HortScience 44(7):1936–1940. 2009.

Uncoupling the Sensory Effects of 1-Methylcyclopropene and Ripening Stage on 'Hayward' Kiwifruit

Domingos P.F. Almeida[1]

University of Porto, Agricultural Sciences, Rua do Campo Alegre, 823, 4150-180 Porto, Portugal; and Escola Superior de Biotecnologia do Porto, Universidade Católica Portuguesa, Rua Dr. António Bernardino de Almeida, 4200-072 Porto, Portugal

Maria Helena Gomes

Escola Superior de Biotecnologia do Porto, Universidade Católica Portuguesa, Rua Dr. António Bernardino de Almeida, 4200-072 Porto, Portugal

Additional index words. Actinidia deliciosa, fruit quality, sensory analysis, texture

***Abstract*. 'Hayward' kiwifruit were treated with 0.5 μL·L^{-1} of 1-methylcyclopropene (1-MCP) and stored in air at 0 °C. Treatment with 1-MCP reduced softening of kiwifruit during storage but did not affect soluble solids or titratable acidity. Sensory analyses were performed by a consumer panel and by trained panelists after 41, 77, and 161 days in storage. 1-MCP treatment negatively affected consumer preference, expressed as degree of liking. The trained panel clearly perceived 1-MCP-treated kiwifruit after 41 days in storage at 0 °C as more sour and firmer but less juicy, less sweet, and less flavorful than untreated fruit. After 161 days in storage, the perceived differences between 1-MCP-treated and untreated fruit had been reduced for sweetness and acidity, but the panel perceived 1-MCP-treated fruit as firmer and lagging behind in the ripening process. Altering the poststorage ripening rate, by placing 1-MCP-treated fruit at a higher temperature than untreated controls, allowed fruit to develop in such a way that a sensory panel was unable to distinguish between treatments. This result indicates that 1-MCP-treated fruit can be perceived by the consumer as similar to untreated fruit if adequately conditioned.**

Flesh softening is a major cause of deterioration in kiwifruit limiting storage life (MacRae and Redgwell, 1992) and affecting consumer acceptability (Stec et al., 1989). Kiwifruit firmness declines rapidly after harvest and is reduced to almost half of the initial value within 4 weeks of storage at 0 °C in air (Benge et al., 2000). Kiwifruit is particularly sensitive to ethylene, a hormone implicated in the softening process. Concentrations of ethylene as low as 0.005 to 0.01 μL·L^{-1} are sufficient to hasten kiwifruit softening and to limit its storage life and marketability (Crisosto et al., 2000).

The ethylene action inhibitor 1-methylcyclopropene (1-MCP) is an effective tool to reduce the negative effects of ethylene in fruits, vegetables, and ornamentals (Blankenship and Dole, 2003). Slower softening rates, higher acidity, and lower emission of flavor volatiles are general effects of 1-MCP observed in several fruit types (Blankenship and Dole, 2003; Watkins, 2006). Applied to kiwifruit immediately after harvest, 1-MCP reduces respiration rate, ethylene production, flesh softening, color development, and decay (Kim et al., 2001; Koukounaras and Sfakiotakis, 2007). 1-MCP has little or no effect on soluble solids content, but titratable acidity is generally higher in 1-MCP-treated kiwifruit (Koukounaras and Sfakiotakis, 2007). When applied to kiwifruit after a period (30 d) in cold storage, 1-MCP is also effective in reducing subsequent softening during shelf life at 20 °C (Boquete et al., 2004), but the treatment becomes less effective after longer periods in cold storage. For example, Kim et al. (2001) observed no reduction in softening during shelf life when kiwifruit were treated with 1-MCP after 32 d in cold storage.

Firmness is an important quality attribute by itself, and it also affects the perception of kiwifruit flavor (Stec et al., 1989). For this reason, technologies aiming at reducing the softening rate of kiwifruit should be evaluated for their effects on other sensory attributes. Despite its beneficial potential as a postharvest treatment to control excessive softening, it is not clear how 1-MCP affects the sensory properties of kiwifruit. Harker et al. (2008) reported that a consumer panel was unable to distinguish between 1-MCP-treated kiwifruit and untreated controls; however, the effects of 1-MCP on firmness are significant (Kim et al., 2001; Koukounaras and Sfakiotakis, 2007) and likely to interact with the perception of other attributes (Stec et al., 1989). In addition to the effect on firmness, 1-MCP affects other kiwifruit attributes with sensory implications: increased acidity, delayed color changes, and lack of aroma (Boquete et al., 2004; Koukounaras and Sfakiotakis, 2007).

The objectives of this study were to evaluate the effect of 1-MCP on some quality traits linked to sensory attributes of kiwifruit after storage periods ranging from short to long term and to assess whether 1-MCP-treated fruit can be conditioned to recover their sensory properties.

Materials and Methods

Plant material. 'Hayward' kiwifruit [*Actinidia deliciosa* (A. Chev.) C.F. Liang et A.R. Ferguson var. *deliciosa*] were harvested from a pergola-trained orchard located in Paços de Ferreira (long. 41°19′ N; lat. 8°23′ W; ≈320 m), northwestern Portugal. Fruit were harvested 159 d after petal fall with an average weight of 136 g, firmness of 65 N, 6.6% soluble solids content (SSC), and 1.87% titratable acidity (TA) expressed as malic acid. After harvest, fruit (≈100 kg) were sorted for uniform size and absence of defects and placed in plastic crates (≈10 kg per crate).

Treatment with 1-methylcyclopropene and storage conditions. Fruit were cooled to a pulp temperature of 1 °C before the application of 1-MCP treatments. Crates containing fruit were placed inside 200-L plastic buckets, airtight-sealed, and exposed to 0.5 μL·L^{-1} of 1-MCP (SmartFresh; Agrofresh, Inc., Springhouse, PA) for 12 h at 1 °C. The 1-MCP concentration was calculated from the concentration of a.i. in SmartFresh (0.14%) and released into the free space of the plastic bucket. After the treatment with 1-MCP, kiwifruit were stored at 0 °C and 90% to 95% relative humidity in a cold room with 1.5 μL·L^{-1} of ozone. Untreated control fruit were handled and stored in the same way, except that no 1-MCP was applied in the plastic bucket.

Physicochemical analyses. Flesh firmness, SSC, and TA were measured in 15 fruit at harvest, after 34, 69, and 160 d in storage at 0 °C, and after a 7-d shelf life at 20 °C after cold storage. Flesh firmness was measured on opposite sides of each fruit, after peel removal, using a digital firmness tester (Model 53205; TR di Turoni, Forli, Italy) mounted in a standard drill press and fitted with a 7.9-mm probe. Results are presented as the mean maximum force (F_{max}) required to penetrate fruit flesh by 8 mm. Juice was made from peeled fruit and filtered through a cellulose paper filter. SSC was measured in each juice sample using a digital refractometer (Model PR-100; Atago Co., Tokyo, Japan), and TA was determined by titration of 10 mL of juice with 0.1 N NaOH to pH 8.2 and expressed as percentage of malic acid. Weight loss was assessed by individually weighing 15 numbered fruit throughout the storage period.

Received for publication 22 June 2009. Accepted for publication 31 July 2009.
This work was supported by project no 518, Program Agro, Ministry of Agriculture, Portugal.
[1]To whom reprint requests should be addressed; e-mail dalmeida@fc.up.pt.

Table 1. Attributes used to describe kiwifruit sensory properties.

Attribute	Definition
Visual	
Color	Color of the surface of the transversal slice indicating the saturation of the flesh green color
Translucency	Watersoaking appearance of the slice
Odor	
Overall intensity	Odor intensity ranging from none to strong
Ripe	Aroma associated with ripe kiwifruit
Taste	
Sweetness	Taste sensation characteristic of sucrose
Sourness	Taste sensation typified by citric acid
Bitterness	Taste sensation characteristic caffeine
Flavor	
Intensity	Flavor intensity ranging from low to intense
Ripe	Flavor characteristic of ripe kiwifruit
Texture	
Consistency of pericarp	Pericarp resistance to chewing
Consistency of columella	Resistance to chewing offered by columella
Juiciness	Perception of juice release during chewing ranging from dry to very juicy

Sensory evaluation. A 10-member permanent panel trained in sensory analyses of foodstuffs was given kiwifruit samples with maturity stages ranging from green to overripe. The panel was asked to generate a descriptive language to evaluate kiwifruit at different ripening stages and agreed on 13 descriptors classified in five groups (Table 1).

The 10-member trained panel assessed fruit visual properties, odor, flavor, and textural attributes as described in Table 1. Panelists were asked to classify the descriptors using a 0 to 7 scale as follows: 1 = color ranging from pale green to dark green; 2 = translucency from opaque to watersoaked; 3 = odor intensity varying from none to strong; 4 = aroma associated with immature to overripe kiwifruit; 5 = flavor intensity ranging from weak to strong; 6 = flavor characteristic of immature and overripe kiwifruit; 7 = sweetness and 8 = sourness ranging from weak to strong; 9 = consistency of columella and 10 = pericarp ranging from very hard to very soft; 11 = juiciness and 12 = bitterness changing from low to high. No off-odors were reported by the panel.

In addition, consumer panels made up of 60 untrained Portuguese kiwifruit consumers, with the demographics and consumption habits summarized in Table 2, were asked to assess the samples. Each consumer tasted a sample of untreated control fruit and 1-MCP-treated fruit and was asked to answer the question "What is your opinion of the overall acceptability of this kiwifruit?" using the 9-point hedonic category scale, in which 1 = dislike extremely, 3 = dislike, 5 = neither like or dislike, 7 = like, and 9 = like extremely (Wismer et al., 2005).

Sensory analyses were performed in fruit removed from cold storage after 41, 77, or 161 d and subsequently allowed to soften at 20 °C to an edible texture. Kiwifruit were peeled and transversely sliced just before evaluation. Three slices from each sample were randomly presented to the panel members on individual coded plates. The analyses were performed in a sensory testing room equipped with individual booths, white tables, and controlled cool white fluorescent light according to the standard ISO 8589 (1988). A sample of the slices provided to the panelists was analyzed for firmness, SSC, acidity, and pH using the procedures described previously.

Fruit conditioning. After 77 d in storage at 0 °C, fruit were transferred to higher temperature. Untreated control fruit were maintained at 5 °C and 1-MCP-treated fruit were kept at 23 °C to alter their poststorage ripening rates. Fruit firmness, SSC, TA, and pH were measured as described previously. After a conditioning period of 7 d, the physicochemical properties were considered to be very similar in 1-MCP-treated and untreated samples. Fruit were then prepared and supplied to the consumer and trained panels, as described previously.

Table 2. Demographic characterization of the consumer panel (n = 60).

Demographic variable	Percentage of total
Gender	
Male	42
Female	58
Age	
18–24	58
25–34	27
35–44	12
45–54	3
Kiwifruit consumption	
Once a month	34
Once a week	45
More than once a week	22

Statistical analysis. Fruit were stored in completely randomized blocks (plastic crates) with two levels of 1-MCP treatment (0 and 0.5 $\mu L \cdot L^{-1}$). Physicochemical data at each sampling date were subjected to analysis of variance (ANOVA) according to a completely randomized design with 15 replicates of individual fruits. Data resulting from sensory evaluation were subjected to two-way ANOVA (Carpenter et al., 2000). Sources of variation were 1-MCP treatment (fixed factor with two levels) and panelists (random factor with 10 or 60).

Results and Discussion

Effect of 1-methylcyclopropene on physicochemical characteristics of kiwifruit. It was observed in a preliminary experiment that kiwifruit treated with 1-MCP at 0.5 and 1.0 $\mu L \cdot L^{-1}$ softened at the same rate during storage (not shown). Therefore, only the smaller dose of 1-MCP was used in the experiment reported here. Treatment with

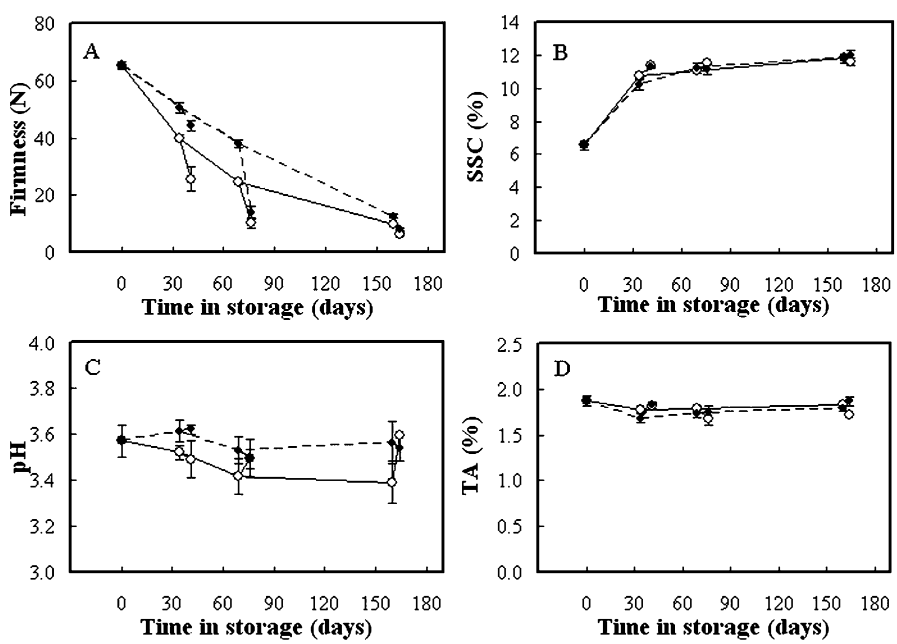

Fig. 1. Physicochemical properties of kiwifruit treated with 1-methylcyclopropene (dashed line, solid circle) and untreated controls (solid line, open circle) during storage at 0 °C and after a 7-d shelf life at 20 °C. Firmness (**A**), soluble solids content (**B**), juice pH (**C**), and titratable acidity (**D**). Values are means ± SE (n = 15).

Table 3. Mean physicochemical characteristics of kiwifruit samples provided to the panels for sensory analyses.

	Storage duration (d)					
	41		77		161	
Variable	Control	1-MCP	Control	1-MCP	Control	1-MCP
Firmness (N)	21.9^z b	43.5 a	11.8 b	19.5 a	8.0 b	9.7 a
Soluble solids content (%)	11.4 a	11.2 b	11.5 a	11.2 b	11.6 a	11.2 b
Acidity (%)	1.9	1.8	1.5	1.5	1.7	1.7
pH	3.5	3.7	3.4 b	3.5 a	3.4	3.6

^{z}Values are means, n = 15. Values followed by a common letter, within each sampling date, are not significantly different ($P \leq 0.05$).
1-MCP = 1-Methylcyclopropene.

Table 4. Mean sensory score recorded by the consumer panel.

	Storage duration (d)		
Treatment	41	77	161
Control	6.8^z a	6.3 a	7.1 a
1-Methylcyclopropene	5.7 b	5.8 b	6.5 b

^{z}Values are means, n = 60. Values followed by a common letter, within a column, are not significantly different ($P \leq 0.05$).

1-MCP affected kiwifruit firmness throughout the storage period (Fig. 1A). Untreated fruit harvested with a flesh firmness of 65 N softened during the first 4 weeks at 0 °C at an average rate of 0.75 $N \cdot d^{-1}$, whereas the treatment with 1-MCP reduced the softening rate during the same period to 0.44 $N \cdot d^{-1}$. Significant differences in firmness remained throughout storage, but the absolute difference in firmness was small after 160 d in storage as a result of the reduction of softening rate of untreated fruit toward the end of the storage period. The firmness differences were not related to water loss; weight loss during the storage period was similar in 1-MCP-treated and untreated fruit, 0.06%/d. Softening rate increased on removal of fruit from cold storage to 20 °C. Although at the end of the first month in storage 1-MCP affected the softening rate at 20 °C, the effect of 1-MCP on poststorage softening at 20 °C had disappeared after 69 d in storage (Fig. 1A). SSC was unaffected by 1-MCP treatment, increasing by ≈60% during the first 4 weeks in storage and subsequently increasing slightly during the remaining storage period (Fig. 1B). pH and TA were unaffected by 1-MCP and showed little variation during storage or subsequent shelf life (Fig. 1C–D). Treatment with 1-MCP had no effect on weight loss (not shown). The effect of 1-MCP on softening rate reported here is generally consistent with the results published elsewhere (Koukounaras and Sfakiotakis, 2007; Watkins, 2006, 2008), although higher acidity (Koukounaras and Sfakiotakis, 2007) and delayed increase in SSC (Boquete et al., 2004) have been observed in kiwifruit treated with 1-MCP. Ozone is used in kiwifruit storage to reduce postharvest decay and oxidize atmospheric ethylene (Dickson et al., 1992). 1-MCP was effective under the experimental conditions used despite the potential ozonolysis of ethylene present in the atmosphere of the refrigerated room, indicating that protection from endogenous ethylene by 1-MCP has considerable benefit.

Because 1-MCP was effective in reducing kiwifruit softening during storage, it remained to be determined whether the differences in texture could be perceived by consumers and whether 1-MCP affected other sensory attributes of the fruit. Although sugars and acids were unaffected by 1-MCP (Figs. 1B and D), ethylene is indispensable for the development of the aroma volatiles in several fruit (Zhu et al., 2005) and likely to affect the volatile profile of kiwifruit.

Sensory analyses were performed on kiwifruit after short (41 d), intermediate (77 d), and long-term storage (161 d). The fruit samples provided to the panelists had the physicochemical characteristics indicated in Table 3. 1-MCP-treated samples were firmer and had slightly lower SSC than untreated controls; acidity and juice pH were generally unaffected by the treatment with 1-MCP.

Consumer evaluation. Consumers considered the fruit acceptable (score greater than 5.0) at every sampling date (Table 4). Consumer preference, expressed as degree of liking, was affected by 1-MCP treatment. When asked to evaluate the kiwifruit samples, consumers preferred untreated fruit in

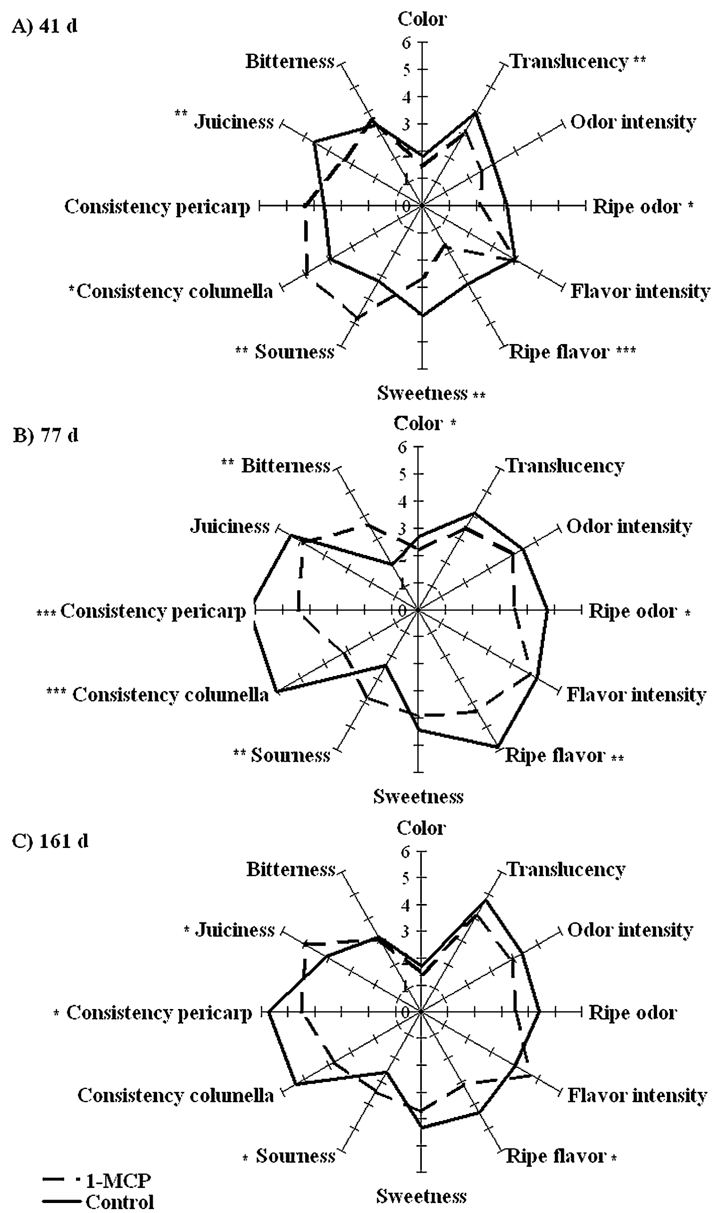

Fig. 2. Effect of 1-methylcyclopropene on sensory profiles of kiwifruit tasted after 41 (**A**), 77 (**B**), and 161 (**C**) d in storage. Values are mean scores recorded by the trained panel (n = 10). *, **, ***, Significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

every sampling date (Table 4). These results contrast with those reported by Harker et al. (2008) who observed no effect of 1-MCP treatment on consumer liking of 'Hayward' kiwifruit.

Consumer preference of ripe kiwifruit depends largely on SSC, TA, firmness, and volatile production (Burdon et al., 2004; Crisosto and Crisosto, 2001; Jaeger et al., 2003; Rossiter et al., 2000). Although consumers in different parts of the world may differ in their preferences, data from Japanese and Californian consumer studies suggests that ripe 'Hayward' kiwifruit with less than 11.0% SSC have a poor flavor and generally the degree of liking increases with SSC (Burdon et al., 2004; Crisosto and Crisosto, 2001). According to this referential, the fruit sampled by consumers in this study had a SSC in the lower limit of acceptability. Titratable acidity is a determinant for consumer acceptance when the fruit SSC is low (Crisosto and Crisosto, 2001). According to their average physicochemical parameters (Table 3), the fruit supplied to consumers in the first sampling date can be regarded as "green," firm, and with a lower sugar/acid ratio than fruit stored for longer periods. Consumer preference for untreated fruit (after 44 and 77 d in cold storage) is likely explained by their softer texture. After 161 d in storage, although the 1-MCP-treated fruit remained firmer than the untreated controls, both have firmness values within the optimal range for consumption. In the fruit stored during long term, it is likely that the higher sugar/acid ratio and possibly aroma volatiles are affecting consumer preference (Burdon et al., 2004; Crisosto and Crisosto, 2001; Jaeger et al., 2003; Rossiter et al., 2000).

Effect of 1-methylcyclopropene on sensory profiles. The trained panel was asked to evaluate the effect of 1-MCP on the sensory profile of kiwifruit considering the previously established descriptors (Table 1). The panel detected differences in a number of attributes of fruit removed from storage in the three dates. After short-term (41 d) storage, untreated control kiwifruit were perceived as more translucent with odor and taste closer to that of ripe fruit, sweeter, less sour, juicier, and with a softer core than 1-MCP-treated fruits (Fig. 2A). Untreated fruit stored for 77 d and ripened to an edible texture were described by the trained panel as less bitter and sour, firmer, and more ripe-flavored that 1-MCP-treated fruit (Fig. 2B). The panel also considered the color of untreated fruit more saturated than that of 1-MCP fruit (Fig. 2B). Differences ($P < 0.05$) between control and 1-MCP-treated fruit were detected in ripe taste, sourness, pericarp consistency, and juiciness after 161 d of storage (Fig. 2C).

Ripe flavor and sourness were the only attributes that were considered significantly affected by 1-MCP throughout the storage period. Oddly, both the pericarp and core of untreated fruit were perceived as firmer than in 1-MCP-treated fruit after 77 d in storage (Fig. 2B) in contrast with the physical measurement of firmness (Table 3). The same assessment applied to the pericarp firmness after 161 d (Fig. 2C). The difference in pericarp firmness between treated and untreated fruit was 7.8 N and 1.7 N after 77 and 161 d in storage, respectively. These differences are small enough to be undetected by trained panelists in a crispy fruit like apple (Harker et al., 2002), but it is not clear why the panelists perceived the softer kiwifruit as more consistent. Conventional firmness measurements in kiwifruit probe the outer pericarp. Although the distinct edible parts of kiwifruit—outer and inner pericarp and columella—seem to soften at similar rates as to maintain relative differences in firmness (Jackson and Harker, 1997; White et al., 2005), it is not known whether 1-MCP differentially alters the relative softening rate of kiwifruit tissue zones. Other possible explanations for the disagreement between sensory and instrumental firmness assessments include the variability among individual fruit, variability between the region probed by the penetrometer and the region sampled by the panelist, and the range of sensory acuity of individual panelists (Harker et al., 2002). Nonetheless, statistical analysis revealed that the effect of panelist on core and pericarp consistency was nonsignificant.

Uncoupling the effects of 1-methylcyclopropene and ripening stage. Inhibition of ethylene action by 1-MCP differentially affects several features of the ripening syndrome. In kiwifruit, 1-MCP exerts a stronger effect on texture than on acidity and color and little or no effect on SSC (Fig. 1; Boquete et al., 2004; Koukounaras and Sfakiotakis, 2007). Moreover, the effect of 1-MCP is transient and the treated fruit resume normal ripening after a period of time. Whenever 1-MCP-treated fruit are compared with untreated controls, a question arises regarding data interpretation with implications on the practical use of the conclusions: are the observed effects the result of 1-MCP per se (i.e., resulting from irreversible effects of the molecule) or can they be totally explained by differences in the ripening stages being compared?

In an attempt to answer this question, fruit were removed from storage after 77 d and kept at 5 or 23 °C to alter their poststorage ripening rate. Fruit with the average physicochemical characteristics indicated in Table 5 were supplied to the consumer and trained panels. Consumers evaluated both samples with an average score of 6.4 and the trained panel generated the sensory profile in Figure 3. By hastening the ripening rate of 1-MCP-treated fruit maintained at 23 °C in relation to that of untreated controls maintained at 5 °C, it was possible to demonstrate that consumers or a trained sensory panel were unable to distinguish 1-MCP treated from untreated fruit. This result indicates that differences in the sensory evaluation of kiwifruit treated with 1-MCP at harvest are only the result of the comparison of different maturity stages. 1-MCP-treated fruit need to be conditioned differently to be perceived by the consumer in the same way as an untreated fruit.

In conclusion, 0.5 $\mu L \cdot L^{-1}$ 1-MCP is effective in reducing the softening rate of kiwifruit, particularly in the first 2 to 3 months in storage and can be an important tool in storage facilities without ethylene-removal systems. Treatment with 1-MCP may negatively impact the perception of kiwifruit when treated and untreated fruit are compared after the same conditioning period. However, 1-MCP-treated fruit conditioned in a way that hastens the ripening process are perceived as indistinct from untreated fruit, indicating that consumers are responding to differences in ripening stage.

Table 5. Physicochemical properties of kiwifruit samples provided to the panelists for sensory analysis after 77 d in storage at 0 °C and subsequent ripening for 7 d at 5 (untreated fruit) or 23 °C (1-MCP-treated fruit).

Variable	Control at 5 °C	1-MCP at 23 °C
Firmness (N)	11.8[z] b	14.3 a
Soluble solids content (%)	11.5	11.7
Acidity (%)	1.5	1.5
pH	3.4	3.4

[z]Values are means, n = 15. Values followed by a common letter, within a line, are not significantly different ($P \leq 0.05$).
1-MCP = 1-Methylcyclopropene.

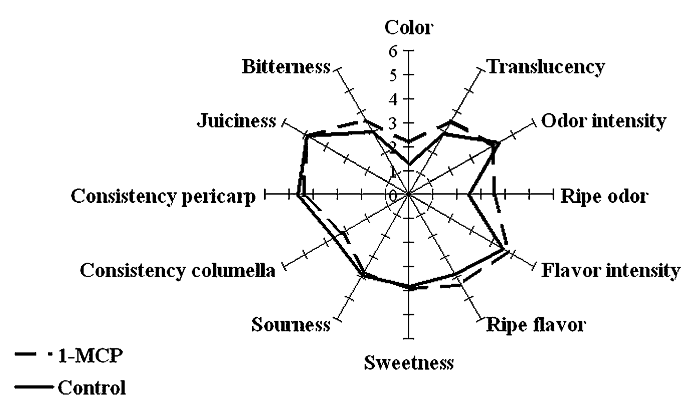

Fig. 3. Sensory profile of kiwifruit treated with 1-methylcyclopropene and conditioned at 23 °C for 7 d compared with untreated control fruits conditioned at 5 °C for the same period of time. Values are mean scores recorded by the trained panel (n = 10).

Literature Cited

Benge, J.R., H.N. De Silva, N.H. Banks, and P.B. Jeffery. 2000. Empirical modelling of postharvest changes in the firmness of kiwifruit. Postharvest Biol. Technol. 19:211–220.

Blankenship, S.M. and J.M. Dole. 2003. 1-Methylcyclopropene: A review. Postharvest Biol. Technol. 28:1–25.

Boquete, E.J., G.D. Trinchero, A.A. Fraschina, F. Vilella, and G.O. Sozzi. 2004. Ripening of 'Hayward' kiwifruit treated with 1-methylcyclopropene after cold storage. Postharvest Biol. Technol. 32:57–65.

Burdon, J., D. McLeod, N. Lallu, J. Gamble, M. Petley, and A. Gunson. 2004. Consumer evaluation of 'Hayward' kiwifruit of different at-harvest dry matter contents. Postharvest Biol. Technol. 34:245–255.

Carpenter, R.P., D.H. Lyon, and T.A. Hasdell. 2000. Guidelines for sensory analysis in food product development and quality control. Aspen Publishers, Gaithersburg, MD.

Crisosto, C.H. and G.M. Crisosto. 2001. Understanding consumer acceptance of early harvested 'Hayward' kiwifruit. Postharvest Biol. Technol. 22:205–213.

Crisosto, C.H., E.J. Mitcham, and A.A. Kader. 2000. Produce facts: Kiwifruit. Management of fruit ripening. Postharvest Hortic. Ser. 9:40–41.

Dickson, R.G., S.E. Law, S.J. Kays, and M.A. Eiteman. 1992. Abatement of ethylene by ozone treatment in controlled atmosphere storage of fruits and vegetables. Proc. International Winter Meeting, Amer. Soc. Agr. Eng. p. 1–9.

Harker, F.R., R.L. Amos, A. White, M.B. Petley, and M. Wohlers. 2008. Flavor differences in heterogeneous foods can be detected using repeated measures of consumer preferences. J. Sens. Stud. 23:52–64.

Harker, F.R., J. Maindonald, S.H. Murray, F.A. Gunson, I.C. Hallett, and S.B. Walker. 2002. Sensory interpretation of instrumental measurements 1: Texture of apple fruit. Postharvest Biol. Technol. 24:225–239.

ISO 8589. 1988. Sensory analysis—General guidance for the design of test rooms. International Organization for Standardization, Geneva, Switzerland.

Jackson, P.J. and F.R. Harker. 1997. Changes in firmness of the outer pericarp, inner pericarp, and core of *Actinidia* species during ripening. N. Z. J. Crop Hortic. Sci. 25:185–189.

Jaeger, S.R., K.L. Rossiter, W.V. Wismer, and F.R. Harker. 2003. Consumer-driven product development in the kiwifruit industry. Food Qual. Prefer. 14:187–198.

Kim, H.O., E.W. Hewett, and N. Lallu. 2001. Softening and ethylene production of kiwifruit reduced with 1-methylcyclopropene. Acta Hort. 553:167–170.

Koukounaras, A. and E. Sfakiotakis. 2007. Effect of 1-MCP prestorage treatment on ethylene and CO_2 production and quality of 'Hayward' kiwifruit during shelf-life after short, medium and long term cold storage. Postharvest Biol. Technol. 46:174–180.

MacRae, E. and R. Redgwell. 1992. Softening in kiwifruit. Postharvest News Inform. 3:49N–52N.

Rossiter, K.L., H. Young, S.B. Walker, M. Miller, and D.M. Dawson. 2000. The effects of sugars and acids on consumer acceptability of kiwifruit. J. Sens. Stud. 15:241–250.

Stec, M.G.H., J.A. Hodgson, E.A. MacRae, and C.M. Triggs. 1989. Role of fruit firmness in the sensory evaluation of kiwifruit (*Actinidia deliciosa* cv Hayward). J. Sci. Food Agr. 47:417–433.

Watkins, C.B. 2006. The use of 1-methylcyclopropene (1-MCP) on fruits and vegetables. Biotechnol. Adv. 24:389–409.

Watkins, C.B. 2008. Overview of 1-methylcyclopropene trials and uses for edible horticultural crops. HortScience 43:86–94.

White, A., H.N. Silva, C. Requejo-Tapia, and F.R. Harker. 2005. Evaluation of softening characteristics of fruit from 14 species of *Actinidia*. Postharvest Biol. Technol. 35:143–151.

Wismer, W.V., F.R. Harker, F.A. Gunson, K.L. Rossiter, K. Lau, A.G. Seal, R.G. Lowe, and R. Beatson. 2005. Identifying flavour targets for fruit breeding: A kiwifruit example. Euphytica 141:93–104.

Zhu, H.L., B.Z. Zhu, D.Q. Fu, Y.H. Xie, Y.L. Hao, and Y.B. Luo. 2005. Role of ethylene in the biosynthetic pathways of aroma volatiles in ripening fruit. Rus. J. Plant Physiol. 52:691–695.