

## Effect of MA Storage and 1-MCP on Storability and Quality of ‘Sanuki Gold’ Kiwifruit Harvested at Two Different Maturity Stages

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The effects of modified atmosphere (MA) storage and application of 1-methylcyclopropene (1-MCP) at harvest on the storability and quality of ‘Sanuki Gold’ kiwifruit harvested at two different maturity stages were investigated. MA storage in both fruit harvested early at 136 days after pollination (DAP) or late at 154 DAP delayed flesh softening, increase in soluble solid concentrations (SSC), decrease in titratable acids (TA), and reduction in fruit flesh color index compared to air stored fruit, suggesting that MA storage is effective in prolonging ‘Sanuki Gold’ kiwifruit storage life. Further, MA stored fruit did not attain full ripening flesh firmness and SSC thresholds even after 4 months of storage under MA conditions, suggesting that early harvested ‘Sanuki Gold’ kiwifruit can be stored for 4 months in MA. Fruit from both harvesting maturity stages stored under air conditions achieved maximum SSC (18%) values during storage, suggesting that two weeks early harvesting did not compromise edible quality characteristics. Only late harvested fruit treated with 1-MCP and stored in MA showed slight inhibitory effect specific to fruit softening during the first and second month of storage, suggesting that 1-MCP may have some limited ripening inhibitory effect during storage of ‘Sanuki Gold’ kiwifruit.

**Key Words:** firmness, maturity stage, modified atmosphere, ripening, storage.

### Introduction

Actinidia consist of more than 72 species which originated from mainland China, among which 4 species, Sarunashi (*Actinidia arguta*), Miyama matatabi (*Actinidia kolomikta*), Matatabi (*Actinidia polygama*), and Shima sarunashi (*Actinidia rufa*), grow naturally in Japan (Kim et al., 2009). Both *Actinidia deliciosa* and *A. chinensis* are widely grown and commercialized globally. ‘Hayward’, belonging to *A. deliciosa* (Chev) C. F. Liang et A. R. Ferguson, is widely known for its relative large fruit size, green flesh, and long storage life (Thompson et al., 2000) but with relatively low soluble solid concentrations (SSC) (average 14%), and high titratable acid (TA) when ripe. ‘Sanuki Gold’ kiwifruit recently bred in Japan (Mworía et al., 2010), belongs to *A. chinensis* and has similarities with ‘Hort 16A’ bred in New Zealand, popular for its attractive golden yellow flesh, high SSC levels, low TA levels, and a sweet sub-

tropical flavor when ripe (Patterson et al., 2003). However, ‘Sanuki Gold’ fruit are twice as large as ‘Hort 16A’ with an average weight of 180–200 g and costs more than 800 Japanese yen (10 US\$) each at prime markets in Japan. Due to its high SSC (18%), vitamin C, carotenoid content, low TA, and attractive golden yellow flesh when ripe, fruit can be consumed fresh or in processed form, such as desserts, jams, or juices. Studies have also shown that ‘Sanuki Gold’ has shorter storage life than ‘Hayward’ and ‘Koryoku’ cultivars grown in Japan (Fukuda and Suezawa, 2008).

The use of modified atmosphere (MA) to prolong the storage life of fruit is widely spread due to its low cost, ease of implementation, and high quality benefits, resulting in increased storage life without quality losses (Kader et al., 1989; Zagory and Kader, 1988). Unlike controlled atmosphere (CA), MA relies on the balance between the consumption of O<sub>2</sub>, the production of CO<sub>2</sub> by the produce and the gaseous diffusion through the polymeric film of the package. Although kiwifruit stored in air at 0°C significantly soften and accumulate high levels of SSC after 1 month of storage, ‘Hayward’ kiwifruit were

Received; July 26, 2010. Accepted; January 20, 2011.

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successfully stored for 4–6 months under CA or MA conditions (Arpaia et al., 1987). Harvesting maturity has also been shown to affect fruit storage life and quality characteristics after harvest. Studies in several kiwifruit cultivars showed that fruit harvested at an early harvesting maturity have higher storage potential than late harvested fruit (Costa et al., 1997; Crisosto et al., 1984; Mitchell et al., 1992). However, early harvested fruit may not attain optimum eating quality threshold levels after storage (Young and Paterson, 1985), while late harvesting may compromise storage performance (Tavarini et al., 2008, 2009). Thus, with the emerging new cultivars and production locations, determination of quality index thresholds to establish the optimum harvesting maturity stage, specific to each cultivar and location could positively influence fruit storage life and the overall market performance without compromising the eating quality characteristics of kiwifruit.

Kiwifruit maturation is known to progress while the fruit is on the vine (Hopkirk et al., 1989). Ethylene has been shown to play a significant role during fruit senescence and ripening (Tatsuki, 2010). Kiwifruit exposed to low concentrations of exogenous ethylene significantly soften and accumulate high levels of SSC (Pratt and Reid, 1974; Saltveit, 1999; Sfakiotakis et al., 2001). However, healthy kiwifruit do not produce detectable levels of ethylene at harvest or during storage although fruit harvested late or stored at low temperatures (4°C) show considerable ripening (Arpaia et al., 1987; Tavarini et al., 2009; Yano and Hasegawa, 1993). 1-Methylcyclopropene (1-MCP), an inhibitor of ethylene action (Sisler and Serek, 1997) with relatively greater affinity than ethylene to the receptor binding site (Jiang et al., 1999) has greatly influenced storage technology and the consumption behavior of several horticultural commodities (Watkins, 2006). The use of 1-MCP largely depends on plant species, maturity stage, timing of application, concentration levels, and storage conditions (Blankenship and Dole, 2003; Sisler and Serek, 1997). The use and effects of 1-MCP have also been demonstrated in several species (Watkins, 2006). Application of 1-MCP to ‘Hayward’ kiwifruit during or after cold storage effectively delayed fruit softening (Boquete et al., 2004; Kim et al., 2001). In this study, we investigated the effect of MA storage and 1-MCP on the storage life and quality indices of the newly bred ‘Sanuki Gold’ kiwifruit harvested at two different maturity stages.

## Materials and Methods

### *Plant materials and ethylene measurements*

Mature ‘Sanuki Gold’ kiwifruit (*A. chinensis*) obtained from a commercial orchard in Takamatsu, Japan between 2005 and 2008 seasons were analyzed. During the growing season which begins with flowering at the middle of May, individual fruit were bagged in paper fruit bags immediately after fruit set and careful spraying regimes

were observed. Fruit were harvested at two different maturity stages; 18 days (136 days after pollination, DAP) before and at commercial maturity stage (154 DAP) and those found with defects or infections were excluded from the experiment. Ethylene production was determined by incubating individual fruit in 1.3 L containers for 2 h, after which 1 mL headspace gas was drawn and injected into a gas chromatograph (Model-GC4 CMPF, Shimadzu, Kyoto, Japan), equipped with a flame ionization detector and an acti-vated alumina column (Nakatsuka et al., 1998).

### *Treatments and storage conditions*

Fruit were either held under ambient conditions as non-treated control or exposed to 10  $\mu\text{L}\cdot\text{L}^{-1}$  1-MCP. 1-MCP was generated from a SmartFresh<sup>SM</sup> powder (active ingredient 0.14%, Rohm and Hass, Philadelphia, USA) in a 30 mL gas tight bottle filled with 5 mL distilled water and with a magnetic stirrer. After stirring for 5 min, headspace gas was drawn using a gas tight hypodermic syringe, ejected into 15 L plastic gas tight containers with fruit, and incubated for 12 h at 25°C. Then each fruit was placed in either a tightly sealed 0.05 mm thick polyethylene film bag (165 mm  $\times$  180 mm, MA) or covered with a polyethylene film bag without sealing (air) and stored at 4°C. Fruit found infected with soft rot or producing ethylene during storage were excluded from the experiment.

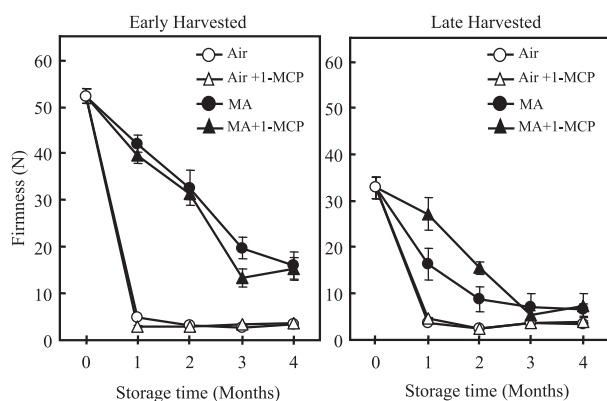
### *Evaluation of fruit quality indices*

Fruit flesh firmness, SSC, TA, and flesh color index were analyzed monthly for 4 months. Flesh firmness was measured at four equatorial regions of the peeled flesh using a penetrometer (model SMT-T-50, Toyo Baldwin, Tokyo, Japan) fitted with an 8 mm plunger. SSC was measured using a digital Atago PR-1 refractometer (Atago Co. Ltd., Tokyo, Japan) and expressed in Brix (%). TA was determined by titration using 0.1 N NaOH and phenolphthalein as a pH indicator and expressed as percentage citric acid equivalents. Flesh color index was measured with a chromameter (CR-200, Minolta, Osaka, Japan), equipped with an 8 mm measuring head and a C illuminant (6774 K). Measurements were carried out at four points on the outer pericarp after a 2 mm thick slice of skin was removed. Color changes were quantified in the L, a, and b color space and color index value calculated based on L (b/|a|).

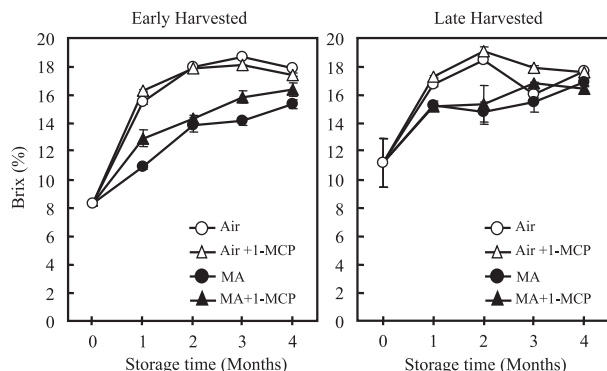
## Results and Discussion

### *MA effectively delays ‘Sanuki Gold’ kiwifruit ripening during long-term low temperature storage*

‘Sanuki Gold’ kiwifruit harvested either early (52 N) or late (33 N) and stored under air conditions at 4°C rapidly softened to less than 10 N after 1 month of storage (Fig. 1). Similarly, in both harvesting maturity stages, SSC increased rapidly to 16% after 1 month of storage followed by a gradual increase to 18% during the storage

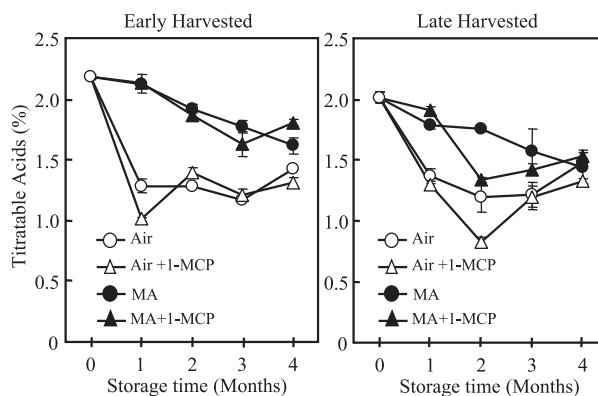


**Fig. 1.** Firmness of ‘Sanuki Gold’ kiwifruit harvested early (136 DAP) or late (154 DAP) and stored at 4°C for 4 months. Fruit were either stored in air (covered with polyethylene film bag without sealing) or MA (sealed in 0.05 mm thick polyethylene film bag) with or without 1-MCP at harvest. Each value is expressed in N, SE represents 3 replications at each time point, and error bars not shown are smaller than the symbol used.

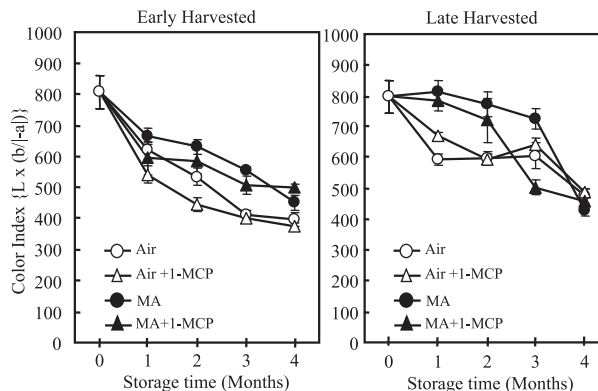


**Fig. 2.** SSC of ‘Sanuki Gold’ kiwifruit harvested early (136 DAP) or late (154 DAP) and stored at 4°C for 4 months. Fruit were either stored in air (covered with polyethylene film bag without sealing) or MA (sealed in 0.05 mm thick polyethylene film bag) with or without 1-MCP at harvest. Each value is expressed in Brix (%), SE represents 3 replications at each time point, and error bars not shown are smaller than the symbol used.

period (Fig. 2) while TA decreased from 2.2% at harvest to less than 1.5% after 1 month of storage (Fig. 3). Also the fruit flesh color index reduced rapidly after 1 month of storage, followed by a gradual decrease in subsequent months of storage (Fig. 4), suggesting that ripening of ‘Sanuki Gold’ kiwifruit proceeded during storage at 4°C under air conditions. The majority of fruit remained healthy without any detectable ethylene production (minimum detectable level of 0.05 nL·g<sup>-1</sup>·h<sup>-1</sup>) in this experiment. However a few fruit found producing detectable ethylene were excluded from the experiment since they showed symptoms of fungal infection within days after observation at room temperature, indicating that the detected ethylene was due to disease infection. ‘Hayward’ fruit stored under air conditions at 0°C softened to 13 N after 60 days, losing between 77–80%



**Fig. 3.** TA of ‘Sanuki Gold’ kiwifruit harvested early (136 DAP) or late (154 DAP) and stored at 4°C for 4 months. Fruit were either stored in air (covered with polyethylene film bag without sealing) or MA (sealed in 0.05 mm thick polyethylene film bag) with or without 1-MCP at harvest. Each value is expressed as percentage (%) citric acid equivalents, SE represents 3 replications at each time point, and error bars not shown are smaller than the symbol used.



**Fig. 4.** Color index of ‘Sanuki Gold’ kiwifruit harvested early (136 DAP) or late (154 DAP) and stored at 4°C for 4 months. Fruit were either stored in air (covered with polyethylene film bag without sealing) or MA (sealed in 0.05 mm thick polyethylene film bag) with or without 1-MCP at harvest. Color values are expressed as the color index (L (b/a)). SE represents 3 replications at each time point and error bars not shown are smaller than the symbol used.

of initial flesh firmness (Ritenour et al., 1999). Arpaia et al. (1987) also demonstrated that fruit lose considerable amount of starch and organic acids during storage, leading to an increase in SSC and reduction of organic acids.

However, in fruit stored under MA conditions, changes in flesh firmness, SSC, TA, and flesh color index were significantly retarded. In early harvested fruit, flesh firmness slightly declined to about 40 N after 1 month of storage, followed by a slow decrease in subsequent months of storage, and remained above 10 N after 4 months of storage (Fig. 1). In addition, SSC rose from 8% to between 11–13% after 1 month of storage and remained below 16% after 4 months of storage, less than the optimum SSC value (18%) at fully ripened stage

(Fig. 2). TA showed slight changes after 1 month of storage and remained above 1.6% after 4 months of storage (Fig. 3). Changes in the flesh color index were also delayed and remained slightly above those observed in air stored fruit after 4 months of storage (Fig. 4). Previous reports have shown that CA or MA retarded flesh softening during storage in ‘Hayward’ kiwifruit (Harman and McDonald, 1983; Hertog et al., 2001; Manolopoulou et al., 1997). Similarly, analysis showed that high CO<sub>2</sub> and low O<sub>2</sub> slowed kiwifruit softening during storage (Arpaia et al., 1980, 1985; McDonald and Harman, 1982). Inhibitory effects of CO<sub>2</sub> on ethylene were reported by Burg and Burg (1969) and have been confirmed in peaches (Mathooko et al., 2001) and other climacteric fruits (Kubo et al., 1990; Mathooko, 1996). Results obtained from the analysis of late harvested fruit stored under MA conditions showed that O<sub>2</sub> dropped to around 2% after 1 month of storage before rising steadily to about 10% by the end of 3 months of storage. CO<sub>2</sub> concentration increased to 5% after 1 day of storage and stabilized slightly above 3% after 3 months of storage, indicating that the delay observed in fruit ripening was occasioned by MA storage conditions.

*Fruit harvesting maturity influences effectiveness of MA storage and 1-MCP applied at harvest*

No significant differences in fruit firmness were observed during storage between MA and MA in combination with 1-MCP in early harvested fruit (Fig. 1). Furthermore, fruit treated with 1-MCP at harvest and stored under air conditions showed a similar softening pattern to 1-MCP non-treated fruit in both harvest maturity stages after 1 month of storage. However, late harvested fruit exhibited some differences between MA and MA in combination with 1-MCP. Late harvested fruit treated with 1-MCP and stored under MA conditions maintained flesh firmness above 25 N after 1 month of storage compared to 16 N in 1-MCP non-treated fruit. Further after 2 months of storage, 1-MCP treated fruit maintained flesh firmness at 15 N compared to less than 9 N in 1-MCP non-treated MA stored fruit, suggesting that 1-MCP has a limited effect on late harvested fruit during early stages of storage under MA conditions (Fig. 1). Similar observations were made during 2006 and 2007 experiments (data not shown). Considering that no ethylene was detected after harvest or during storage, it is only reasonable to assume that low level ethylene below detectable levels could have existed at the time of harvest in fruit harvested late. In the event that such low ethylene exists, then 1-MCP, a well-known inhibitor of ethylene action (Sisler and Serek, 1997), and CO<sub>2</sub>, known to antagonize ethylene by competitively interfering with its perception at higher concentration (Burg and Burg, 1969), may act cooperatively or independently to slow down fruit softening. Whether ethylene is involved is not yet clear since fruit stored in air with or without 1-MCP ripened rapidly. We have

previously demonstrated that in ‘Sanuki Gold’ kiwifruit, a single shot of 1-MCP is only effective for 5 days at room temperature after which further treatment is required to counter any effects of ethylene (Mworia et al., 2010). Since fruit were treated once at harvest with 1-MCP and analyzed monthly, it is therefore possible that ethylene played a role in fruit ripening at 4°C. In addition, studies have also showed that kiwifruit is highly sensitive to low concentrations of ethylene (Pratt and Reid, 1974; Saltveit, 1999) while studies in tomato revealed that more mature fruit are more sensitive to ethylene than younger fruit (Kevany et al., 2007), suggesting that differences in harvest maturity could influence fruit sensitivity to ethylene, resulting in such variations observed in the efficacy of 1-MCP in MA stored fruit. More work is required to explain further the relationship between 1-MCP and MA during kiwifruit storage. From these observations, we can only conclude that 1-MCP and MA cooperatively slowed ‘Sanuki Gold’ softening in late harvested fruit.

At harvest, early harvested fruit had 8% SSC compared to 11% in late harvested fruit which increased gradually in both harvesting stages to about 16% after 4 months of storage under MA conditions (Fig. 2). Under air conditions, fruit achieved maximum SSC levels (18%) after the third month (early harvested) and second month (late harvested) of storage, suggesting that two weeks early harvesting did not compromise eating quality characteristics at the fully ripened stage. MA stored fruit did not attain full ripening flesh firmness after 4 months while SSC showed increasing trends during storage. These observations suggest that early harvested ‘Sanuki Gold’ kiwifruit under MA conditions can be stored for 4 months and have potential to ripen further after storage. Only slight differences were observed between the two maturity stages in TA and color index at harvest. Previous studies in kiwifruit and other fruit demonstrated that harvesting maturity has a significant effect on post-harvest quality characteristics associated with metabolic conversion on and off tree (Hopkirk et al., 1989; Jason et al., 2002; Yamaki, 2010), thus influencing fruit storage life and edible quality characteristics (Crisosto et al., 1984). Recent studies in ‘Hayward’ have also demonstrated that late harvested fruit have a shorter storage life than early harvested fruit (Tavarini et al., 2009). Minimum acceptable flesh firmness and maximum SSC levels are critical threshold indicators of market suitability and harvesting maturity, respectively. In Chile and New Zealand, kiwifruit harvest is recommended to start when fruit have attained at least 6.2% SSC, while in New Zealand the minimum recommended storage flesh firmness for exporting ‘Hayward’ kiwifruit is 11.8 N (Hopkirk et al., 1996). In this study, fruit achieved minimum flesh firmness slightly below 10 N and maximum SSC at about 18%. However in order to understand the commercial value of MA storage and 1-MCP treatment of ‘Sanuki Gold’

kiwifruit, more studies are required on organoleptic studies to assess the quality of fruit after storage.

In conclusion, these observations confirm that MA storage is effective in prolonging storage life of the high quality cultivar, 'Sanuki Gold' kiwifruit. Since kiwifruit harvest maturity varies with the production season, these results indicate that harvest maturity may influence the effectiveness of MA and 1-MCP storage; thus, determination of optimum harvesting maturity is crucial for prolonged kiwifruit storage benefits. Accumulative heat unit summation (Fukuda and Suezawa, 2008) and non-destructive measurements such as acoustic vibration techniques (Taniwaki and Sakurai, 2010; Takahashi et al., 2010) would be useful for maturity evaluation. In the event of delayed harvesting, treatment of fruit with 1-MCP at harvest before commencement of MA storage may be helpful in prolonging the storage life of 'Sanuki Gold' kiwifruit. However, in order to fully understand the benefits of MA and 1-MCP in kiwifruit, more studies are required to demonstrate whether kiwifruit ripening during storage is dependent on, or independent of ethylene.

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