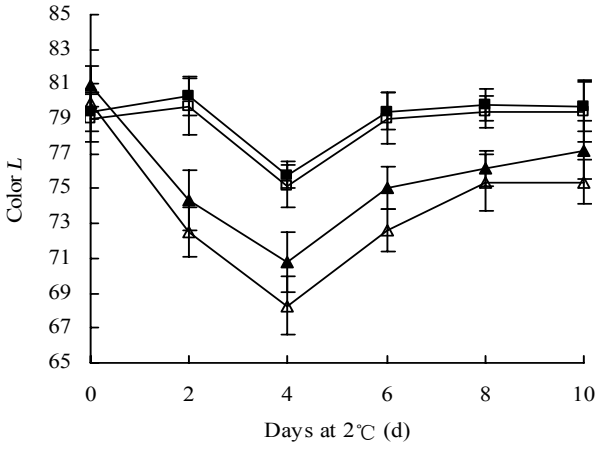

Figure 2. Changes of color *L* value in fresh-cut and intact apples during storage at 2℃. Intact fruit were treated with 1 μL/L 1-MCP for 10 h (■) and then cut in halves (▲). Intact fruit without the treatment of 1-MCP (□) and cut in halves (Δ).

of storage. [15] 1-MCP pre-treatment showed a similar effect as this modified atmosphere.

Browning after cutting would most probably be due to enzymatic browning reaction stimulated by tissue damage with consequent enhanced contact between enzymes and substrates. Application of 1-MCP could significantly inhibit this browning, and thus delay the deterioration of fresh-cut apple fruit. This study observed that shelf-life of fresh-cut apple without 1-MCP treatment was 10 days at 2℃. Pro-long storage resulted in browning and decay, although the firmness may still remain higher than 24 N. However, fresh-cut apple exposed to 1-MCP before cutting remained fresh-looking and had little infection and browning even after 14 days at 2℃. The enhancement of the resistance to browning and decay by 1-MCP also might be linked to the delayed softening and physiological breakdown.

Respiration and ethylene

Respiration rates in fresh-cut apple applied with 1-MCP declined rapidly within the first 4 days. Thereafter, it increased until approximately day 6 (Fig 3). At the first 4 days, there is a similar change of respiration rate in the untreated fresh-cut apple, and then it increased until about day 8, when an obvious respiratory climacteric was observed. In intact 1-MCP treated apples, respiration rates decreased slowly during the storage. Regardless of cutting, the level of respiration rate of 1-MCP treated apples is lower than that of non-treated ones. 1-MCP pretreatment can distinctly decrease respiration rates of either intact or fresh-cut apples. A wound response was detected in cut fruit in comparison to intact fruit, indicating by an increase in CO_2 production immediately after cutting and the higher level of CO_2 productions during all the storage period (Fig 3).

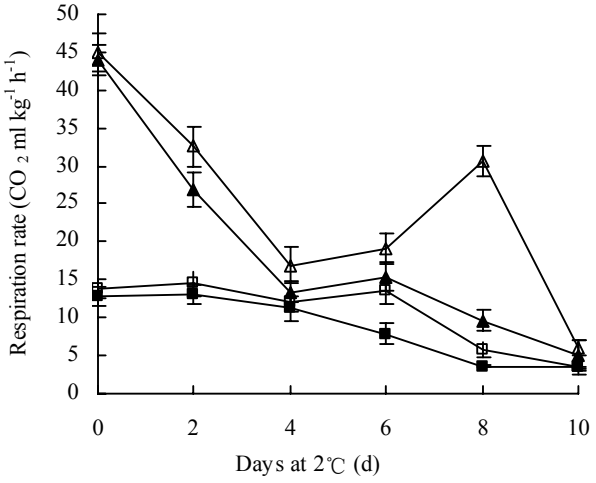

Figure 3. Respiration rates in intact and fresh-cut apples during storage at 2℃. Intact fruit were treated with 1 μL/L 1-MCP for 10 h (■) and then cut in halves (▲). Intact fruit without the treatment of 1-MCP (□) and cut in halves (Δ).

Ethylene production in intact fruit treated with 1 μL/L 1-MCP was the lowest during storage period (Fig 4). Ethylene productions of fresh-cut fruit were higher than those of intact fruit. However, this wound-induced increase was highly reduced when 1-MCP was pre-applied before cutting. Furthermore, 1-MCP markedly reduced ethylene

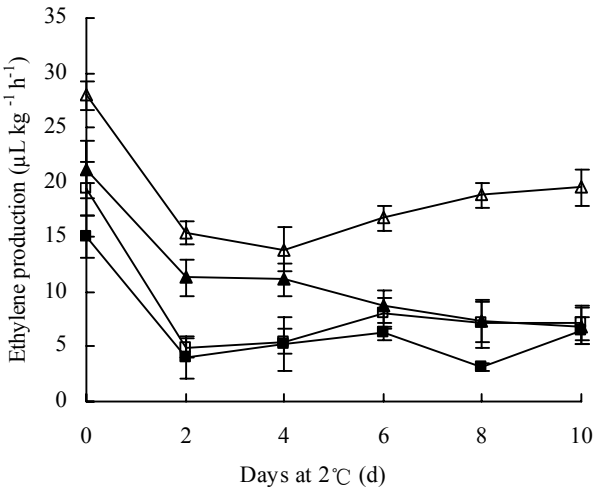

Figure 4. Ethylene production in fresh-cut and intact apples during storage at 2℃.Intact fruit were treated with 1 μL/L 1-MCP for 10 h (■) and then cut in halves (▲). Intact fruit without the treatment of 1-MCP(□) and cut in halves (Δ)..

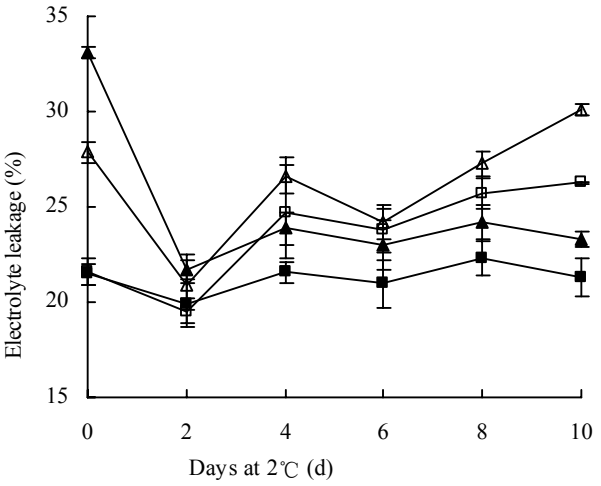

Figure 5. Electrolyte leakage in fresh-cut and intact apples during storage at 2℃.Intact fruit were treated with 1 μL/L 1-MCP for 10 h (■) and then cut in halves (▲). Intact fruit without the treatment of 1-MCP (□) and cut in halves (Δ).

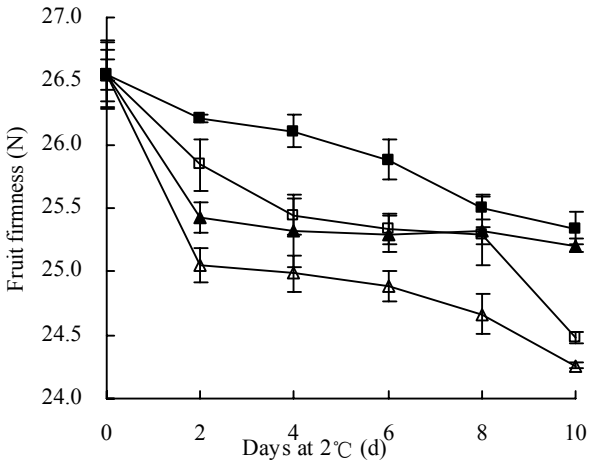

Figure 6. Flesh firmness in fresh-cut and intact apples during storage at 2℃. Intact fruit were treated with 1 μL/L 1-MCP for 10 h (■) and then cut in halves (▲). Intact fruit without the treatment of 1-MCP (□) and cut in halves (Δ).

production in both intact and cut fruit. There was a rapid decrease of ethylene productions in the initial 2 days in all the treatments. By the end of storage, ethylene production in fresh-cut fruit without 1-MCP treatment was as high as 19.58 ± 1.62 μL/kg/h, in contrast to a low value of 6.53 ± 1.21μL/kg/h when 1-MCP was applied before cutting.

For measured parameters, the response to cutting was maximal in respiration rate and ethylene production. The higher respiration rate and ethylene production in fresh-cut apples than intact ones during storage indicated that wounding caused by cutting resulted in physiological responses. Changes of respiration rate and ethylene production in apples seem to be concomitant. Therefore, the initial increased respiration in cut fruit could be the direct induction by wound ethylene. This wound-activated respiration rates could also be due to both the increased surface area exposed to the atmosphere after cutting which allows oxygen to diffuse into the interior cells more rapidly and to the increased metabolic activity of injured cells.[16] Cut-induced increases of respiration rate and ethylene production were prevented by the application of 1-MCP before cutting.

Electrolyte leakage

Electrolyte leakage in fresh-cut apple fruit decreased rapidly within the initial 2 days. Afterward, fresh-cut and intact fruit had little changes in electrolyte leakage during storage when 1-MCP was applied (Fig. 5). 1-MCP induced the transient increases of electrolyte leakage of the fresh-cut apples at the first day. Without 1-MCP treatment, fresh-cut fruit had the highest electrolyte leakage during most of the storage period. In fact, fresh-cut and intact fruit had much lower electrolyte leakages after 4 days of storage when 1-MCP was pre-applied, indicating that wound-induced increase of electrolyte leakages was also prevented by 1-MCP.

Firmness

The marketability of fresh-cut fruit is generally judged by the maintenance of firmness among other parameters.[17] Application of 1-MCP retarded firmness loss in both intact and cut fruit during storage (Fig. 6). Intact fruit had higher firmness than fresh-cut ones throughout the most period of storage. Firmness in 1-MCP treatment fruit was higher than those without the application of 1-MCP. A continuous loss of firmness occurred during storage in all treatments. Wound-induced firmness loss was observed by indicating the lower firmness in cut fruit than that in intact fruit. By the end of storage, firmness in fruit treated with 1-MCP was 25.34－25.21N, higher than those without 1-MCP treatment (24.48－24.26N). Softening is prevented or delayed by 1-MCP, the effects of treatment often closely associated with ethylene production.[7, 10, 18-22]

Conclusion

1-MCP treatment significantly reduced wound-activated respiration rate and ethylene production, slowed down fruit softening and browning. The present study indicated that treatment with 1 μL/L 1-MCP for 10 h at 20℃ prior to cutting and stored at 2℃ can significantly reduce wound-mediated responses, and thus maintained the fresh quality of fresh-cut apple fruit.

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