

Effect of the application timing of 1-MCP on postharvest traits and sensory quality of a yellow-fleshed kiwifruit



Juan Salazar^a, Claudia Jorquera^a, Reinaldo Campos-Vargas^b, Chad Jorgensen^a, Patricio Zapata^a, Rodrigo Infante^{a,*}

^a Departamento de Producción Agrícola, Universidad de Chile, Santiago, Chile

^b Centro Biotecnología Vegetal, Facultad Ciencias de la Vida, Universidad Andres Bello, Santiago, Chile

ARTICLE INFO

Keywords:

Actinidia chinensis
Postharvest
Cold storage
1-MCP
Sensorial attributes

ABSTRACT

Chile is the third largest exporter of kiwifruit in the world. Its varietal production has traditionally been focused on green-fleshed kiwifruit varieties, with 'Hayward' being the most exported variety. 'Soreli' is a new Italian kiwifruit variety, which is characterized by its early ripening, big size, sweet taste, as well as its yellow flesh. This gives 'Soreli' a good opportunity to promote the consumption of yellow-fleshed varieties, and a wider assortment of kiwifruit in the market. The aim of this work is to evaluate postharvest traits and consumer acceptance in kiwifruit var. 'Soreli', with a combination of storage temperatures of 0 °C and 20 °C and 1-methylcyclopropene (1-MCP) applications.

Cold storage and 1-MCP treatments caused a positive response in kiwifruit var. 'Soreli'. In the case of fruits stored at 20 °C, 1-MCP treatment extended the postharvest life of the fruits at least 3 weeks while the fruits stored in cold at 0 °C treated with 1-MCP reached 8 weeks. In general, the respiration rate was higher in the control treatments with respect to the 1-MCP treatments, as well as the ethylene emission occurred earlier in the control. In addition, the kiwifruit sensory quality attributes were adequate in all cases, reaching a medium or high acceptability in the evaluation panel.

1. Introduction

In the last years worldwide kiwifruit production has increased substantially, from 2.5 MT to 4.3 MT. Sixty percent of kiwifruit production is generated in Asia, with China being the world's largest producer (2.39 MT), followed by Italy (0.52 MT), New Zealand (0.43 MT), Iran (0.29 MT) and Chile (0.23 MT). However, the largest exporters in the world are Italy, New Zealand and Chile, with 0.34, 0.32 and 0.21 MT exported, respectively (FAOSTAT, data retrieved in 2018). The production of kiwifruit worldwide is based mainly on green-fleshed kiwi, especially var. 'Hayward' (Cruzat, 2014). It was not until the late 1990s that the first varieties of yellow-fleshed kiwi appeared, highlighted by 'Jintao', 'Enza Gold', and recently by 'Soreli'.

On these days, the fresh fruit market is in search of novelties for an empowered and much more demanding consumer, and the yellow-fleshed kiwifruit appear to be an interesting option due to their lower acidity and high fruit quality. New cultivars with yellow flesh have been developed in the last 20 years, some of them gaining a consistent place in the market. Currently, the demand for the presence of new varieties in the market is becoming more evident, which requires a

better knowledge of fruit quality and postharvest behavior of yellow-fleshed kiwi varieties.

In the yellow-fleshed cultivars, more so than the green cultivars, there is the need to prolong the postharvest life span, because these cultivars naturally have less viability after harvest than 'Hayward' or other green fleshed varieties. 'Hayward' could be kept in cold storage for 140 days or even more (Park et al., 2015a), but a yellow-fleshed cultivar such as 'Sanuki Gold' rarely maintains edibility for more than 60 days in cold storage (Asiche et al., 2017).

The product 1-methylcyclopropene (1-MCP) is an inhibitor of ethylene action that delays the natural senescence of fleshy fruit and is applied commercially in some climateric fruit that have a final destination in distant markets and require prolonged postharvest. 1-MCP has been used commercially for more than 10 years in different fresh horticulture products, widening the window for fresh produce in cold storage. Thus, it is left to the companies that pick and package the fruit to control the flesh softening and ripening processes through the application of 1-MCP. The fruit is subsequently drawn from the cold chamber, at different times, to be displayed on store shelves. The beneficial effect of 1-MCP on decreasing the softening rate in green-

* Corresponding author.

E-mail address: rinfante@uchile.cl (R. Infante).

<https://doi.org/10.1016/j.scienta.2018.09.028>

Received 4 June 2018; Received in revised form 31 August 2018; Accepted 12 September 2018

Available online 24 September 2018

0304-4238/ © 2018 Elsevier B.V. All rights reserved.

fleshed kiwifruit is accomplished through the higher activities of phenylalanine ammonia-lyase, cinnamyl-alcohol dehydrogenase, peroxidase and higher lignification postharvest (Li et al., 2017). This effect has been profusely documented, particularly in cultivars 'Hayward' (Boquete et al., 2004; Koukounaras and Sfakiotakis, 2007; Park et al., 2015a; Vieira et al., 2012), 'Allison' (Sharma et al., 2012), 'Quinmei' (Deng et al., 2015), and in hardy kiwifruit too (*A. arguta* (Siebold and Zucc.) Planch. ex. Miq.) (Lim et al., 2016; Wang et al., 2015). However, it has been shown that its application in kiwifruit may reduce the sensorial quality of these products (Deng et al., 2015).

The increased excitement currently enjoyed by yellow-fleshed kiwifruit varieties is a fantastic opportunity to introduce them more broadly and consistently into the market. To do this, studies are required, not only of sensorial quality and consumer acceptance, but of their postharvest behavior as well. Therefore, the aim of this work is to determine the effect of the application timing of 1-MCP on the quality and postharvest behavior of the yellow-fleshed 'Soreli' kiwifruit.

2. Material and methods

2.1. Plant material

'Soreli' (*Actinidia chinensis*) is a kiwifruit variety which is characterized by its big size, yellow flesh, sweet taste, and early harvest date. This variety was grafted on 'Hayward' vines (*Actinidia deliciosa*) in 2012, in 1 ha of a commercial orchard located in Teno, region VII, Chile (longitude -71° 12' 48" and latitude -34° 52' 58"). Rows were distributed 4 m apart, and vines were planted 2 m apart in the row. Each row was irrigated with drip irrigation under conventional management. In 2015, for assuring homogeneous fruit size, manual pollination was performed using pollen of the male cultivar 'Belén'. The storage and fruit quality evaluations were carried out in Fruit Breeding and Quality Laboratory of the University of Chile.

2.2. Experimental trial and fruit quality evaluation

A total of 500 'Soreli' kiwi fruit were harvested when the flesh turned to yellow color with a soluble solids concentration (SSC) of 9.15% and flesh firmness around 50 Newtons (N) (Table 1). Finally, 300 homogeneous fruit were selected to perform 1-MCP applications for storage at 20 °C (F1) and storage at 0 °C for 45 days and 20 °C after cold

Table 1
Summary of descriptive analysis of the evaluated traits in kiwi fruit 'Soreli' at harvest.

Trait	n	Mean	SE	Min	Max
Fruit weight (g)	12	105.98	2.61	92.72	123.01
Ecuatorial diameter 1 (mm)	12	52.03	0.62	47.87	56.08
Ecuatorial diameter 2 (mm)	12	49.37	0.40	46.77	52.60
Polar diameter (mm)	12	65.98	0.78	60.25	70.44
Skin I_{AD}	24	0.71	0.02	0.53	0.87
Skin color (L*)	24	52.10	0.65	45.69	57.74
Skin color (a*)	24	0.42	0.57	-3.79	6.81
Skin color (b*)	24	29.04	0.33	25.66	31.88
Skin color (C)	24	29.17	0.32	25.76	31.92
Skin color (H°)	24	89.07	1.15	75.96	97.27
Flesh I_{AD}	24	0.07	0.01	0.00	0.16
Flesh color (L*)	24	71.43	0.69	64.75	76.30
Flesh color (a*)	24	-7.22	0.13	-8.49	-5.62
Flesh color (b*)	24	37.74	0.59	29.60	41.66
Flesh color (C)	24	38.43	0.59	30.39	42.34
Flesh color (H°)	24	100.87	0.22	97.68	103.08
Flesh firmness (N)	24	52.08	1.99	31.99	63.84
Placenta firmness (N)	12	10.89	0.68	6.48	14.33
Dry matter (%)	12	17.03	0.34	14.91	18.75
Soluble solids (%)	12	9.15	0.40	7.10	11.00
pH	6	3.30	0.03	3.18	3.37
Acidity (g/l)	6	1.23	0.05	1.07	1.38

(F2).

Thus, immediately after harvest, the F1 fruit set was divided in two subgroups, 0 ppb of 1-MCP as control (T0) and 625 ppb of 1-MCP (T1) which it was applied for 24 h, storing both at 20 °C.

Fruit quality evaluations started 24 h after harvest for both treatments. The F2 fruit set was divided into three subgroups; 0 ppb of 1-MCP as control (T0), 625 ppb of 1-MCP (T1, pre-cold storage) and 625 ppb of 1-MCP (T2, post-cold storage) storing all of them at 0 °C for 45 days before fruit quality evaluation. 1-MCP treatments were applied before cold storage (T1) and after 45 days of cold storage (T2) for 24 h and then all of them were storage at 20 °C. All evaluations were carried out until consumption maturity (6–8 N).

1-MCP treatments for F1 and F2 fruit set were carried out in wairtight polypropylene chambers of 70 litres and 1-methyl cyclopropene (1-MCP) was gasified as a SmartFresh™ product 0.14% (625 ppb).

To characterize the quality and postharvest behavior of 'Soreli', weight loss, chlorophyll absorbance (I_{AD}), soluble solid content (SSC), dry matter, skin and flesh color, the flesh and placenta firmness, respiration rate (CO_2) and ethylene production were evaluated.

The chlorophyll absorbance at two wave-length (I_{AD}) as a maturity index was monitored by the kiwifruit specific DA-meter device (T.R. Turoni, Forlì, Italy; Gottardi et al., 2009), until consumption maturity.

The SSC was determined using a hand-held refractometer (ATAGO Co. LTD., Tokyo, Japan), calibrated as the percentage of sucrose at 20 °C, and dry matter was determined as a percentage of weight after 16 h in air dryer. SSC and dry matter were evaluated at 60, 20 and 8 N in both treatments (T0 and T1) in the F1 fruit set (storage at 20 °C), and at consumption maturity (6–8 N) for F2 fruit set (45 days after cold storage). The skin and flesh color (H°, L*, a*, b*) of the fruit were determined using a CR-400 colorimeter (Konica Minolta Inc., Marunouchi, Chiyoda, Tokyo) at consumption maturity in each treatment. Firmness was quantified in Newton (N) by a texture analyzer (TA.XT plus, Texture Technologies, Hamilton, MA, USA) using 7.9 mm and 2 mm diameter plungers by penetration of 8 mm, and a 20 mm cylinder by compression of 3 mm depth (non-destructive method). Firmness was measured in alternative days (at least 6 measurements) according to the fruit maturity.

Respiration rate ($ml\ CO_2\ kg^{-1}\ h^{-1}$) and ethylene production ($\mu l\ kg^{-1}\ h^{-1}$) were monitored until consumption maturity using PBI Dansensor check mate 3 (MOCON Inc., Minneapolis, MN, USA) and SHIMADZU GC 2014 gas chromatograph (Shimadzu Corp., Kyoto, Japan) equipped with FID detector and alumina column, respectively.

In addition, sensory quality parameters were evaluated by twelve trained evaluators on a continuous and unstructured scale of 15 cm using a visual phase for skin color (light-dark brown), flesh color (light-dark yellow), flesh brightness (opaque-gloss), and seed color (pale-dark); nasal phase including typical aroma (low-high), and aromatic intensity (low-high); gustatory phase as sweetness (low-intense), acidity (low-high), and strange taste (low-intense); texture phase including hardness (very soft-very hard), chewability (little-much), and juiciness (little-much) and finally general acceptability (dislike much-like very much) (Table S1).

2.3. Experimental design and fruit quality data analysis

In all cases, a completely randomized experimental design was followed. The experimental unit corresponded to ten fruit per treatment and evaluation for destructive methods (firmness by punction, dry matter, SSC and flesh color), and fifteen fruit for non-destructive methods (fruit weight, skin I_{AD} and firmness by compression and skin color), except for respiration rate and ethylene emission that used five fruit. The results were analyzed by analysis of variance (ANOVA) and Tukey multiple comparison test (p -value ≤ 0.05). In addition, a multivariate analysis of principal components was performed. All analyses were calculated and edited using INFOSTAT v16 software (Universidad Nacional de Córdoba, Argentina).

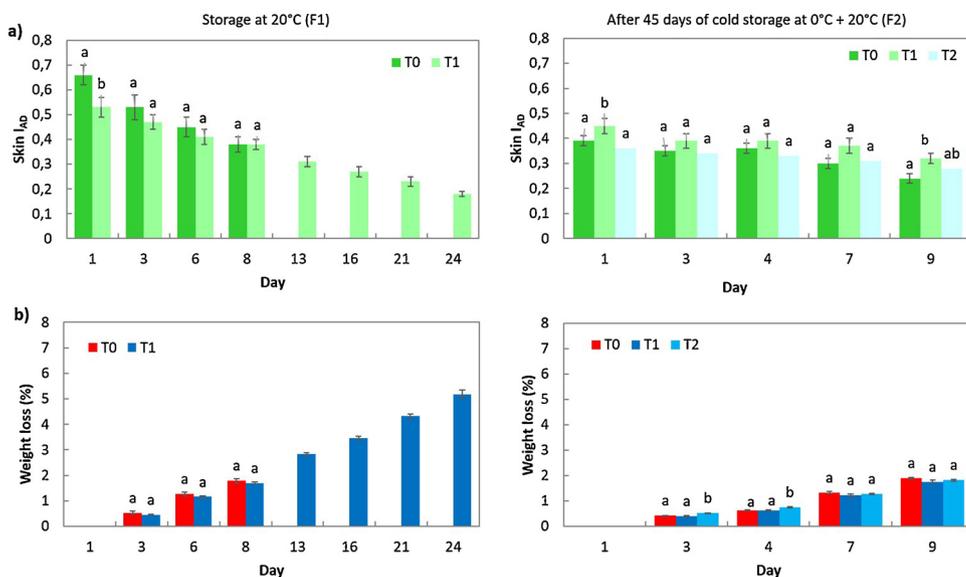


Fig. 1. a) Skin chlorophyll evolution (I_{AD}) for ‘Soreli’ kiwifruits during storage at 20 °C (F1:T0, control; T1, 1-MCP, left) and after 45 days of cold storage at 0 °C and storage at 20 °C (F2:T0, control; T1, 1-MCP pre-cold; T2, 1-MCP post-cold, right). b) Weight loss (%) of ‘Soreli’ kiwifruits for conditions F1 (left) and F2 (right). Statistically significant differences (Tukey’s test, $p < 0.05$) are shown.

3. Results and discussion

Ripening and therefore senescence of kiwifruit is related to the loss of chlorophyll, which is degraded in both, green and yellow-fleshed. The chlorophyll degradation is regulated differentially; green-fleshed kiwifruit maintains high chlorophyll levels while in yellow kiwifruit chlorophyll is degraded to colorless catabolites upon fruit ripening, leaving yellow carotenoids visible (Pilkington et al., 2012).

As expected, skin chlorophyll degraded over time, but no significant differences for I_{AD} were seen between treatments for both groups (F1 and F2), with one exception a slightly tendency to a higher I_{AD} in the T1 (1-MCP pre-cold storage) (Fig. 1a). In the F1 fruit set Skin I_{AD} reached values around 0.4 for control (T0) in day 8 and around 0.2 for 1-MCP treatment (T1) in day 24, while for F2 fruit set all of values ranged from 0.3 to 0.4. No values were obtained for Skin I_{AD} and weight loss for the F1 fruit set after day 8, because the fruit had become over-ripe.

In general, there were not differences in weight loss between treatments in both groups (F1 and F2) for each evaluation day. However, weight loss was greater in T1, especially in the F1 group, with values around 5% due to the longer time taken to reach its consumption maturity, which was the reason for the greater dehydration (Fig. 1b). The weight loss for group F2 was lower during the period of 20 °C due to more advanced fruit maturity. In an experiment where kiwi *Actinidia deliciosa* cv ‘Allison’ (Sharma et al., 2012) was treated with different concentrations of 1-MCP, the control showed a weight loss of nearly 20% during 18 days at 22 °C, but 1-MCP treated fruit lost 10 and 15% of their weight. Those values are still much higher than those mentioned here. In our experiment, no differences were found between T0 and T1 of ‘Soreli’ contrary to ‘Allison’ kiwifruit where 1-MCP treatments caused lower weight loss (Sharma et al., 2012).

According to Celano and co-workers (2008), water loss in kiwifruit is related to the degeneration of hairiness, outer layers and cell death of skin tissue. Thus, the changes in the fruit firmness are also related to the fruit dehydration, which consequently results in the loss of cell turgor.

In the first fruit set (F1: Harvest + 20 °C), SSC increased as firmness decreased, with values between 10 and 15%. No significant differences between treatments were observed, except at the 20 N, where a higher SSC was observed in the T1 (1-MCP), with respect to the control (T0) (a).

In the second fruit set (F2: 45 days at 0 °C + 20 °C) the SSC and dry matter were evaluated only at consumption maturity (8N), because after 45 days of cold storage, all treatments were very close to consumption maturity (Fig. 2ab). In this case, the SSC was between 14 and 15% (Fig. 2a), and the dry matter was between 18 and 19%. Dry matter

showed no apparent changes during softening or between treatments, ranging from 18 to 20% (Fig. 2b).

The higher SSC in the T1 of both groups is likely due to the fact that the treatments with 1-MCP needed a longer time to reach their consumption maturity, especially in the F1 where the T1 needed 25 days for the consumption maturity and the T0 only 9 days (Fig. 3a). In other studies of cold storage and 1-MCP applications of ‘Quinmei’ kiwi fruit (Deng et al., 2015), the SSC reach values between 13 and 14% after 150 days of cold storage and 12 days of shelf-life period. However, ‘Soreli’ increases its SSC from 9 to 15% in only 9 days. In addition, higher dry matter and SSC is often related to better perception by consumers (Nardoza et al., 2010), reaching ‘Soreli’ kiwifruits a high content for both.

In terms of ripening and loss firmness of kiwifruit we can assert that kiwifruit behaves like a viscoelastic solid, appreciating important expansions and contractions of the tissue, which causes the effort to be gradually dissipated (Castro-Giráldez et al., 2011; Celano et al., 2009). Moreover there are different patterns during the ripening of the fruit that imply changes in the different tissues (MacRae et al., 1989). These changes affect the texture properties of the flesh and placenta tissues due to its different chemical and structural composition. Therefore, it is important to evaluate the evolution of flesh and placenta firmness independently.

In our evaluations, clear differences were observed for flesh firmness (P 7.9 mm), flesh firmness by compression (P 20 mm) and placenta firmness (P 2 mm) evaluations in both fruit sets (F1 and F2) (Fig. 3). However, the greatest reduction in flesh firmness was observed in the F1 group, between day 1 and day 4, where firmness falls from 60 to 20 N for T0, while in T1 there was only a slight difference between day 1 and 4 (Fig. 3a). Therefore, in F1 fruit set T0 needed 9 days to reach consumption maturity (6–8 N), unlike T1 which reached this state after 25 days, due to the effect of 1-MCP. In the F2 fruit set (Harvest + cold storage at 0 °C + 20 °C), there were also significant differences after 45 days of cold storage. T1 (1-MCP pre-cold) had a firmness value around 10 N, while the T0 (control) and T2 (1-MCP post-cold) showed firmness values around 5 N (Fig. 3a). According to flesh firmness, as a non-destructive method, a similar trend was found (Fig. 3b). In ‘Hayward’ stored at 20 °C, the consumption maturity was reached after 25 days, while fruit treated with 1-MCP maintained firmness for more than 30 days (Ilina et al., 2010). This demonstrated the longer shelf-life for green-fleshed kiwi, compared to yellow-fleshed kiwi like ‘Soreli’.

If we compare the results of the chlorophyll degradation and flesh firmness between T0 and T1 in the F1 fruit set (Figs. 1a and 3a), it was observed that flesh firmness was maintained longer with the treatment

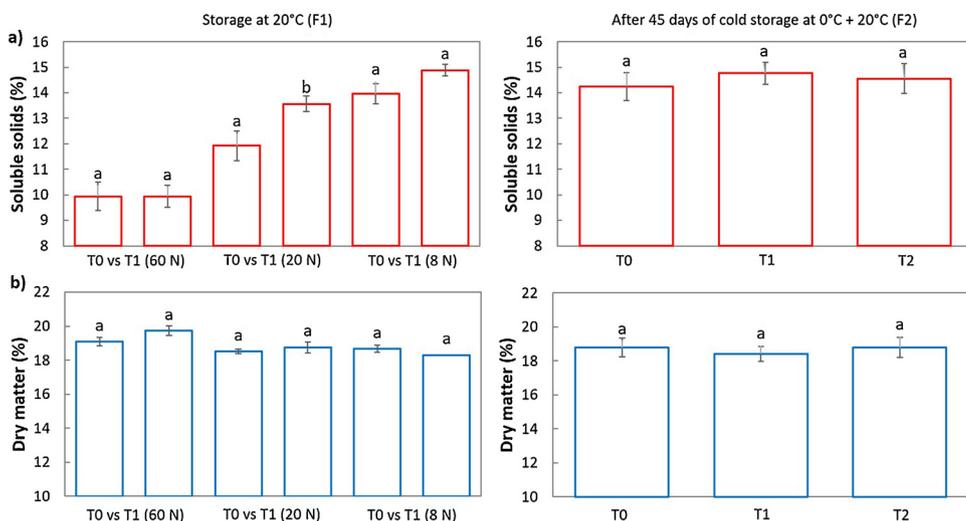


Fig. 2. abc. a) Soluble solids content (%) of ‘Soreli’ kiwi fruits during storage at 20 °C (F1:T0, control; T1, 1-MCP, left) for different states of firmness (60, 20 and 8 N) and for cold storage after 45 days at 0 °C and storage at 20 °C (F2:T0, control; T1, 1-MCP pre-cold; T2, 1-MCP post-cold, right) at maturity consumption (8 N). b) Dry matter content (%) of ‘Soreli’ kiwi fruits for conditions F1(left) and F2 (right). Statistically significant differences (Tukey’s test, $p < 0.05$) are shown.

of 1-MCP, contrary to the control treatment (Fig. 3a). Conversely, there were no significant differences in Skin I_{AD} between the control and 1-MCP treated fruits for each day (Fig. 1a). Thus, higher chlorophyll degradation is not always related to major fruit softening especially when we apply 1-MCP treatments. Moreover, through principal component analysis, as expected, SSC was the most variable parameter on time for the F1 while in the F2 fruit set, T1 explained the highest variation in Skin I_{AD} , flesh firmness and SSC (Fig. S1).

Kiwifruit as climacteric fruit is characterized by the ethylene emission that accelerates the fruit ripening and softening due to the continued respiration of the fruit as a result of chlorophyll and starch degradation (Wang et al., 2015). For this reason, it is also important to analyze both the respiration rate and the ethylene emission of the fruit. Thus, respiration rate (CO_2 production) in the F1 fruit set was generally higher in the control (T0), with values above $15 \text{ ml } CO_2 \text{ kg}^{-1} \text{ h}^{-1}$, unlike for the 1-MCP (T1) treatment, which maintained its respiration rate below $15 \text{ ml } CO_2 \text{ kg}^{-1} \text{ h}^{-1}$, between days 4 and 14 (Fig. 4a). In the control (T0), ethylene emission was only registered after the respiration

was considerably increased, where the fruit started to emit ethylene coinciding with the maximum CO_2 emission ($25 \text{ ml } kg^{-1} \text{ h}^{-1}$), while the ethylene emission of T1 occurred 10 days later (Fig. 4b). This also coincides with a decrease in flesh firmness close to consumption maturity, in both cases (Figs. 3 and 4). Some authors consider that the climacteric stage should be followed by an increase in respiration and ethylene (Vieira et al., 2010 and Park et al., 2015b). However, an increase in ethylene production may occur before or after increased respiration (Lim et al., 2016).

In fruit set F2, CO_2 emission values were higher than F1 set due to their more advanced ripening stage, ranging from 25 to $45 \text{ ml } CO_2 \text{ kg}^{-1} \text{ h}^{-1}$ for all treatments (Fig. 4). In this case, there was an opposite trend between T0 (control) and T1 (1-MCP pre-cold), where T1 fruit showed a higher CO_2 emission than T0. T1 fruit produced ethylene one week before T0 as well. This apparently contradictory situation may be due to the fact that, after 45 days of cold storage, the 1-MCP treatment (T1) loses its effect, leading to an increase in respiration rate and the ethylene emission. Crisosto and Garner (2001)

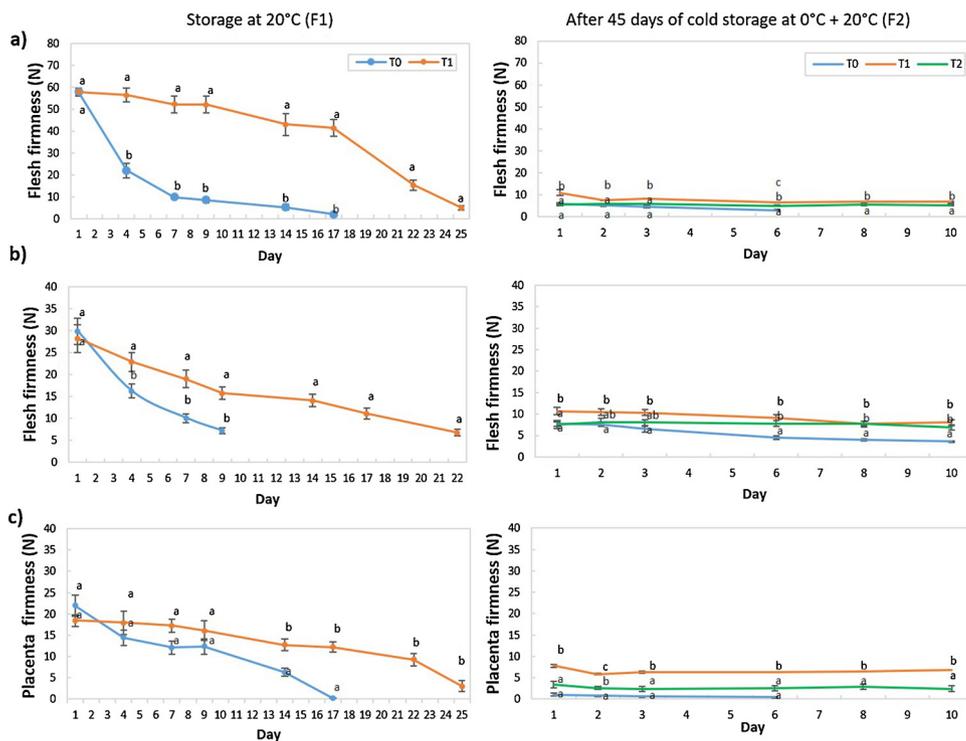


Fig. 3. abc. a) Flesh firmness (N) evolution by puncture with a 7.9 mm plunger of ‘Soreli’ kiwi fruits during storage at 20 °C (F1:T0, control; T1, 1-MCP, left) and after 45 days of cold storage at 0 °C and storage at 20 °C (F2:T0, control; T1, 1-MCP pre-cold; T2, 1-MCP post-cold, right). b) Flesh firmness (N) by compression with a 20 mm cylinder of ‘Soreli’ kiwi fruits for the conditions F1 (left) and F2 (right). c) Placenta firmness (N) by puncture with a 2 mm plunger of ‘Soreli’ kiwi fruits for the conditions F1 (left) and F2 (right). Statistically significant differences (Tukey’s test, $p < 0.05$) are shown.

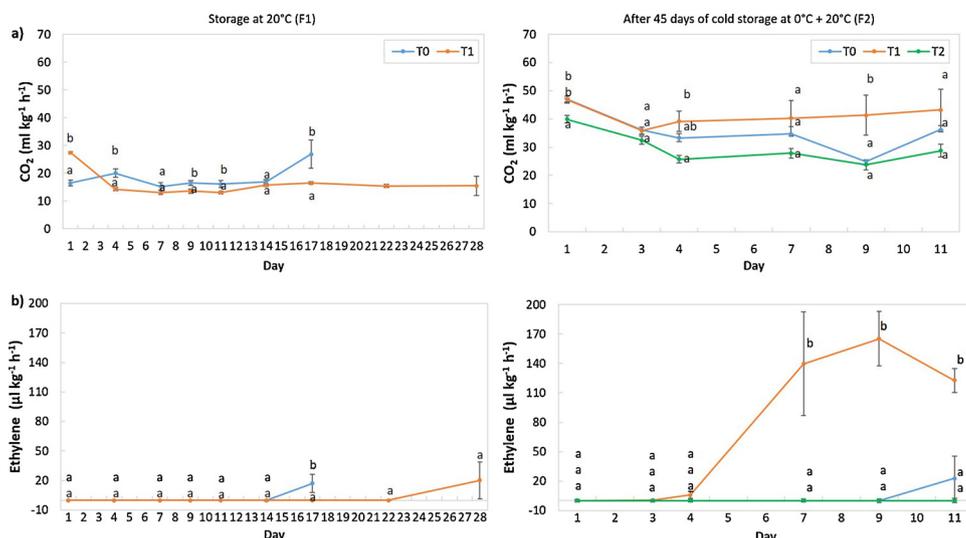


Fig. 4. ab. a) CO₂ emission (ml CO₂ kg⁻¹ h⁻¹) of 'Soreli' kiwi fruits during storage at 20 °C (F1:T0, control; T1, 1-MCP, left) and after 45 days of cold storage at 0 °C and storage at 20 °C (T0, control; T1, 1-MCP pre-cold; T2, 1-MCP post-cold, right). b) Ethylene emission (µl CO₂ kg⁻¹ h⁻¹) of 'Soreli' kiwi fruits for the conditions F1 (left) and F2 (right). Statistically significant differences (Tukey's test, p < 0.05) are shown.

asserts that 1-MCP applications lose their effect after 4 weeks. This could explain the increase of respiration rate and ethylene production for 1-MCP treatment. However, this situation is not reflected in the flesh firmness, where fruit of T1 maintained higher levels of firmness than T0 (Fig. 3). As expected, the ethylene emission does not occur in the T2 treatment (1-MCP treatment post-cold), despite showing lower levels of firmness, because the 1-MCP treatment was applied only a few days prior.

Currently, the evaluation of the different sensory quality attributes for any fruit are especially important in an increasingly changing and demanding market. In addition, kiwi fruit is characterized by low calories level and highly nutritious, which can bring great health benefits (Drummond, 2013 and Park et al., 2014). In the sensory evaluation, no significant differences were observed between the F1 and F2 groups or between treatments (Fig. 5 and Table S2). Thus, we can assert that there were no negative effects of 1-MCP on fruit sensorial quality of kiwi 'Soreli'. In general, parameters as important as the typical juiciness, chewiness, sweetness, and aroma showed medium or high values and low values for acidity and strange taste. It should be noted that, for skin and flesh color, there were no significant differences between treatments for each group (F1 and F2) (data not shown).

One of the most important parameters to consider in fruits such as kiwi is related to homogeneous texture when consumed, so it is very important that the flesh and placenta texture evolve in a similar way. For example, Li and co-workers (2017) report that cold storage together with 1-MCP treatments produce an increase in lignin, especially in the placenta tissue due to positive regulation of the AcPOD1 gene which could lead to a less uniform texture between the tissues of the whole

fruit, affecting their sensory attributes.

However, there are not many studies that evaluate differences in the texture of both tissues (Jackson and Harker, 1997). In the case of the green-fleshed kiwi 'Hayward' placenta firmness was related to flavour intensity and acceptability (Stec et al., 1989). Other recent studies also relate higher dry matter and SSC to consumer acceptability (Nardozza et al., 2011).

Consumers showed a considerable degree of acceptance for the yellow-fleshed kiwi, 'Soreli', despite of cold storage or 1-MCP applications.

4. Conclusions

In general, SSC of 'Soreli' kiwifruit is not particularly affected by cold storage when fruit reach consumption ripeness. The 1-MCP treatment of the F1 fruit (fruit exposed to room temperature) caused a two-week delay to reach consumption maturity, while 1-MCP treatments of F2 fruit set induced a one-week delay after 45 days in cold storage. In the F1 fruit, there was a higher respiration rate for control (T0) coinciding its respiratory peak at the beginning of the ethylene emission and a slightly lower firmness than the consumption. Therefore, 'Soreli' kiwifruit can be harvested and stored at 20 °C for at least 9 days whereas if we apply 1-MCP treatment and storage at 20 °C their shelf-life can be extended to 25 days. After 45 days in cold storage, 'Soreli' kiwi fruit are ready to eat, but by applying 1-MCP pre-cold and post-cold storage, we can extend their shelf-life ten more days. In addition, there was no negative effect of 1-MCP treatment on the sensorial fruit quality and acceptability of 'Soreli' kiwifruit, obtaining a medium or high

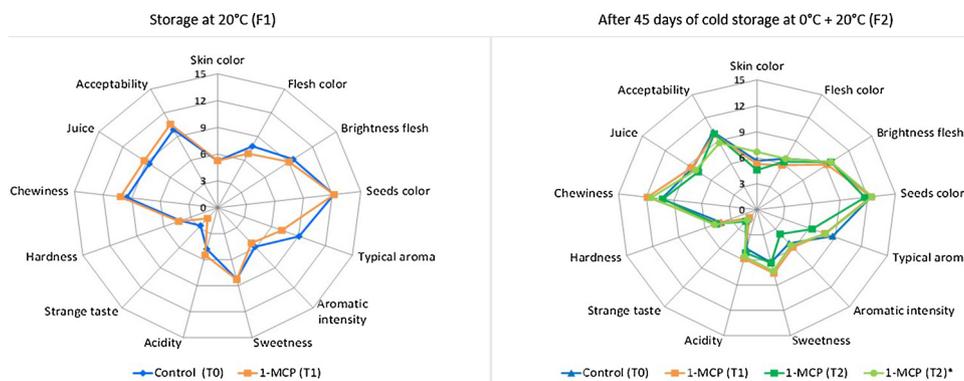


Fig. 5. Sensorial attributes evaluated in 'Soreli' kiwi fruits at maturity consumption (8 N) after storage at 20 °C (F1: T0, control; T1, 1-MCP, left) and after 45 days of cold storage at 0 °C and storage at 20 °C (F2: T0, control; T1, 1-MCP pre-cold; T2, 1-MCP post-cold, right). T2* correspond to T2 five days later.

acceptability by the consumer in all cases.

Acknowledgements

The authors would like to thank FONDEF N° D09i-1136 and FONDECYT N° 3160080 research projects.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:<https://doi.org/10.1016/j.scienta.2018.09.028>.

References

- Asiche, W.O., Witere Mitalo, O., Kasahara, Y., Tosa, Y., Mworio, E.G., Ushijima, K., Nakano, R., Kubo, Y., 2017. Effect of storage temperature on fruit ripening in Three kiwifruit cultivars. *Hortic. J.* 86, 403–410.
- Boquete, E., Trincherio, G., Frascina, A., Vilella, F., Sozzi, G., 2004. Ripening of 'Hayward' kiwifruit treated with 1-methylcyclopropene after cold storage. *Postharvest Biol. Technol.* 32, 57–65.
- Castro-Giráldez, M., Tylewicz, U., Fito, P.J., 2011. Analysis of chemical and structural changes in kiwifruit (*Actinidia deliciosa* cv Hayward) through the osmotic dehydration. *J. Food Eng.* 105, 599–608.
- Celano, G., Minnocci, A., Sebastiani, L., D'Auria, M., Xiloyannis, C., 2009. Changes in the structure of the skin of kiwifruit in relation to water loss. *J. Hortic. Sci. Biotechnol.* 84, 41–46.
- Crisosto, C.H., Garner, D., 2001. 1-MCP inhibits kiwifruit softening during storage. *Perishables Handl. Q.* 108, 19–20.
- Cruzat, C., 2014. The kiwifruit in Chile and in the world. *Revista Brasileira de Fruticultura, Jaboticabal* 36 (1) 112–12.
- Deng, L., Jiang, C.Z., Mu, W., Wang, Q., 2015. Influence of 1-MCP treatments on eating quality and consumer preferences of "Qinmei" kiwifruit during shelf life. *J. Food Sci. Technol.* 52 (1), 335–342.
- Drummond, L., 2013. The composition and nutritional value of kiwi fruit. *Adv. Food Nutr. Res.* 68, 33–57.
- Gottardi, F., Noferini, M., Fiori, G., Barbanera, M., Mazzini, C., Costa, G., 2009. The index of absorbance difference (I_{AD}) as a tool for segregating peaches and nectarines into homogeneous classes with different shelf-life and consumer acceptance. *Proceedings of the 8th Pangborn Sensory Science Symposium.*
- Iliina, N., Alem, H.J., Pagano, E.A., Sozzi, G.O., 2010. Suppression of ethylene perception after exposure to cooling conditions delays the progress of softening in "Hayward" kiwifruit. *Postharvest Biol. Technol.* 55 (3), 160–168.
- Jackson, P.J., Harker, F.R., 1997. Changes in firmness of the outer pericarp, inner pericarp, and core of *Actinidia* species during ripening. *N. Z. J. Crop Hortic. Sci.* 25 (2), 185–189.
- Koukounaras, A., Sfakiotakis, E., 2007. Effect of 1-MCP prestorage treatment on ethylene and CO₂ production and quality of 'Hayward' kiwifruit during shelf-life after short, medium and long term cold storage. *Postharvest Biol. Technol.* 46, 174–180.
- Li, H., Suo, J., Han, Y., Liang, C., Jin, M., Zhang, Z., Rao, J., 2017. The effect of 1-methylcyclopropene, methyl jasmonate and methyl salicylate on lignin accumulation and gene expression in postharvest "Xuxiang" kiwifruit during cold storage. *Postharvest Biol. Technol.* 124, 107–118.
- Lim, S., Han, S.H., Kim, J., Lee, H.J., Lee, J.G., Lee, E.J., 2016. Inhibition of hardy kiwifruit (*Actinidia arguta*) ripening by 1-methylcyclopropene during cold storage and anticancer properties of the fruit extract. *Food Chem.* 190, 150–157.
- MacRae, E.A., Lallu, N., Searle, A.N., Bowen, J.H., 1989. Changes in the softening and composition of kiwifruit (*Actinidia deliciosa*) affected by maturity at harvest and postharvest treatments. *J. Sci. Food Agric.* 49, 413–430.
- Nardoza, S., Gamble, J., Axten, L.G., Wohlers, M.W., Clearwater, M.J., Feng, J., Harker, F.R., 2011. Dry matter content and fruit size affect flavour and texture of novel *Actinidia deliciosa* genotypes. *J. Sci. Food Agric.* 91, 742–748.
- Park, Y.S., Im, M.H., Choi, J.H., Lee, H.C., Ham, K.S., Kang, S.G., Park, Y.K., Suhaj, M., Namiesnik, J., Gorinstein, S., 2014. Effect of long-term cold storage on physico-chemical attributes and bioactive components of kiwi fruit cultivars. *CYTA J. Food* 12, 360–368.
- Park, Y.S., Im, M.H., Gorinstein, S., 2015a. Shelf life extension and antioxidant activity of "Hayward" kiwi fruit as a result of prestorage conditioning and 1-methylcyclopropene treatment. *J. Food Sci. Technol.* 52 (5), 2711–2720.
- Park, Y.S., Polovka, M., Suhaj, M., Ham, K.S., Kang, S.G., Park, Y.K., Arancibia-Avila, P., Toledo, F., Sánchez, M.R., Gorinstein, S., 2015b. The postharvest performance of kiwi fruit after long cold storage. *Eur. Food Res. Technol.* 24, 601–613.
- Pilkington, S.M., Montefiori, M., Jameson, P.E., Allan, A.C., 2012. The control of chlorophyll levels in maturing kiwifruit. *Planta* 236, 1615–1628.
- Sharma, R.R., Jhalegar, M.J., Pal, R.K., 2012. Response of kiwifruit (*Actinidia deliciosa* cv. Allison) to post-harvest treatment with 1-methylcyclopropene. *J. Hortic. Sci. Biotechnol.* 87 (3), 278–284.
- Stec, M.G.H., Hodgson, J.A., MacRae, E.A., Triggs, C.M., 1989. Role of fruit firmness in the sensory evaluation of kiwifruit (*Actinidia deliciosa* cv Hayward). *J. Sci. Food Agric.* 47 (4), 417–433.
- Vieira, M.J., Argenta, L.C., Amarante, C.V.T., Steffens, C.A., Vieira, A.M.F.D., 2010. Preservação da qualidade pós-colheita de kiwi 'Bruno' pelo controle do etileno. *Revista Brasileira de Fruticultura, Jaboticabal* 32 (2), 309–406.
- Vieira, M.J., Argenta, L.C., Furtado Drehmer, A.M., Steffens, C.A., 2012. Qualidade Pós-Colheita De Quivi "Hayward" with 1-Mcp and stored under different atmospheres. *Revista Brasileira de Fruticultura* 34 (2), 400–408.
- Wang, Y., Xu, F., Feng, X., MacArthur, R.L., 2015. Modulation of *Actinidia arguta* fruit ripening by three ethylene biosynthesis inhibitors. *Food Chem.* 173, 405–413.