AGREEMENT INIFAP-NMB

EFFECTIVENESS OF AQUEOUS 1-METHYLCYCLOPROPENE (1-MCP) ON MANGO FRUIT WITH AND WITHOUT QUARANTINE HOT WATER TREATMENT

JORGE A. OSUNA GARCIA, Ph. D.

POSTHARVEST AND FOOD SAFETY RESEARCHER

INIFAP-SANTIAGO IXCUINTLA EXPERIMENTAL STATION

Santiago Ixcuintla, Nayarit, Mexico. March, 2015.

ABSTRACT

One of the major challenges to overcome in most exporting countries to the USA, with the exception of Mexico, is that they require up to four weeks of refrigerated transport in sea containers, leading to over ripe fruit since refrigeration per se is not enough to delay the ripening process. Gaseous 1-methylcyclopropene (1-MCP) delays mango fruit ripening, but requires 12 hours of application in sealed containers. An aqueous formulation applied as a postharvest dip for only 1 to 5 minutes has shown the same effectiveness as gaseous 1-MCP. This research was conducted to determine the effectiveness of aqueous 1-MCP on delay of the ripening process, extension of shelf-life, and maintenance of fruit quality of 'Ataulfo', 'Tommy Atkins', 'Haden', 'Kent', and 'Keitt' mango fruit with or without Quarantine Hot Water Treatment (QHWT). Two experiments were conducted during the 2013 and 2014 seasons in Nayarit. Differences among varieties in response to aqueous 1-MCP were detected. 'Ataulfo', 'Tommy Atkins', and 'Haden' didn't show any significant difference for all variables except for external appearance. 'Kent' and 'Keitt' retained longer firmness during shipping simulation; however, the external appearance was negatively affected for the 1-MCP in combination with the QHWT in the five varieties, showing surface spots and lenticel blackening. At the end of shipping simulation or at consumption stage fruit treated with 1-MCP before or after QHWT showed fair to poor external appearance while the absolute control (No 1-MCP; No QHWT) or the 1-MCP control (1-MCP without QHWT) had an excellent to good external appearance. Aqueous 1-MCP had a good performance in 'Kent' and 'Keitt' fruit since caused delay of fruit ripening as shown by maintenance of fruit firmness, attenuation of pulp color development, and delayed increase of total soluble solids. However, it had a negative interaction with QHWT, causing surface spots and lenticel blackening to develop during shipping simulation (3 weeks at 12 ± 1 °C; 90 ± 5 % RH) and final ripening (7 days at 22 ± 2 ºC; 75 ± 10 % RH). It seems that 1-MCP is not a good alternative for mangos exported to the USA, but may be most useful for mango markets that do not require mandatory QHWT.

BACKGROUND

Mango is one of the favorite fruits in the US market, where consumption has doubled in the past 10 years. During the last three years (2009-2011) on average 71.7 million 10-pound boxes have been imported; mainly from Mexico (65.1 %), Peru (9.7 %), Ecuador (9.4 %), Brazil (7.4 %), Guatemala (4.6 %), and Haiti (2.5 %) [USDA-FAS, 2012]. However, most of the time the quality of mango fruit at the consumer level is compromised, since exporter countries face several challenges in delivering high quality fruit (Brecht *et al*., 2009). One of the major challenges to overcome in most exporting countries to the USA, with the exception of Mexico, is that they require up to four weeks of refrigerated transport in sea containers, leading to over ripe fruit since refrigeration per se is not enough to delay the ripening process. In addition, the problem becomes worse because often packers harvest immature fruit, leading to hot water and chilling injury, since immature mango fruit is more susceptible to both those disorders. Immature harvesting also prevents the fruit from realizing its full flavor potential at consumption time.

There are several techniques other than early harvesting that may be used to delay ripening, extend shelf life, and maintain fruit quality. Recently a new tool, 1-Methylcyclopropene (1-MCP) has been added to these techniques. 1-MCP is a potent ethylene inhibitor that binds to ethylene receptors, blocking its action (Sisler and Serek, 1997, 1999). Since the approval of 1-MCP for use in edible produce (EPA, 2002), extensive research has been performed. Blankenship and Dole (2003) described over 100 studies detailing 1-MCP action, its application, and effects on ethylene inhibition. They stated that 1-MCP prevents ethylene effects in several fruits, vegetables, and flowers; making it important not only for commercial purposes but also in helping scientists to further understand the role of ethylene in plants. In fact, Huber (2008) found that 1-MCP is an effective tool for understanding the role of ethylene in senescence and ripening processes, especially for climacteric fruits like mango. Also, Watkins and Miller (2005) summarized the effects of 1-MCP on physiological processes or disorders in fruits, vegetables, and ornamental products while Watkins (2006, 2008), pointed out that 1-MCP influences ripening and senescence of several fruits and vegetables by reducing ethylene production and respiration, affecting mainly softening and color changes.

The beneficial effect of 1-MCP has been proven for several mango varieties like ‘Zihua’ (Jiang and Joyce, 2000), ‘Kensington Pride’ (Hofman *et al*., 2001), ‘Keitt’ (Osuna-

García and Beltran, 2002; Osuna-García, 2006), 'Rosa', 'Espada' and 'Jasmim' (Silva *et al*., 2004), 'Kent' (Osuna and Beltran, 2004; Osuna-García and Muñoz-Ramírez, 2004; Osuna-García *et al*., 2005; Osuna-García *et al*., 2009), 'Tommy Atkins' (Alves *et al*., 2004; Coelho de Lima *et al*., 2006; Pereira-Bomfim *et al*., 2011), 'Nam Dokmai' (Penchaiya *et al*., 2006) and 'Namh-dawg-mai-sri-tong' (Chaiprasart and Hansawasdi, 2009). Most experiments used gaseous 1-MCP in sealed chambers with doses ranging from 100 to 1200 ppb applied for 12 or 24 h at room temperature (22-25 °C) or while cooling the fruit at 12 °C. In general, results showed that 1-MCP delayed the climacteric peak and decreased ethylene production, maintained pulp firmness longer, and delayed ripening related color changes.

In spite of the outstanding results, the adoption of 1-MCP at the commercial level has been very limited mainly due to the difficulty of its application. In addition, as suggested by research with other commodities, 1-MCP effectiveness could be affected by several factors such as the quarantine hot water treatment (QHWT). Osuna-García *et al*. (2007) evaluated the effect of 1-MCP (0 and 300 ppb) applied after different levels of hot water treatment (Control, 52 °C for 5 min and 46.1 °C for 110 min) on the physiology and quality of 'Keitt' mangos. They found the effectiveness of 1-MCP was greatly affected by the extent of hot water treatment. 1-MCP treated fruit without hot water treatment by the end of shipping simulation (20 days at 13 $\pm$ 2 ºC; 85 $\pm$ 10 % RH) kept 80 % of their initial pulp firmness; those heat-treated at 52 °C for 5 min kept only 50 % firmness, whereas those treated at 46 °C for 110 min (the insect quarantine treatment) had firmness levels that were almost the same as control fruit, since they kept only 10 % of their initial pulp firmness.

Recently, an aqueous 1-MCP formulation of greater potency has been developed, allowing more flexibility for its application. Initially, the aqueous solution was intended for preharvest application, but when applied as a postharvest dip for only one to five minutes, it has shown the same effectiveness as a 9 to 12 h application of gaseous 1-MCP, delaying the ripening and softening process in mango, avocado, tomato, carambola, and pear fruits (Contreras-Martínez *et al*., 2007; Choi *et al*., 2008; Choi and Huber, 2008; Warren, 2009; Cheng *et al*., 2012). This new formulation could be much more easily incorporated into the mango packinghouse processes than gaseous 1-MCP application, either right after washing the fruit or following the hot water treatment. If we test both scenarios, we can find out what is the most suitable step to apply aqueous 1-

MCP successfully and provide the mango industry with a powerful tool to allow harvest of fully mature fruit and subsequently delay ripening, extend shelf life, and maintain fruit quality.

OBJECTIVES

- To determine the effectiveness of aqueous 1-MCP on mango fruit with or without QHWT.
- To determine the best step during the mango packing process to apply aqueous 1-MCP.
- To evaluate the effect of aqueous 1-MCP on ripening process, extension of shelf life and keeping fruit quality of several mango varieties.

METHODOLOGY (2013 SEASON)

1. **Dose of 1-MCP:** 625 µg L^{-1}
2. **Times for 1-MCP application:** (Before and after QHWT).
3. **Design:** Completely random
4. **Treatments:**
    a. Absolute control (Without QHWT; without 1-MCP)
    b. Control 1-MCP (1-MCP applied to fruit without QHWT)
    c. Control hydrothermal (only QHWT)
    d. 1-MCP before QHWT without hydrocooling
    e. 1-MCP after QHWT without hydrocooling
    f. 1-MCP after QHWT + hydrocooling
5. **Varieties: '**Ataulfo', 'Tommy Atkins', 'Kent', 'Haden' and 'Keitt'

Variety	Origen	Harvest	Treatment	QHWT	Packinghouse
Ataulfo	Las Varas, Nay	03/Jun/13	04/Jun/13	75 + 10'	NATURAMEX
Tommy	La Libertad, Nay	04/Jun/13	05/Jun/13	90 + 10'	ALEX
Haden	La Libertad, Nay	11/Jun/13	12/Jun/13	75 + 10'	HUGUIN
Kent	Pta Mangos, Nay	08/Jul/13	09/Jul/13	90 + 10'	ALEX
Keitt	Sauta, Nay	11/Jul/13	11/Jul/13	90 + 10'	HUGUIN

6. **Ripening stage:** Physiologically mature fruit

7. **Times for QHWT:** According to weight fruit and protocol USDA-APHIS: Ataulfo and Haden (75 min); Tommy Atkins, Kent and Keitt (90 min) + 10 additional minutes since at the end of QHWT hydrocooling for 20 minutes was applied in all varieties

a. **Storage:** Simulation of refrigerated shipment (Three weeks at 12 ± 1 °C; 90 ± 5 % RH) + Market simulation (22 ± 2 °C; 75 ± 10 %RH) until consumption stage.

b. **Sampling:** Initial, at the end of refrigerated period and then at day 4^{th} and 7^{th} of market simulation.

8. **Variables to measure:** Dry matter, weight loss, external appearance, skin color, firmness, pulp color, total soluble solids (°Bx), and tritatable acidity.

Detailed description of methodology

For each variety in particular, 70 fruit per treatment (2 boxes with 35 fruit each) were selected considering only physiologically mature fruit with excellent external appearance and free of mechanical injury and/or pests and diseases. Fruit were collected after the washing and selection process in the packinghouse, prior to QHWT, and subjected to the following treatments: 1) Absolute control (without QHWT, without 1-MCP); 2) 1-MCP control (1-MCP applied to fruit without QHWT); 3) Hydrothermal control (only QHWT without hydrocooling); 4) 1-MCP before QHWT without hydrocooling; 5) 1-MCP after QHWT without hydrocooling, and 6) 1-MCP after QHWT + hydrocooling. The aqueous 1-MCP (AFxRD-038; 3.8 % 1-MCP, ≤ 5 % dextrose, 88-95 % ciclodextrine and 1-5 % inert material) treatment was conducted as a separate step using a tap water solution of 1-MCP at 625 µg L^{-1} a.i. by dipping the fruit for 5 min for all treatments containing 1-MCP. The QHWT was immersion in 46.1 °C water for 90 minutes and the hydrocooling immersion in 21-23 °C water for 30 minutes; both treatments were conducted in a commercial facility operating under APHIS-USDA regulations. After that, fruit were refrigerated (12 ± 1 ºC; 90 ± 5 % RH) for 3 weeks and then transferred to market simulation conditions (22 ± 2 ºC; 75 ± 10 % RH) until full ripeness. Sampling was done at the beginning and at the end of refrigerated storage, and on days 4^{th} and 7^{th} of market simulation. A completely randomized design was used with 20 single-fruit replications for weight loss and eight for other variables. Analysis was done individually for each variety.

METHODOLOGY (2014 SEASON)

1. **1-MCP doses:** 0, 400, 800 y 1200 µg L^{-1}.
2. **Method and time of 1-MCP application:** By immersion for 3 min before QHWT.
3. **Design:** Factorial with Factor A with or without QHWT, and Factor B with the four 1-MCP doses.
4. **Treatments:**
    a. Absolute control (without QHWT; without 1-MCP)
    b. 1-MCP at 400 µg L^{-1} for 3 min without QHWT
    c. 1-MCP at 800 µg L^{-1} for 3 min without QHWT
    d. 1-MCP at 1200 µg L^{-1} for 3 min without QHWT
    e. Hydrothermal control (with QHWT; without 1-MCP)
    f. 1-MCP at 400 µg L^{-1} for 3 min with QHWT
    g. 1-MCP at 800 µg L^{-1} for 3 min with QHWT
    h. 1-MCP at 1200 µg L^{-1} for 3 min with QHWT
5. **Varieties: '**Ataulfo', 'Tommy Atkins', 'Kent', y 'Keitt'

Variety	Origen	Harvest	Treatment	QHWT	Packinghouse
Ataulfo	El Zopilote, Nay	26/May/14	27/May/14	75 + 10'	NATURAMEX
Tommy	Nva. Italia Mich.	26/Abr/14	28/Abr/14	90 + 10'	ALEX
Kent	Tierra Generosa, Nay	25/Jun/14	26/Jun/14	90 + 10'	ALEX
Keitt	Culiacan Sin.	21/Jul/14	22/Jul/14	90 + 10'	ALEX

6. **Ripening stage:** Physiological ripe fruit.
7. **Time for QHWT:** According to USDA-APHIS protocol: Ataulfo (75 min); Tommy Atkins, Kent and Keitt (90 min) with 10 additional min for hydrocooling just after QHWT.
8. **Storage:** Three weeks in refrigeration (12 ± 1 °C; 90 ± 5 % RH) + Marketing simulation (22 ± 2 °C; 75 ± 10 % RH) until full ripeness.
9. **Sampling:** Sampling was done at the beginning and at the end of refrigerated storage, and on days 4 and 7 of market simulation.
10. **Variables to measure:** Dry matter, weight loss, external appearance rating**,** fruit firmness, pulp color, total soluble solids, and tritatable acidity

Detailed description of the methodology

For each variety in particular, 40 physiologically mature fruit were selected in a commercial packinghouse after the washing process and classified for 90 min of QHWT. Fruit had uniform size, good external appearance, and were freedom from mechanical damage, pests, and diseases. The fruit were divided into two groups, a) fruit with QHWT + hydrocooling, and b) fruit without QHWT or hydrocooling. Fruit received the following treatments: 1) Absolute control (without 1-MCP, without QHWT); 2) 1-MCP at 400 µg L^{-1} without QHWT; 3) 1-MCP at 800 µg L^{-1} without QHWT; 4) 1-MCP at 1,200 µg L^{-1} without QHWT; 5) Hydrothermal control (without 1-MCP, with QHWT); 6) 1-MCP at 400 µg L^{-1} with QHWT; 7) 1-MCP at 800 µg L^{-1} with QHWT; and 8) 1-MCP at 1,200 µg L^{-1} with QHWT. The 1-MCP was applied before QHWT by dipping the fruit in tap water with appropriate 1-MCP concentrations for 3 min. The fruit receiving QHWT were exposed to 46.1 °C water for 90 min + hydrocooling in 21-23 °C water for 30 min while those without QHWT were kept at ambient conditions. Both fruit sets were then refrigerated (12 ± 1 ºC; 90 ± 5 % RH) for 3 weeks and then transferred to market simulation conditions (22 ± 2 ºC; 75 ± 10 % RH) until full ripeness. Sampling was done at the beginning and at the end of refrigerated storage, and then on days 4 and 7 of market simulation. A factorial design was used considering Factor A (with or without QHWT), and Factor B (1-MCP doses at 0, 400, 800, and 1,200 µg L^{-1}) with 10 single-fruit replications for weight loss and five for other variables.

RESULTS AND DISCUSSION

I. 2013 SEASON.

I.1. ATAULFO VARIETY.

In Table 1 it is consigned the analysis of variance for the effect of aqueous 1-MCP treatments on the main quality variables of 'Ataulfo'. It was observed that the effect of aqueous 1-MCP was only the fruit external appearance, and no significant differences were detected for any other variables.

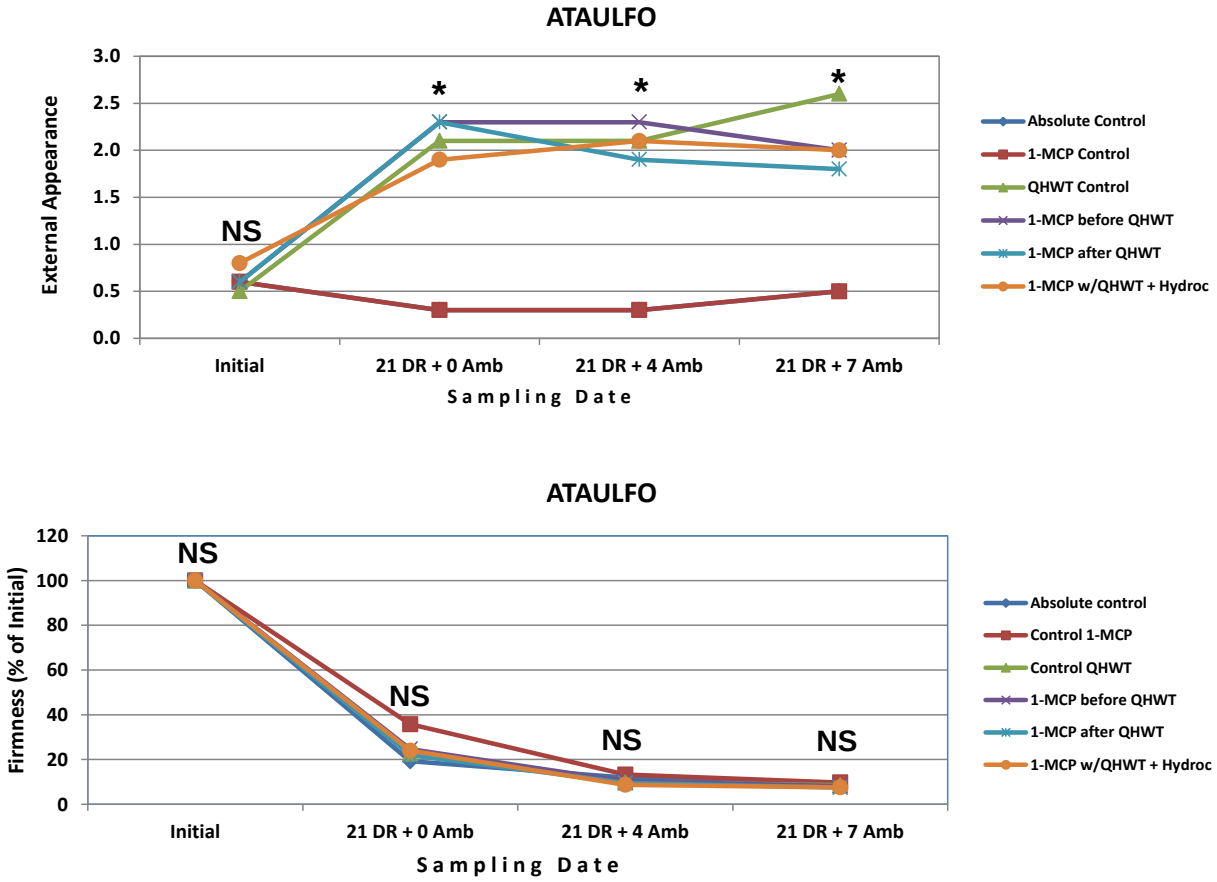
Table 1. Analysis of variance for the effect of aqueous 1-MCP treatments on the main quality variables of 'Ataulfo'. Nayarit, Mexico. 2013 season.

Variable	Initial	21 DR + 0 Amb	21 DR + 4 Amb	21 DR + 7 Amb
Weight loss	NS	NS	NS	NS
External Appearance	NS	*	*	*
Firmness	NS	NS	NS	NS
Pulp Color	NS	NS	NS	NS
TSS	NS	NS	NS	NS
Tritatable acidity	NS	NS	NS	NS

NS = No Significant * = Significant ($p \leq 0.05$) ** Highly significant ($p \leq 0.01$)

In the Figure 1 it is illustrated the effect of aqueous 1-MCP on External Appearance and fruit firmness of 'Ataulfo' variety. It was observed that the Absolute control (without QHWT and without 1-MCP) and the 1-MCP control (1-MCP applied to fruit without QHWT) did not cause any fruit damage in none of the sampling times. However, at the end of refrigerated simulation, the Hydrothermal control and the 1-MCP at any combination with the QHWT caused excessive fruit injury (spots in the fruit surface and lenticel blackening), trend that was observed until consumption stage.

Regarding to fruit firmness, the aqueous 1-MCP did not work for any combination treatment since no significant differences were detected for this variable in none of the sampling times.



0 = Excellent (No damage); 1 = Good (slight damage); 2 = Regular (moderate damage); 3 = Poor (severe damage)

Figure 1. Effect of aqueous 1-MCP treatments on External Appearance and fruit firmness (N) of 'Ataulfo' variety. Nayarit, Mexico. 2013 season.

PHOTO GALLERY ATAULFO 2013

a. Pictures at the beginning of the experiment

b. Pictures at the end of refrigerated period

c. Pictures at consumption

I.2. TOMMY ATKINS VARIETY.

In Table 2 it is consigned the analysis of variance for the effect of aqueous 1-MCP treatments on the main quality variables of 'Tommy Atkins'. It was observed that the effect of aqueous 1-MCP was mainly on weight loss and fruit external appearance, however, significant differences were found for pulp color and TSS but not for firmness and tritatable acidity.

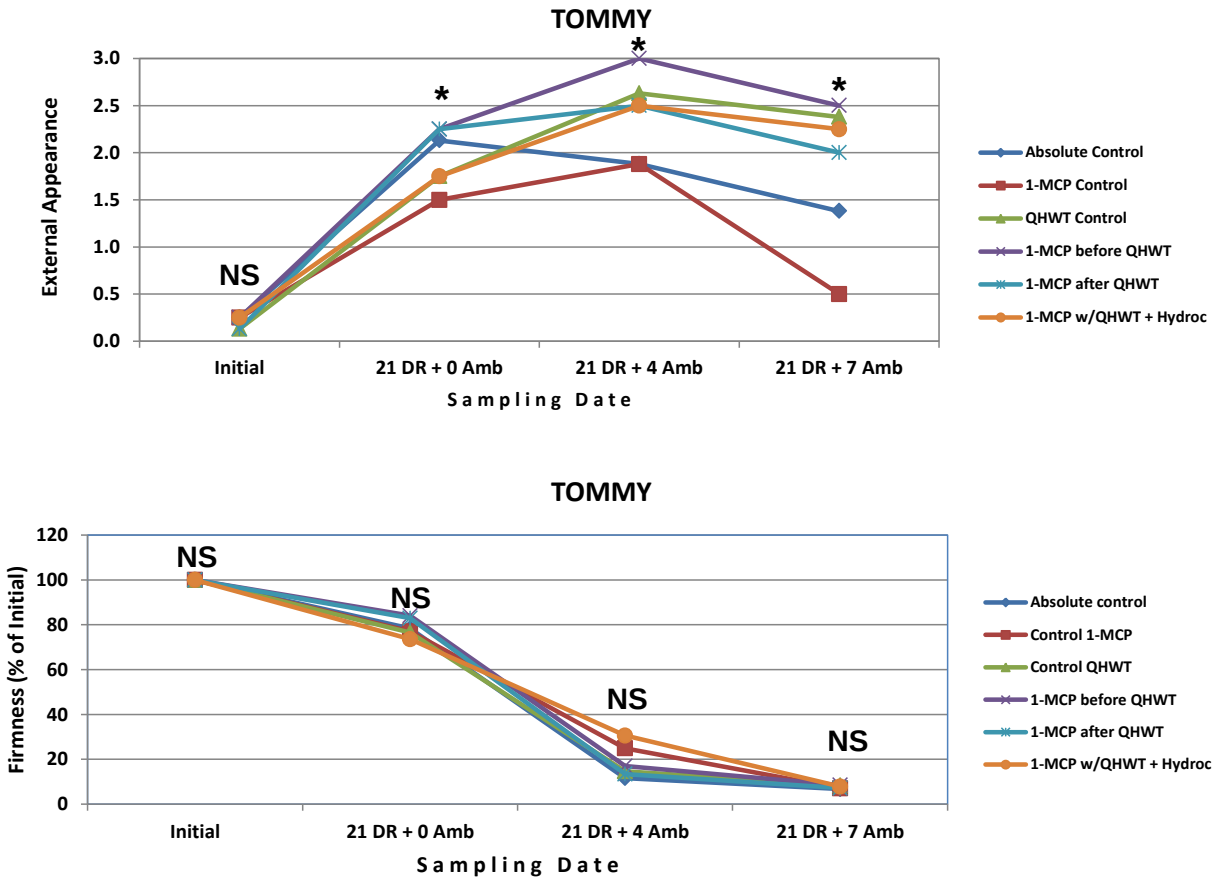
Table 2. Analysis of variance for the effect of aqueous 1-MCP treatments on the main quality variables of 'Tommy Atkins'. Nayarit, Mexico. 2013 season.

Variable	Initial	21 DR + 0 Amb	21 DR + 4 Amb	21 DR + 7 Amb
Weight loss	NS	*	*	*
External Appearance	NS	NS	*	*
Firmness	NS	NS	NS	NS
Pulp Color	NS	NS	NS	*
TSS	NS	*	NS	*
Tritatable acidity	NS	NS	NS	NS

NS = No Significant * = Significant ($p \leq 0.05$) ** Highly significant ($p \leq 0.01$)

In the Figure 2 it is illustrated the effect of aqueous 1-MCP on External Appearance and fruit firmness of 'Tommy Atkins' variety. It was observed that the Absolute control (without QHWT and without 1-MCP) and the 1-MCP control (1-MCP applied to fruit without QHWT) caused significantly less fruit damage at the end of the refrigerated period than any of the 1-MCP treatments in combination with QHWT. However, at consumption stage the damage caused by the 1-MCP in combination with QHWT was exacerbated with fruit showing excessive injury (spots in the fruit surface and lenticel blackening), while the Absolute control and the 1-MCO control showed less damage.

Regarding to fruit firmness, the aqueous 1-MCP did not work for any combination treatment since no significant differences were detected for this variable in none of the sampling times.

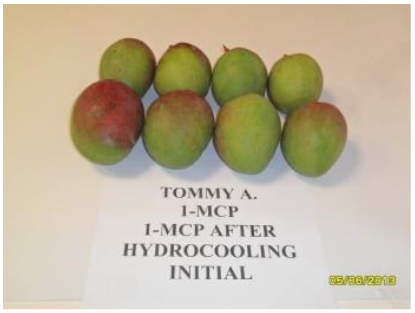


0 = Excellent (No damage); 1 = Good (slight damage); 2 = Regular (moderate damage); 3 = Poor (severe damage)

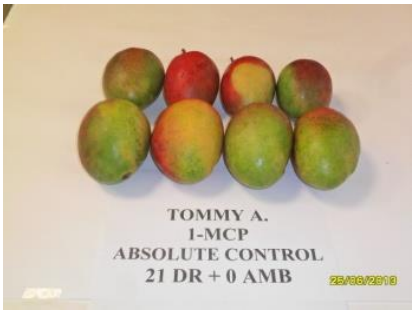
Figure 2. Effect of aqueous 1-MCP treatments on External Appearance and fruit firmness (N) of 'Tommy Atkins' variety. Nayarit, Mexico. 2013 season.

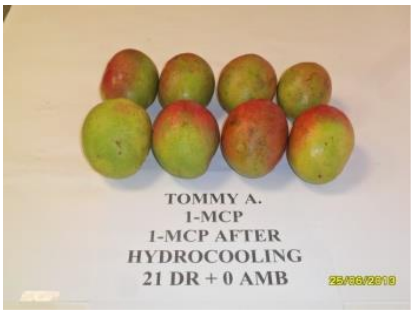
PHOTO GALLERY TOMMY ATKINS 2013

a. Pictures at the beginning of the experiment

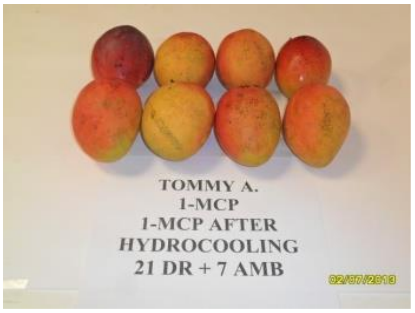


b. Pictures at the end of refrigerated period





c. Pictures at consumption



I.3. HADEN VARIETY.

In Table 3 it is consigned the analysis of variance for the effect of aqueous 1-MCP treatments on the main quality variables of 'Haden'. It was observed that the effect of aqueous 1-MCP was significant only fruit external appearance from the end of refrigerated until consumption stage. With respect to firmness, significant differences were detected only at the end of the refrigerated period. No significant differences were found for none of the other variables

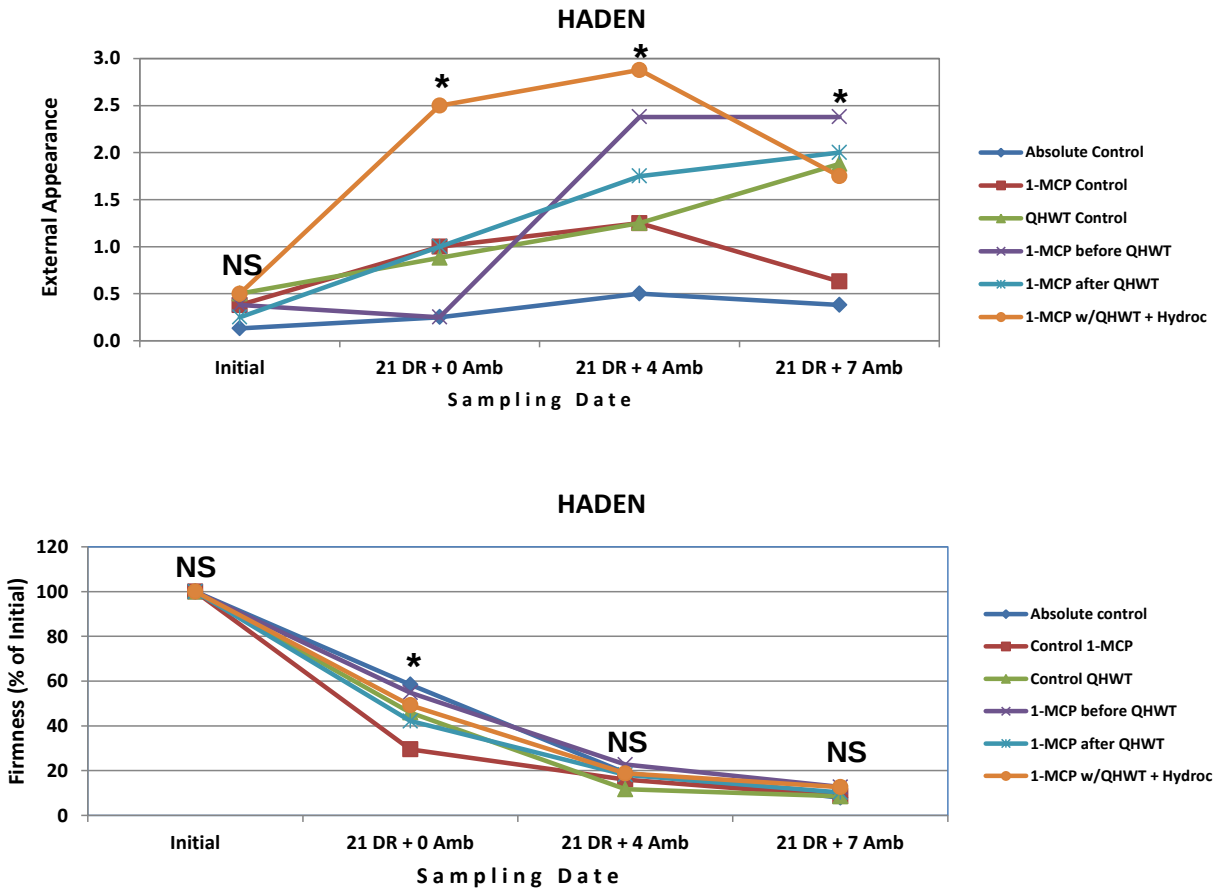
Table 3. Analysis of variance for the effect of aqueous 1-MCP treatments on the main quality variables of 'Haden'. Nayarit, Mexico. 2013 season.

Variable	Initial	21 DR + 0 Amb	21 DR + 4 Amb	21 DR + 7 Amb
Weight loss	NS	NS	NS	NS
External Appearance	NS	*	*	*
Firmness	NS	*	NS	NS
Pulp Color	NS	NS	NS	NS
TSS	NS	NS	NS	NS
Tritatable acidity	NS	NS	NS	NS

NS = No Significant * = Significant ($p \leq 0.05$) ** Highly significant ($p \leq 0.01$)

In the Figure 3 it is illustrated the effect of aqueous 1-MCP on External Appearance and fruit firmness of 'Haden' variety. With relation to External Appearance, results were more irregular comparing to 'Ataulfo' or 'Tommy Atkins' at the end of the refrigerated period since aqueous 1-MCP applied after QHWT + hydrocooling was the treatment with more severe damage than 1-MCP applied before or after QHWT. However, at consumption stage the trend was very similar to 'Ataulfo' and 'Tommy Atkins' since the Absolute control (without QHWT and without 1-MCP) and the 1-MCP control (1-MCP applied to fruit without QHWT) caused significantly less fruit damage than any of the 1-MCP treatments in combination with QHWT.

Regarding to fruit firmness, the aqueous 1-MCP did not work for any combination treatment, although significant differences were detected at the end of refrigerated simulation period, those were opposite to expected since the Absolute control was the treatment that kept the highest percentage of initial firmness and the treatment of 1-MCP without QHWT showed the lowest firmness. These results also showed that aqueous 1-MCP response depended on the variety. For that reason, it is not possible to assume that 1-MCP could work at the same manner in most mango varieties.



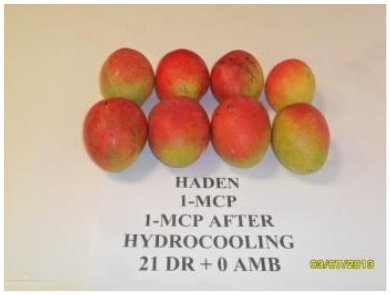
0 = Excellent (No damage); 1 = Good (slight damage); 2 = Regular (moderate damage); 3 = Poor (severe damage)

Figure 3. Effect of aqueous 1-MCP treatments on External Appearance and fruit firmness (N) of 'Haden' variety. Nayarit, Mexico. 2013 season.

PHOTO GALLERY HADEN 2013

a. Pictures at the beginning of the experiment

b. Pictures at the end of refrigerated period



c. Pictures at consumption

I.4. KENT VARIETY.

In Table 4 it is consigned the analysis of variance for the effect of aqueous 1-MCP treatments on the main quality variables of 'Kent'. In this variety a higher performance of aqueous 1-MCP was detected since significant differences were detected for weight loss and External Appearance at the end of the refrigerated period, at market simulation, and at consumption stage. Regarding to firmness, significant differences were detected at the end of the refrigerated period and at market simulation, while for pulp color significant differences were found at the end of the refrigerated period and at consumption stage. TSS showed significant differences only at the end of the refrigerated period. No significant differences for tritatable acidity were detected at any of the sampling times.

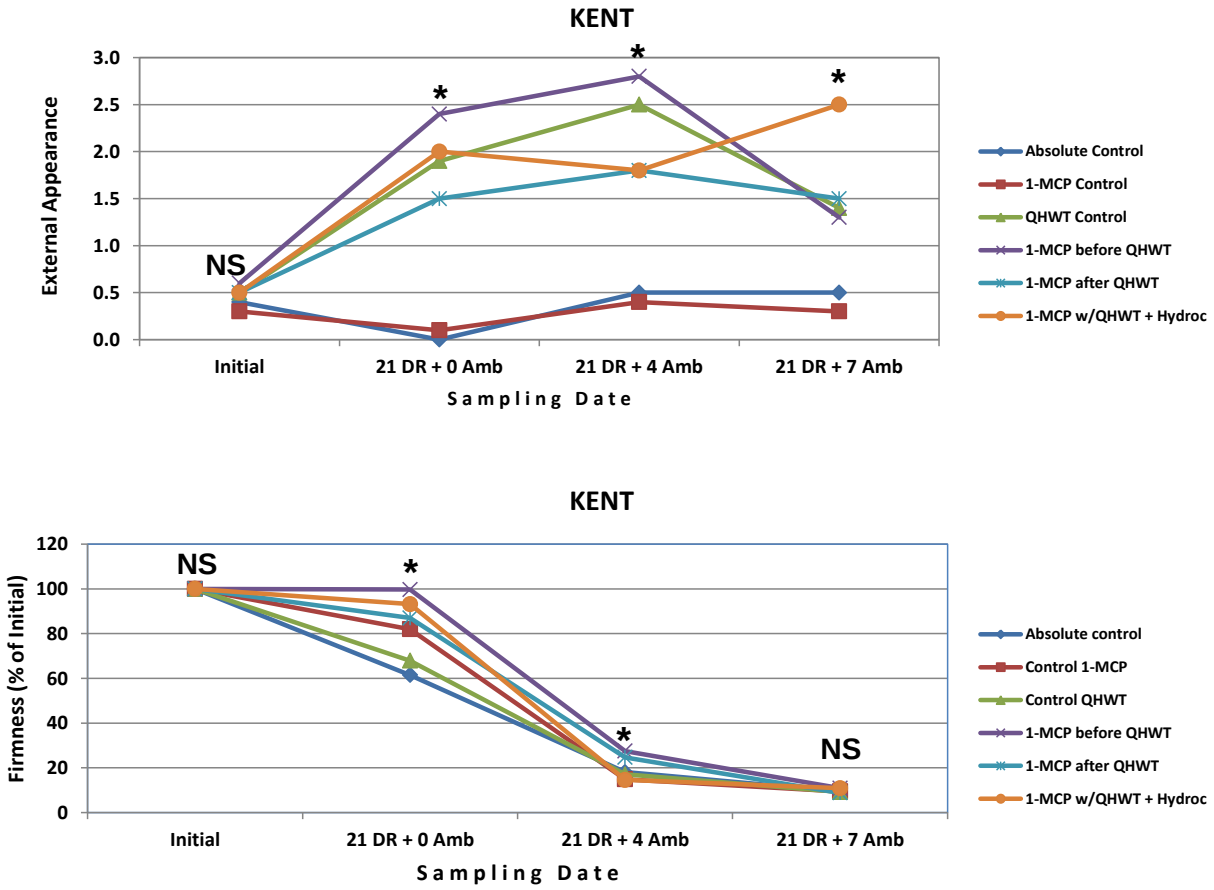
Table 4. Analysis of variance for the effect of aqueous 1-MCP treatments on the main quality variables of 'Kent'. Nayarit, Mexico. 2013 season.

Variable	Initial	21 DR + 0 Amb	21 DR + 4 Amb	21 DR + 7 Amb
Weight loss	NS	*	*	*
External Appearance	NS	*	*	*
Firmness	NS	*	*	NS
Pulp Color	NS	*	NS	*
TSS	NS	*	NS	NS
Tritatable acidity	NS	NS	NS	NS

NS = No Significant * = Significant ($p \leq 0.05$) ** Highly significant ($p \leq 0.01$)

In the Figure 4 it is illustrated the effect of aqueous 1-MCP on External Appearance and fruit firmness of 'Kent' variety. It was observed that the Absolute control and the 1-MCP control did not cause any fruit damage in none of the sampling times. However, at the end of the refrigerated period, the hydrothermal control and 1-MCP treatment in combination with QHWT caused excessive fruit damage (surface spots and lenticel blackening). This trend was observed until the consumption stage.

Regarding to fruit firmness, the aqueous 1-MCP demonstrated its potential to length shelf life since at the end of the refrigerated period the aqueous 1-MCP treatments kept at least 80% of the initial fruit firmness. This stage is the most critical in the shipping of mango from south America. Unfortunately although the aqueous 1-MCP showed maintenance of firmness comparing with controls, a negative interaction with QHWT was detected since fruit showed surface spots and lenticel blackening. The Absolute control and the 1-MCP control did not show any fruit damage. This situation compromises the use of aqueous 1-MCP for mango market requiring QHWT, but it may be most useful for markets not demanding QHWT like the European Union and Canada. In addition, 1-MCP delayed the ripening process because it attenuated pulp color development, and delayed the increase in TSS.



0 = Excellent (No damage); 1 = Good (slight damage); 2 = Regular (moderate damage); 3 = Poor (severe damage)

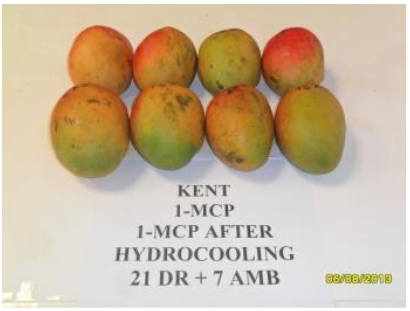
Figure 4. Effect of aqueous 1-MCP treatments on External Appearance and fruit firmness (N) of 'Kent' variety. Nayarit, Mexico. 2013 season.

PHOTO GALLERY KENT 2013

a. Pictures at the beginning of the experiment

b. Pictures at the end of refrigerated period

c. Pictures at consumption stage



I.5. KEITT VARIETY.

In Table 5 it is consigned the analysis of variance for the effect of aqueous 1-MCP treatments on the main quality variables of 'Keitt'. In this variety a higher performance of aqueous 1-MCP was detected since significant differences were detected for weight loss and External Appearance at the end of the refrigerated period, at market simulation, and at consumption stage. Regarding to firmness, significant differences were detected at the end of the refrigerated period and at market simulation, while for pulp color significant differences were found only at the end of the refrigerated period. No significant differences were detected for TSS or tritatable acidity at any of the sampling times.

Table 5. Analysis of variance for the effect of aqueous 1-MCP treatments on the main quality variables of 'Keitt'. Nayarit, Mexico. 2013 season.

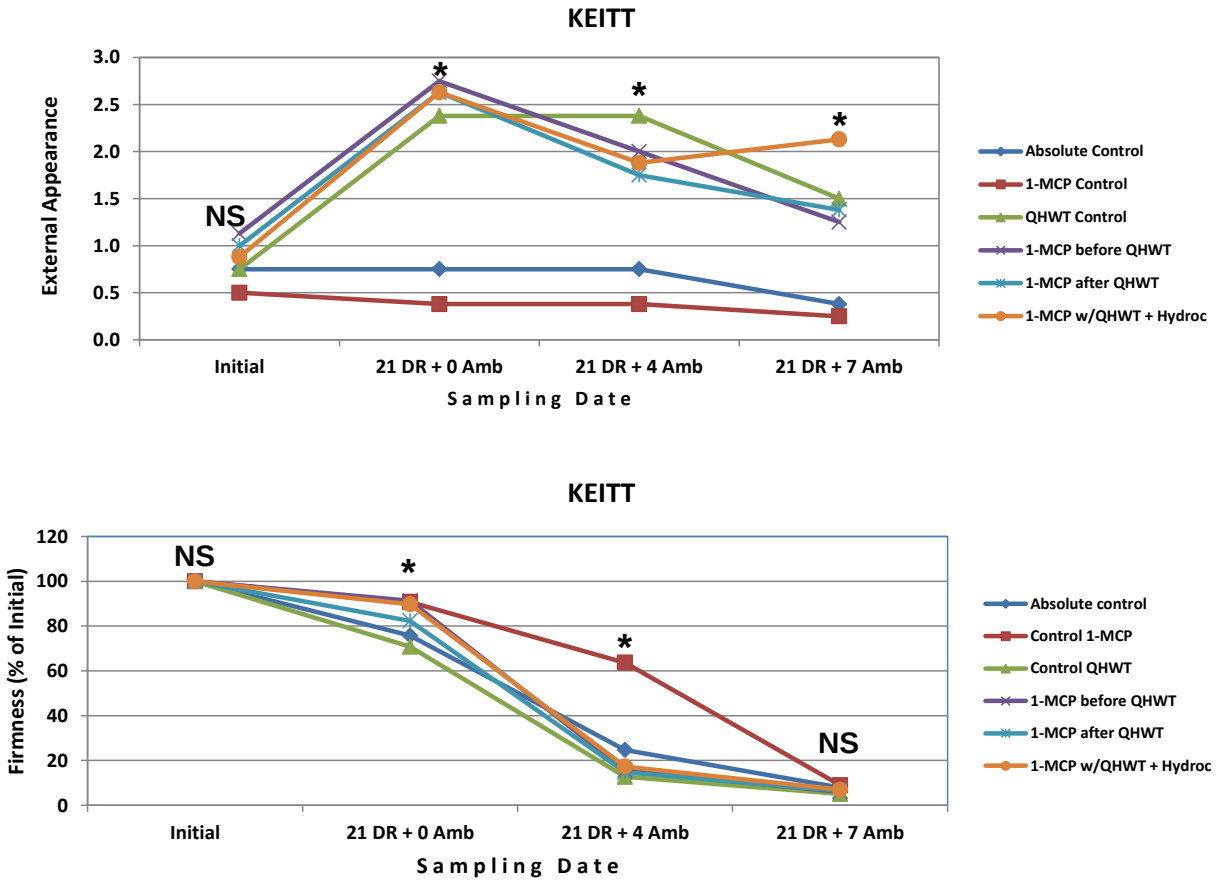
Variable	Initial	21 DR + 0 Amb	21 DR + 4 Amb	21 DR + 7 Amb
Weight loss	NS	*	*	*
External Appearance	NS	*	*	*
Firmness	NS	*	*	NS
Pulp Color	NS	*	NS	NS
TSS	NS	NS	NS	NS
Tritatable acidity	NS	NS	NS	NS

NS = No Significant * = Significant ($p \leq 0.05$) ** Highly significant ($p \leq 0.01$)

In the Figure 5 it is illustrated the effect of aqueous 1-MCP on External Appearance and fruit firmness of 'Keitt' variety. It was observed that the Absolute control and the 1-MCP control did not cause any fruit damage in none of the sampling times. However, at the end of the refrigerated period, the Hydrothermal control and 1-MCP treatment in combination with QHWT caused excessive fruit damage (surface spots and lenticel blackening). This trend was observed until the consumption stage.

Regarding to fruit firmness, the aqueous 1-MCP demonstrated its potential to length shelf life since at the end of the refrigerated period the aqueous 1-MCP treatments kept at least 80% of the initial fruit firmness. This trend continued for the 1-MCP control at the day 4^{th} of market simulation since it maintained 60% of the initial firmness while the other treatments only kept about 20% of the initial firmness. Unfortunately 'Keitt' showed a similar trend than 'Kent, although the aqueous 1-MCP showed maintenance of firmness comparing with controls, a negative interaction with QHWT was also detected with fruit showing surface spots and lenticel blackening. The Absolute control and the 1-MCP control did not show any fruit damage. This situation compromises the use of aqueous 1-MCP for mango markets requiring QHWT, but it may be most useful for markets not demanding QHWT like the European Union and Canada.

In addition, 1-MCP delayed the ripening process because it maintained firmness longer and attenuated pulp color development.



0 = Excellent (No damage); 1 = Good (slight damage); 2 = Regular (moderate damage); 3 = Poor (severe damage)

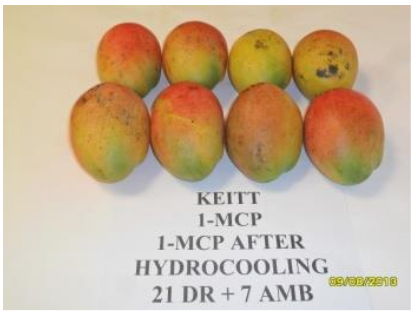
Figure 5. Effect of aqueous 1-MCP treatments on External Appearance and fruit firmness (N) of 'Keitt' variety. Nayarit, Mexico. 2013 season.

PHOTO GALLERY KEITT 2013

a. Pictures at the beginning of the experiment

b. Pictures at the end of the refrigerated period

c. Pictures at consumption



II. 2014 SEASON.

II.1. ATAULFO VARIETY.

Because during the 2013 season it was not possible to clarify if fruit damage was due to 1-MCP application, due to QHWT or both, during the 2014 season a second set of experiments was established to find out the effect of both factors. In Table 6 it is consigned the Analysis of variance of the effect of QHWT on the main quality variables in 'Ataulfo' variety. It was observed that QHWT significantly affected the fruit external appearance in all the sampling dates while for peel color was significant for sampling at the end of refrigerated period and at day 4th of market simulation. Firmness, pulp color and TSS were not affected in none of the sampling dates while tritatable acidity and the ratio °Bx/Acidity were affected only at consumption stage.

Table 6. Analysis of Variance of the effect of QHWT on main quality variables in 'Ataulfo' variety. Nayarit, México. 2014 season.

	QHWT			
Variables	**Initial**	**21 DR + 0 AMB**	**21 DR + 4 AMB**	**21 DR + 7 AMB**
Weight loss	**NS**	**NS**	**NS**	**NS**
External appearance	**NS**	*****	*****	*****
Peel color	**NS**	*****	*****	**NS**
Firmness	**NS**	**NS**	**NS**	**NS**
Pulp color	**NS**	**NS**	**NS**	**NS**
TSS	**NS**	**NS**	**NS**	**NS**
Tritatable	**NS**	**NS**	**NS**	*****
Ratio °Bx/Acidity	**NS**	**NS**	**NS**	*****

NS = Non Significant * = Significant ($p \leq 0.05$) ** Highly significant ($p \leq 0.01$)

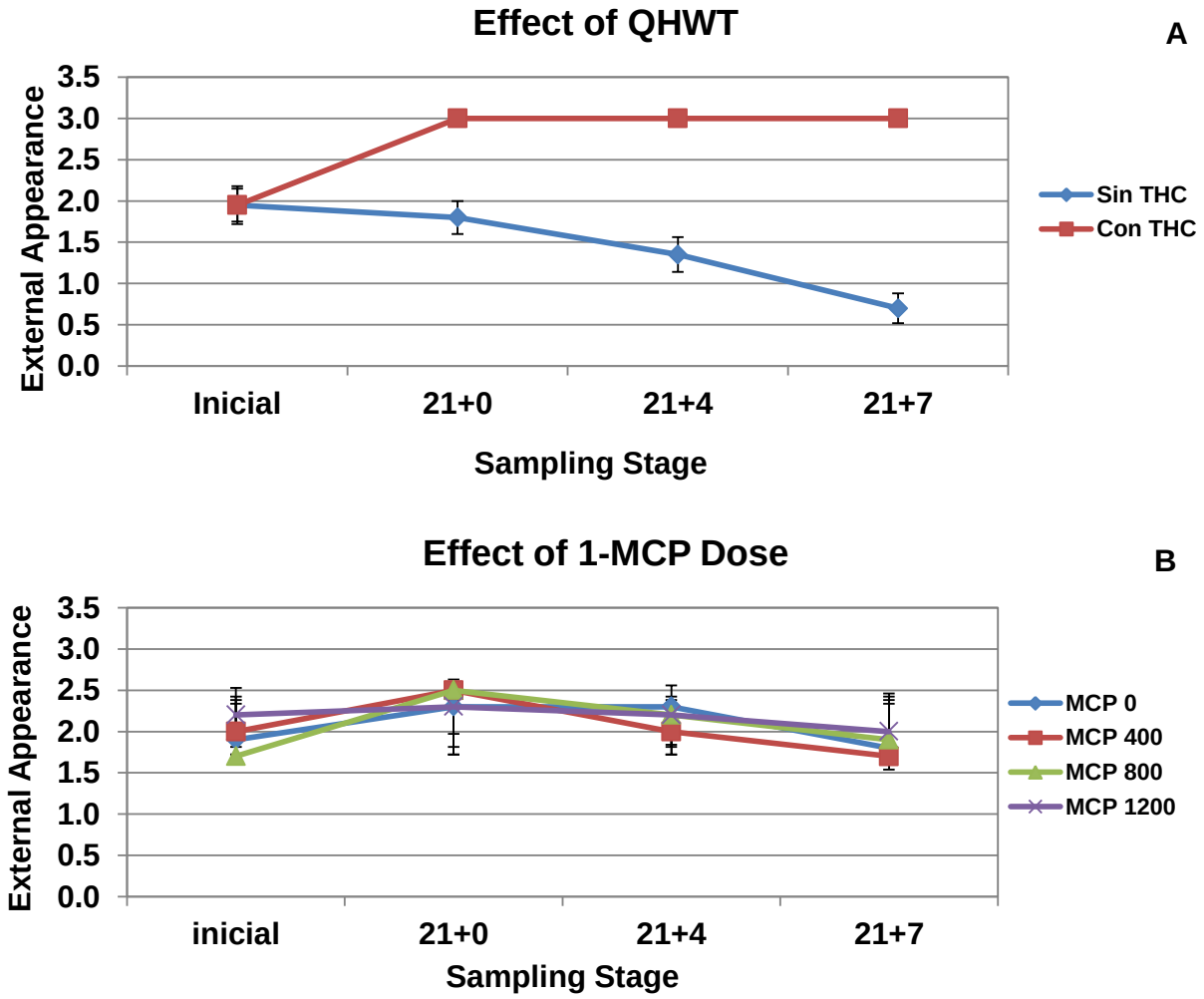
In relation to the effect of 1-MCP doses (0, 400, 800 y 1200 µg L^{-1}), only weight loss was significantly affected at the end of refrigerated period, market simulation, and consumption stage. 1-MCP doses practically did not affect any other variable at the end of refrigerated period (with exception of TSS and the rate °Bx/Acidity). At consumption stage, besides weight loss, significant differences were detected for peel color, pulp color, and TSS content.

Table 7. Analysis of Variance of the effect of 1-MCP doses (0, 400, 800 y 1200 µg L^{-1}) on main quality variables in 'Ataulfo' variety. Nayarit, México. 2014 season.

	1-MCP			
Variables	**Initial**	**21 DR + 0 AMB**	**21 DR + 4 AMB**	**21 DR + 7 AMB**
Weight loss	**NS**	*****	*****	*****
External appearance	**NS**	**NS**	**NS**	**NS**
Peel color	**NS**	**NS**	**NS**	*****
Firmness	**NS**	**NS**	**NS**	**NS**
Pulp color	**NS**	**NS**	**NS**	*****
TSS	**NS**	*****	**NS**	*****
Tritatable acidity	**NS**	**NS**	**NS**	**NS**
Ratio °Bx/Acidity	**NS**	*****	**NS**	**NS**

NS = Non Significant * = Significant ($p \leq 0.05$) ** Highly significant ($p \leq 0.01$)

The most spectacular effect of QHWT was observed on fruit external appearance (Figure 6A). Those fruit with QHWT showed a severe damage since the end of the refrigerated period until consumption stage. Fruit without QHWT showed a moderate damage at the end of the refrigerated period end of the refrigerated period while at consumption stage their external appearance was from excellent to good. By contrast, the 1-MCP doses (Figure 6B) did not indicate any significant difference among them in none of the sampling times showing only a moderate damage.



0=Excellent (no damage); 1=Good (slight damage); 2=Regular (moderate damage); 3=Poor (severe damage)

Figure 6. Effect of QHWT (A) and 1-MCP doses (B) on External Appearance on 'Ataulfo' fruit. Nayarit, Mexico. 2014 season.

With respect to firmness, the beneficial effect of QHWT was noticed since at the end of the refrigerated period and at consumption stage fruit with QHWT showed a significant firmness higher than those without QHWT (Figure 7A). By contrast, no significant differences were found for 1-MCP doses for this variable in any of the sampling time (Figure 7B).

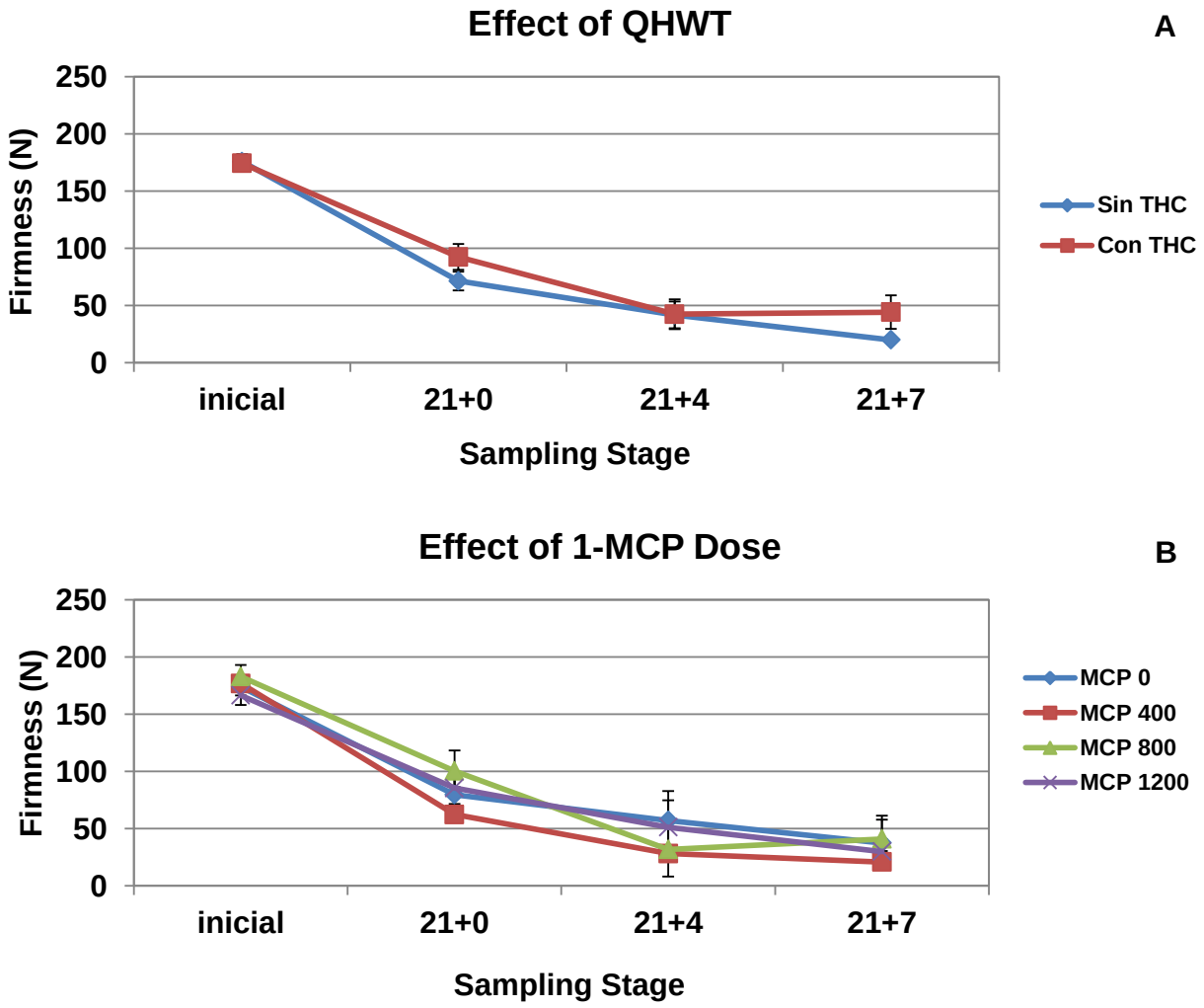


Figure 7. Effect of QHWT (A) and 1-MCP doses (B) on Firmness (N) on 'Ataulfo' fruit. Nayarit, Mexico. 2014 season.

PHOTO GALLERY ATAULFO 2014

a. Pictures at the beginning of the experiment

b. Pictures at the end of the refrigerated period

c. Pictures at consumption

II.2. TOMMY ATKINS VARIETY.

In Table 8 it is consigned the Analysis of variance of the effect of QHWT on the main quality variables in ‘Tommy Atkins’ variety. It was observed that QHWT significantly affected weight loss and fruit firmness in all the sampling stages. For external appearance, significant differences were detected at the end of the refrigerated period and at consumption stage, while pulp color was significant only at consumption stage. TSS were not affected in any sampling stage, but tritatable acidity and the ratio °Bx/Acidity were affected only at the end of the refrigerated period.

Table 8. Analysis of Variance of the effect of QHWT on main quality variables in 'Tommy Atkins' variety. Nayarit, México. 2014 season.

	QHWT			
Variables	Initial	21 DR + 0 AMB	21 DR + 4 AMB	21 DR + 7 AMB
Weight loss	NS	*	*	*
External Appearance	NS	*	NS	*
Firmness	NS	*	*	*
Pulp color	NS	NS	NS	*
TSS	NS	NS	NS	NS
Tritatable acidity	*	*	NS	NS
Ratio °Bx/Acidity	*	*	NS	NS

NS = Non Significant * = Significant ($p \leq 0.05$) ** Highly significant ($p \leq 0.01$)

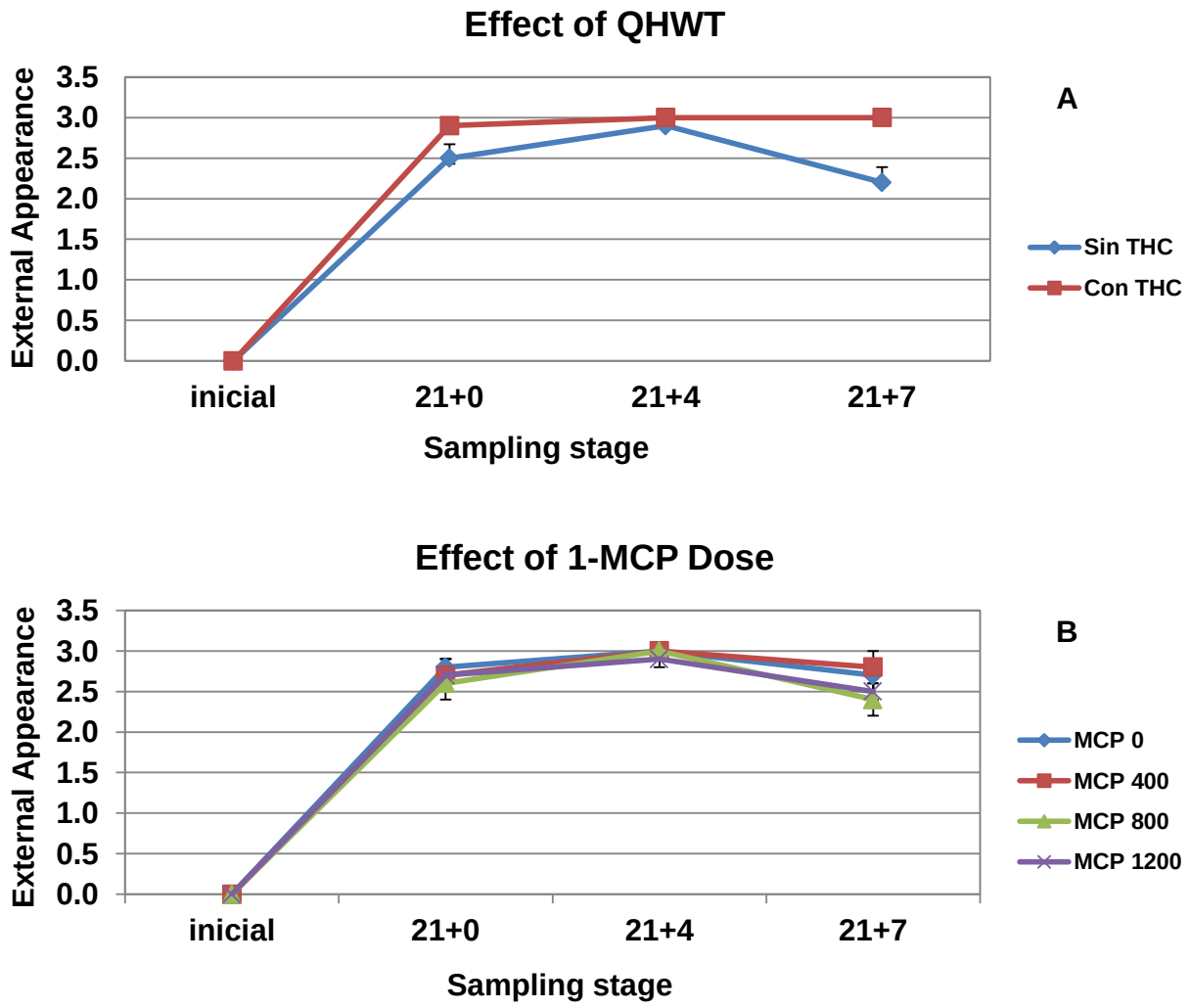
In relation to the effect of 1-MCP doses (0, 400, 800 y 1200 µg L^{-1}), only weight loss was significantly affected for all sampling stages (Table 9). The external appearance and TSS were not affected in any of the sampling times while fruit firmness was affected only during marketing simulation. Pulp color and the ratio °Bx/Acidity were significant at consumption stage whereas tritatable acidity was significant during marketing simulation and at consumption stage.

Table 9. Analysis of Variance of the effect of 1-MCP doses (0, 400, 800 y 1200 µg L^{-1}) on main quality variables in 'Tommy Atkins' variety. Nayarit, México. 2014 season.

	1-MCP			
Variables	Initial	21 DR + 0 AMB	21 DR + 4 AMB	21 DR + 7 AMB
Weight loss	NS	*	*	*
External Appearance	NS	NS	NS	NS
Firmness	*	NS	*	NS
Pulp color	NS	NS	NS	*
TSS	NS	NS	NS	NS
Tritatable acidity	NS	NS	*	*
Ratio °Bx/Acidity	NS	NS	NS	*

NS = Non Significant * = Significant ($p \leq 0.05$) ** Highly significant ($p \leq 0.01$)

For this variety in particular, the effect of QHWT on external appearance was not so spectacular (Figure 8A). Although significant differences were detected between fruit with or without QHWT at the end of the refrigerated period and at consumption stage, in both cases fruit had an external appearance from Regular to Poor. By contrast, the 1-MCP doses did not show significant differences among them for this variable in any of the sampling times, showing fruit damage from moderate to severe (Figure 8B).



0=Excellent (no damage); 1=Good (slight damage); 2=Regular (moderate damage); 3=Poor (severe damage)

Figure 8. Effect of QHWT (A) and 1-MCP doses (B) on External Appearance on 'Tommy Atkins' fruit. Nayarit, Mexico. 2014 season.

With respect to firmness, the beneficial effect of QHWT was noticed since at the end of the refrigerated period, at market simulation, and at consumption stage fruit with QHWT showed a significant firmness higher than those without QHWT (Figure 9A). By contrast, no significant differences were found for 1-MCP doses for this variable in any of the sampling time (Figure 9B).

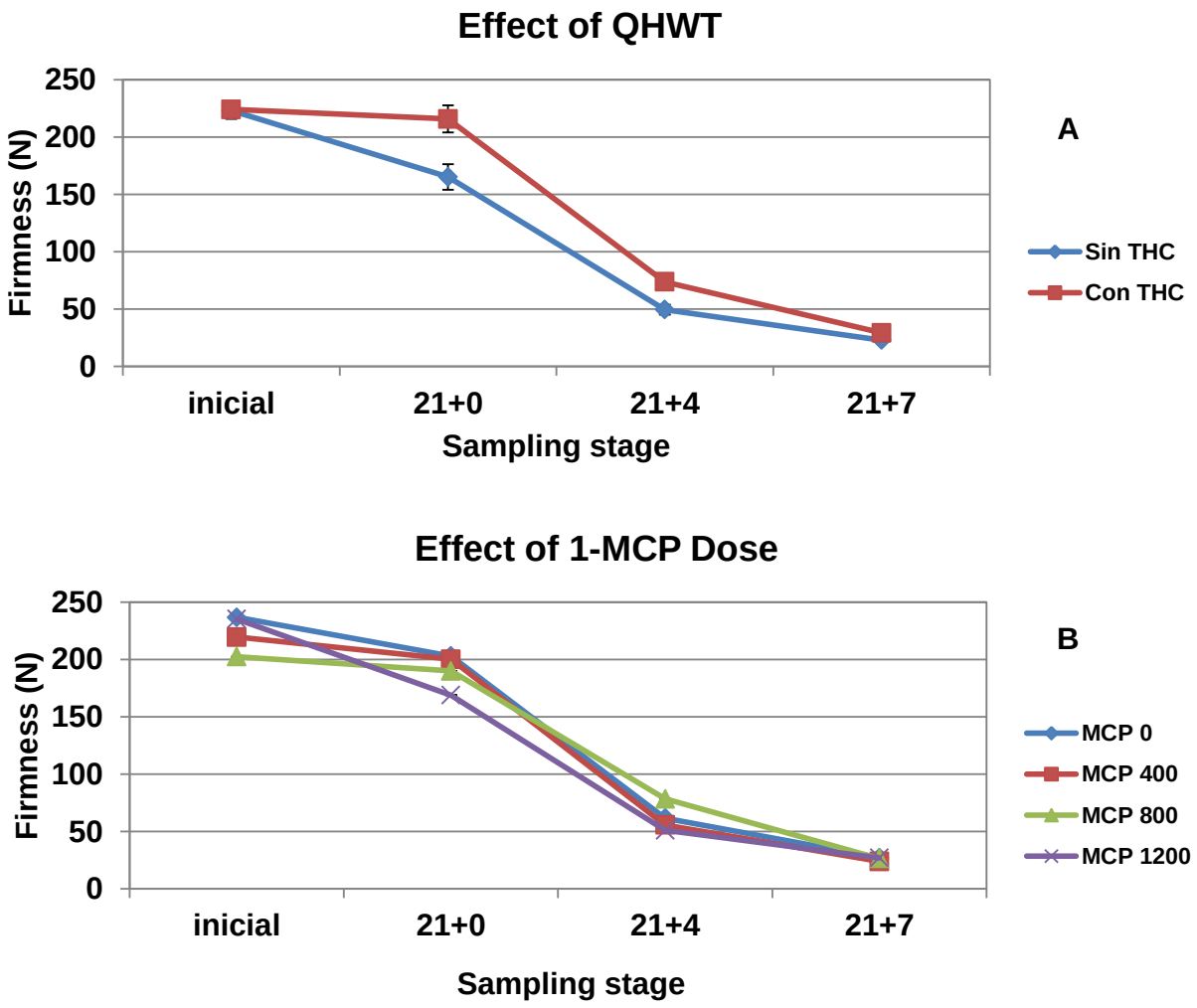
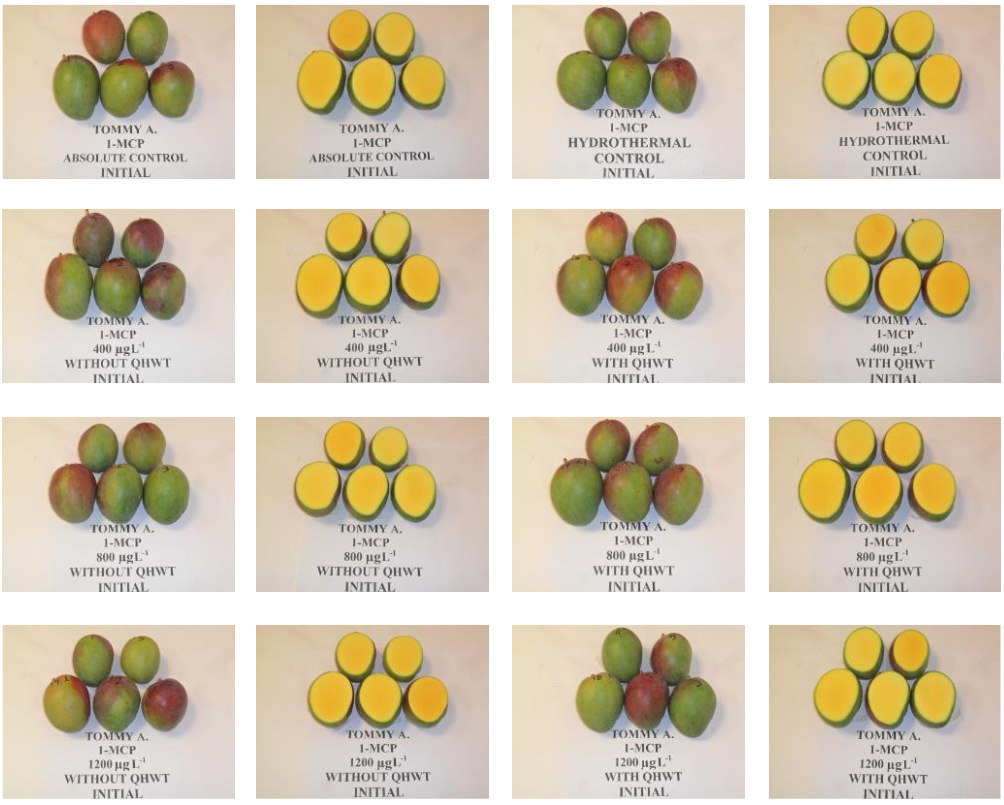


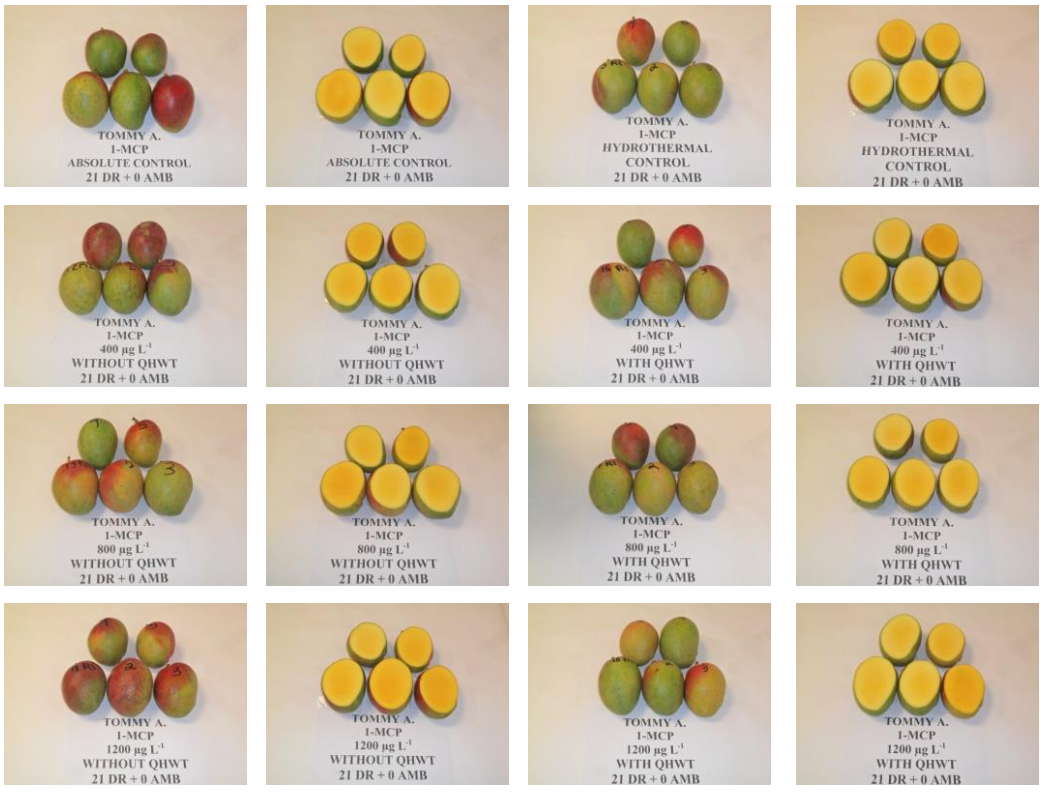
Figure 9. Effect of QHWT (A) and 1-MCP doses (B) on Firmness (N) on 'Tommy Atkins' fruit. Nayarit, Mexico. 2014 season.

PHOTO GALLERY TOMMY ATKINS 2014

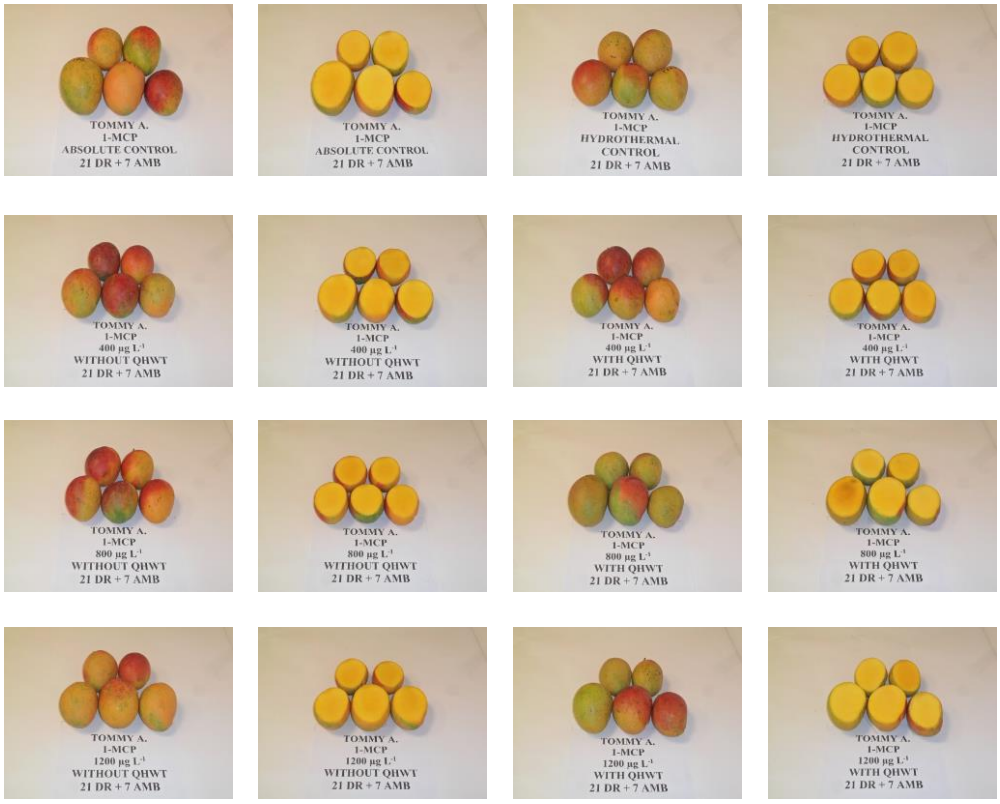
a. Pictures at the beginning of the experiment



b. Pictures at the end of refrigeration



c. Pictures at consumption



II.3. KENT VARIETY.

In Table 10 it is consigned the Analysis of variance of the effect of QHWT on the main quality variables in ‘Kent’ variety. It was observed that QHWT significantly affected weight loss and external appearance in all the sampling stages. For firmness, significant differences were detected only at the end of the refrigerated period. Pulp color, tritatable acidity, and the ratio °Bx/Acidity were affected only at day 4th of marketing simulation while TSS were affected at day 4th of marketing simulation and at consumption stage.

Table 10. Analysis of Variance of the effect of QHWT on main quality variables in 'Kent' variety. Nayarit, México. 2014 season.

	QHWT			
Variables	Initial	21 DR + 0 AMB	21 DR + 4 AMB	21 DR + 7 AMB
Weight loss	NS	*	*	*
External Appearance	NS	*	*	*
Firmness	NS	*	NS	NS
Pulp color	NS	NS	*	NS
TSS	NS	NS	*	*
Tritatable acidity	*	NS	*	NS
Ratio °Bx/Acidity	NS	NS	*	NS

NS = Non Significant * = Significant ($p \leq 0.05$) ** Highly significant ($p \leq 0.01$)

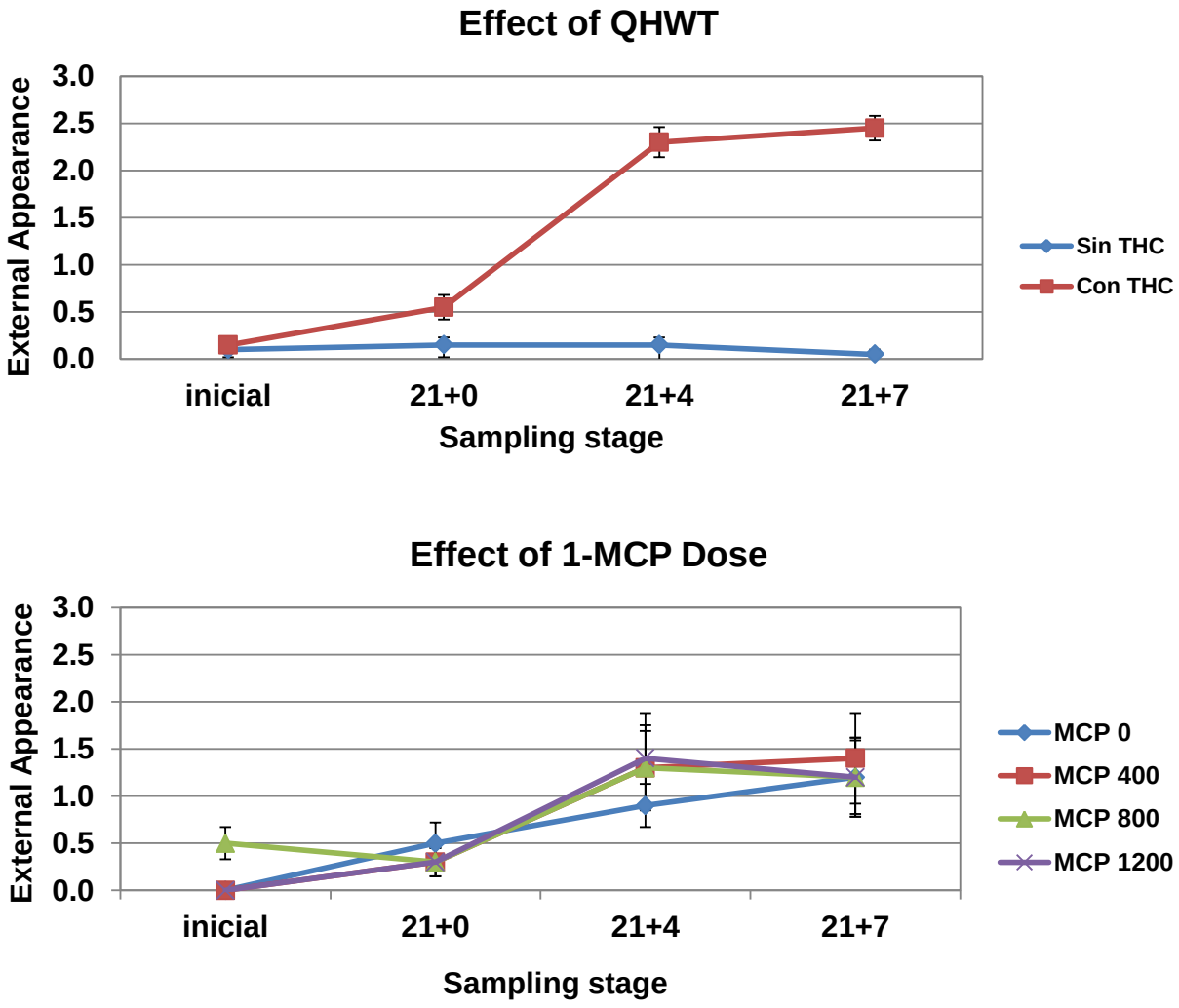
In relation to the effect of aqueous 1-MCP doses (0, 400, 800 y 1200 µg L^{-1}), only weight loss was significantly affected for all sampling stages (Table 11). The external appearance and pulp color showed significant differences only at day 4th of market simulation. Firmness was not affected at any sampling stage while TSS were affected at the end of the refrigerated period and at day 4th of market simulation. Tritatable acidity and the ratio °Bx/Acidity were significant only at consumption stage.

Table 11. Analysis of Variance of the effect of 1-MCP doses (0, 400, 800 y 1200 µg L^{-1}) on main quality variables in 'Kent' variety. Nayarit, México. 2014 season.

	1-MCP			
Variables	Initial	21 DR + 0 AMB	21 DR + 4 AMB	21 DR + 7 AMB
Weight loss	NS	*	*	*
External Appearance	*	NS	*	NS
Firmness	NS	NS	NS	NS
Pulp color	NS	NS	*	NS
TSS	NS	*	*	NS
Tritatable acidity	NS	NS	NS	*
Ratio °Bx/Acidity	NS	NS	NS	*

NS = Non Significant * = Significant ($p \leq 0.05$) ** Highly significant ($p \leq 0.01$)

For this variety in particular, the effect of QHWT on external appearance was very spectacular (Figure 10A), since at the end of the refrigerated period fruit with or without QHWT although showed significant differences, both were rated in the range from Excellent to Good. However, fruit with QHWT showed severe damage during marketing simulation and at consumption stage, whereas the fruit without QHWT maintained an excellent external appearance. Apparently, QHWT was the most responsible for fruit damage (surface spots and lenticel blackening). However, when individually analyzed at day 4th of marketing simulation, the hydrothermal control was rated as 1.4 while 1-MCP doses at 400, 800 y 1,200 µg L^{-1} were rated with values of 2.4, 2.6, and 2.8, respectively, suggesting a negative additive effect of 1-MCP doses (Figure 10 B).



0=Excellent (no damage); 1=Good (slight damage); 2=Regular (moderate damage); 3=Poor (severe damage)

Figure 10. Effect of QHWT (A) and 1-MCP doses (B) on External Appearance on 'Kent' fruit. Nayarit, Mexico. 2014 season.

With respect to firmness, the beneficial effect of QHWT was noticed since at the end of the refrigerated period, at market simulation, and at consumption stage fruit with QHWT showed a significant firmness higher than those without QHWT (Figure11A). However, during market simulation at consumption stage, no significant differences were detected between fruit with or without QHWT. By contrast, no significant differences were found for 1-MCP doses for this variable in any of the sampling time (Figure 11B).

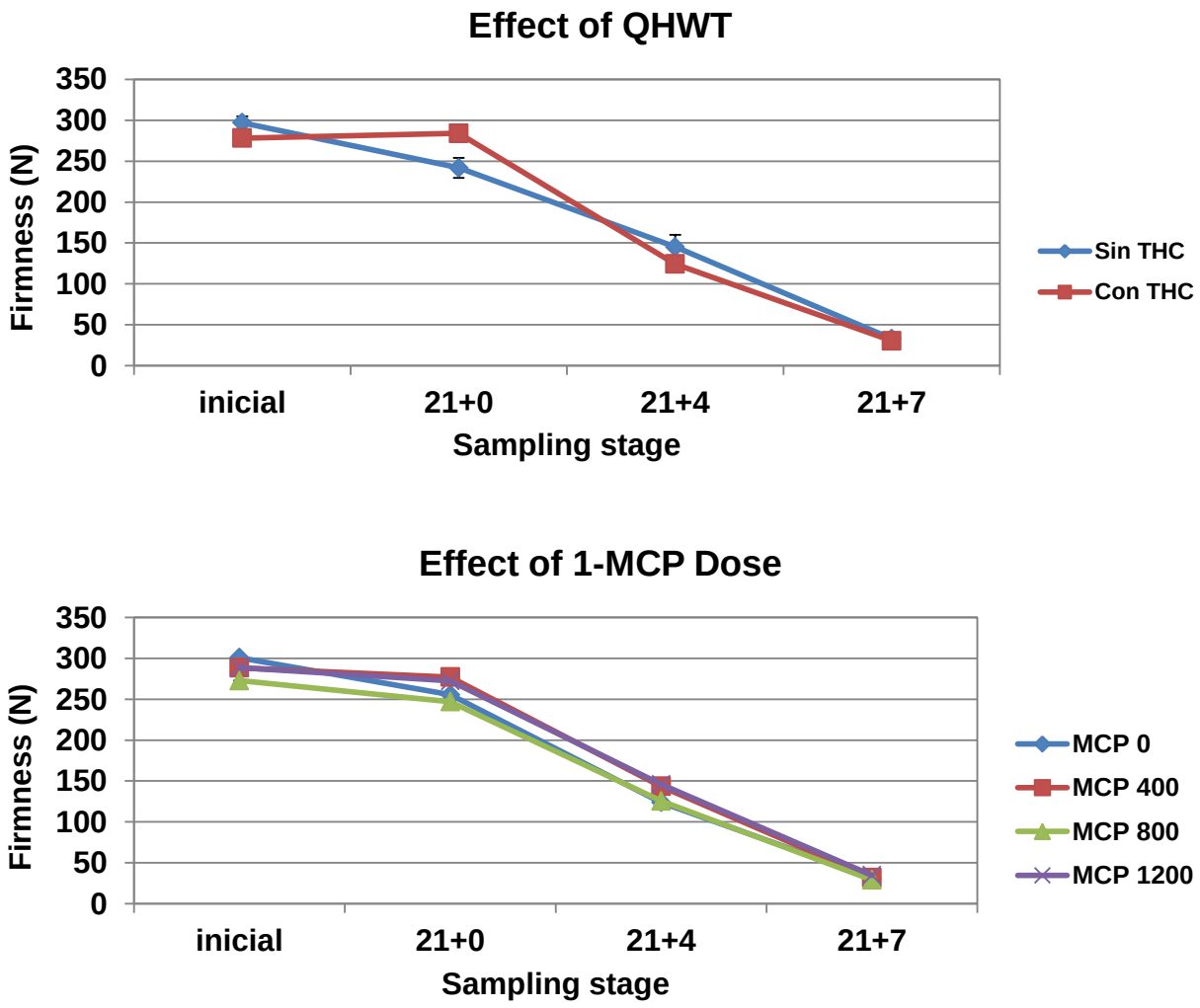
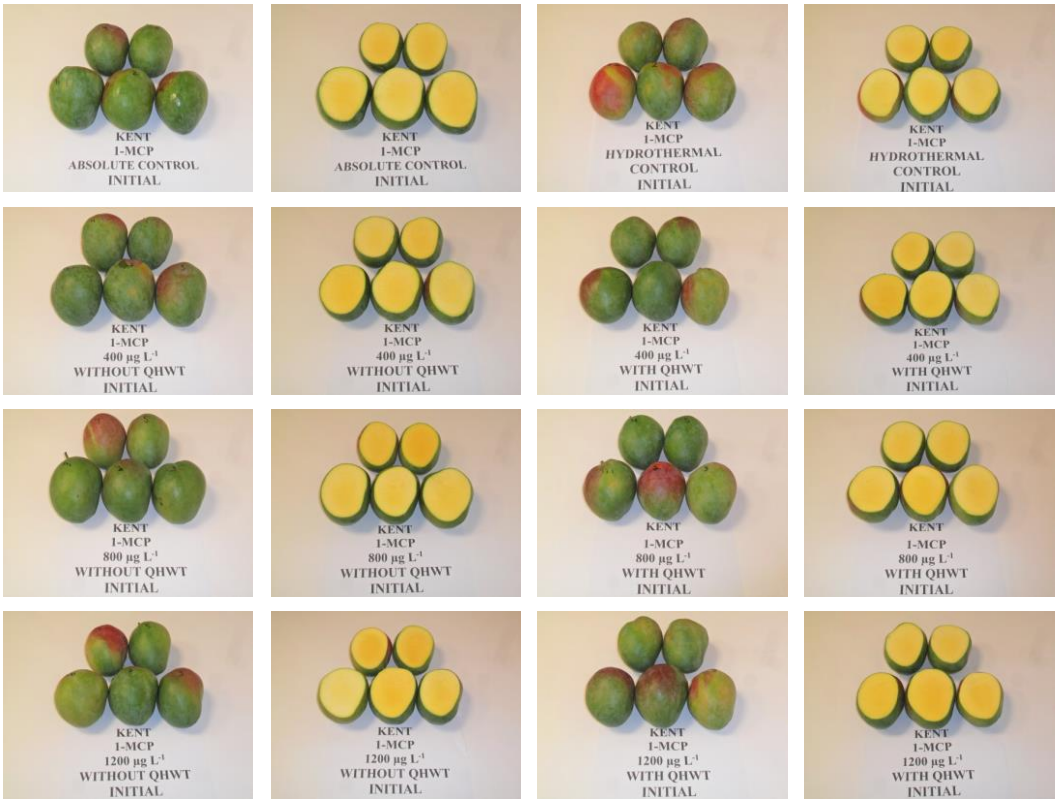


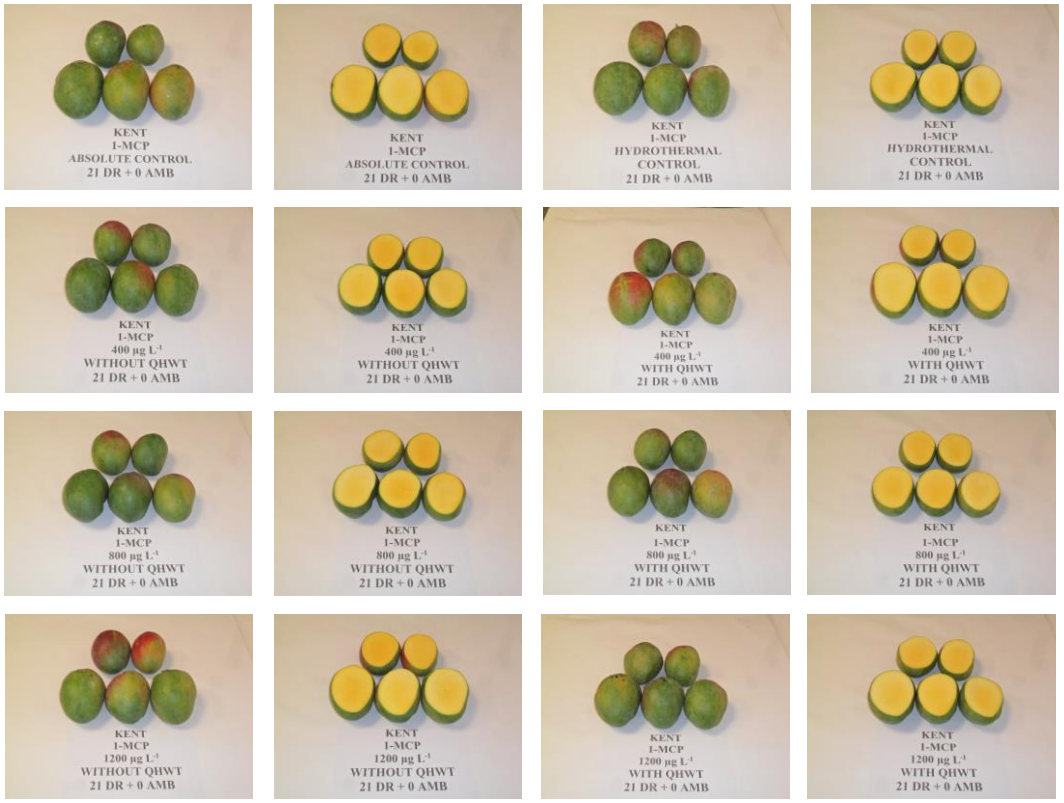
Figure 11. Effect of QHWT (A) and 1-MCP doses (B) on Firmness (N) on 'Kent' fruit. Nayarit, Mexico. 2014 season.

PHOTO GALLERY KENT 2014

a. Pictures at the beginning of the experiment



b. Pictures at the end of refrigerated period



c. Pictures at consumption stage

II.4. KEITT VARIETY.

In Table 12 it is consigned the Analysis of variance of the effect of QHWT on the main quality variables in 'Keitt' variety. It was observed that QHWT significantly affected weight loss and external appearance in all the sampling stages. Firmness and TSS were not significant at any of the sampling stages. By contrast, the QHWT affected significantly the pulp color only at day 4th of market simulation, whereas tritatable acidity and the ratio °Bx/Acidity were significant only at the end of refrigerated period.

Table 12. Analysis of Variance of the effect of QHWT on main quality variables in 'Keitt' variety. Nayarit, México. 2014 season.

	QHWT			
Variable	**Initial**	**21 DR + 0 Amb**	**21 DR + 3 Amb**	**21 DR + 6 Amb**
Weight loss	**NS**	*	*	*
External Appearance	**NS**	*	*	*
Firmness	**NS**	**NS**	**NS**	**NS**
Pulp color	**NS**	**NS**	*	**NS**
TSS	**NS**	**NS**	**NS**	**NS**
Tritatable acidity	*	*	**NS**	**NS**
Ratio °Bx/Acidity	*	*	**NS**	**NS**

NS = Non Significant * = Significant ($p \leq 0.05$) ** Highly significant ($p \leq 0.01$)

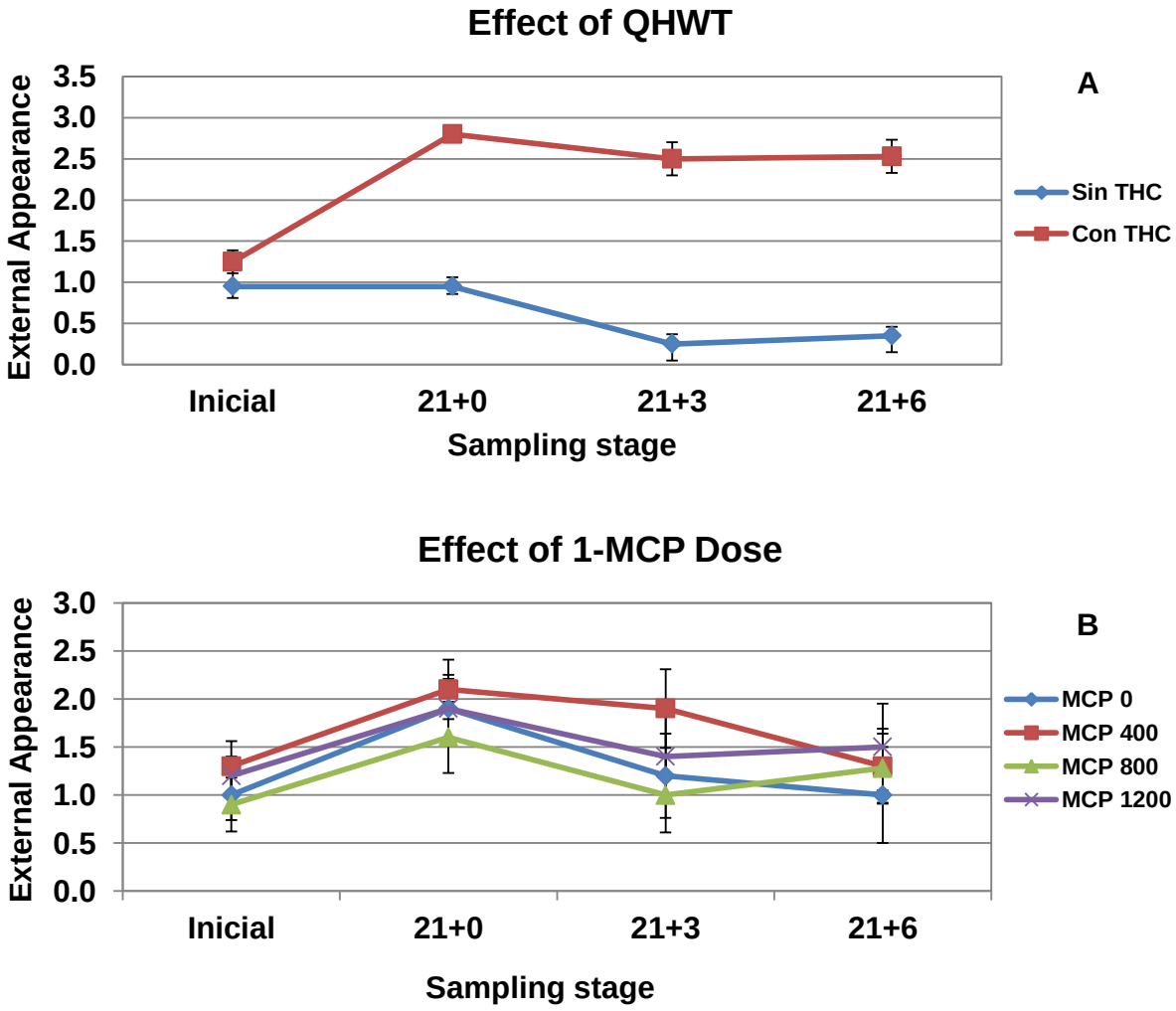
In relation to the effect of aqueous 1-MCP doses (0, 400, 800 y 1200 µg L^{-1}), practically any of the variables was affected for this factor (Table 13). Only weight loss and pulp color showed statistical differences at consumption stage.

Table 13. Analysis of Variance of the effect of 1-MCP doses (0, 400, 800 y 1200 µg L^{-1}) on main quality variables in 'Keitt' variety. Nayarit, México. 2014 season.

	1-MCP			
Variable	**Initial**	**21 DR + 0 Amb**	**21 DR + 3 Amb**	**21 DR + 6 Amb**
Weight loss	**NS**	**NS**	**NS**	*****
External Appearance	**NS**	**NS**	**NS**	**NS**
Firmness	**NS**	**NS**	**NS**	**NS**
Pulp color	**NS**	**NS**	**NS**	*****
TSS	**NS**	**NS**	**NS**	**NS**
Tritatable acidity	**NS**	**NS**	**NS**	**NS**
Ratio °Bx/Acidity	**NS**	**NS**	**NS**	**NS**

NS = Non Significant * = Significant ($p \leq 0.05$) ** Highly significant ($p \leq 0.01$)

The effect of QHWT on external appearance on 'Keitt' fruit was very similar to 'Kent' but more contrasting (Figure 12A). From the end of the refrigerated period until consumption stage fruit with QHWT showed severe damage, while those without QHWT maintained an excellent appearance. In this case it was observed that QHWT was the main responsible for fruit damage (surface spots and lenticel blackening). The 1-MCP doses at 400, 800 y 1,200 µg L^{-1} in combination with QHWT showed lower values to the hydrothermal control and no significant differences were detected among them (Figure 12 B).



0=Excellent (no damage); 1=Good (slight damage); 2=Regular (moderate damage); 3=Poor (severe damage)

Figure 12. Effect of QHWT (A) and 1-MCP doses (B) on External Appearance on 'Keitt' fruit. Nayarit, Mexico. 2014 season.

With respect to firmness, practically no significant differences were detected between fruit with or without QHWT in any of the sampling stages (Figure 13A). However, significant differences were detected for 1-MCP doses (400, 800 y 1,200 µg L^{-1}) comparing to the hydrothermal control only for day 3 of market simulation and at consumption stage (Figure 13B).

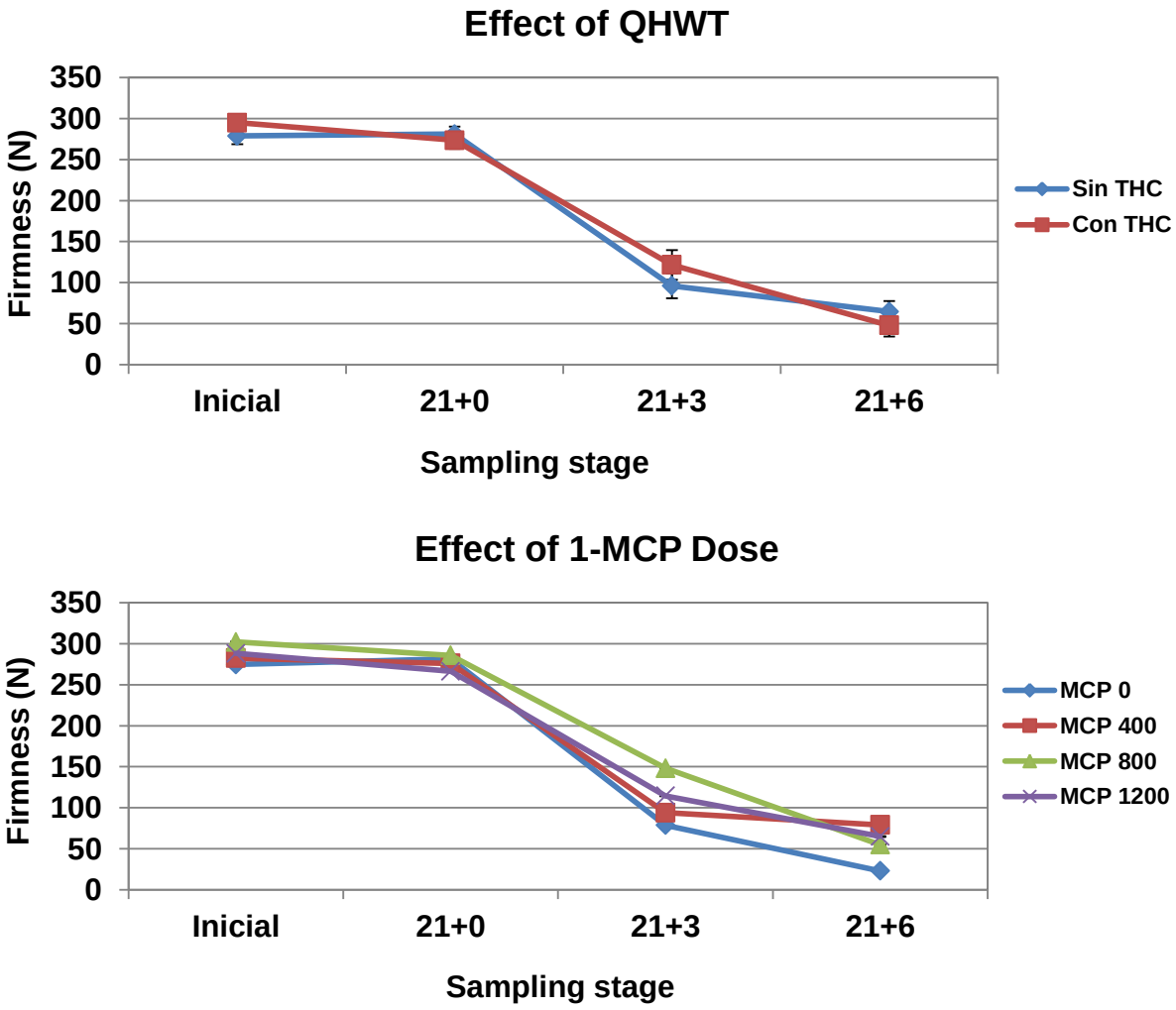
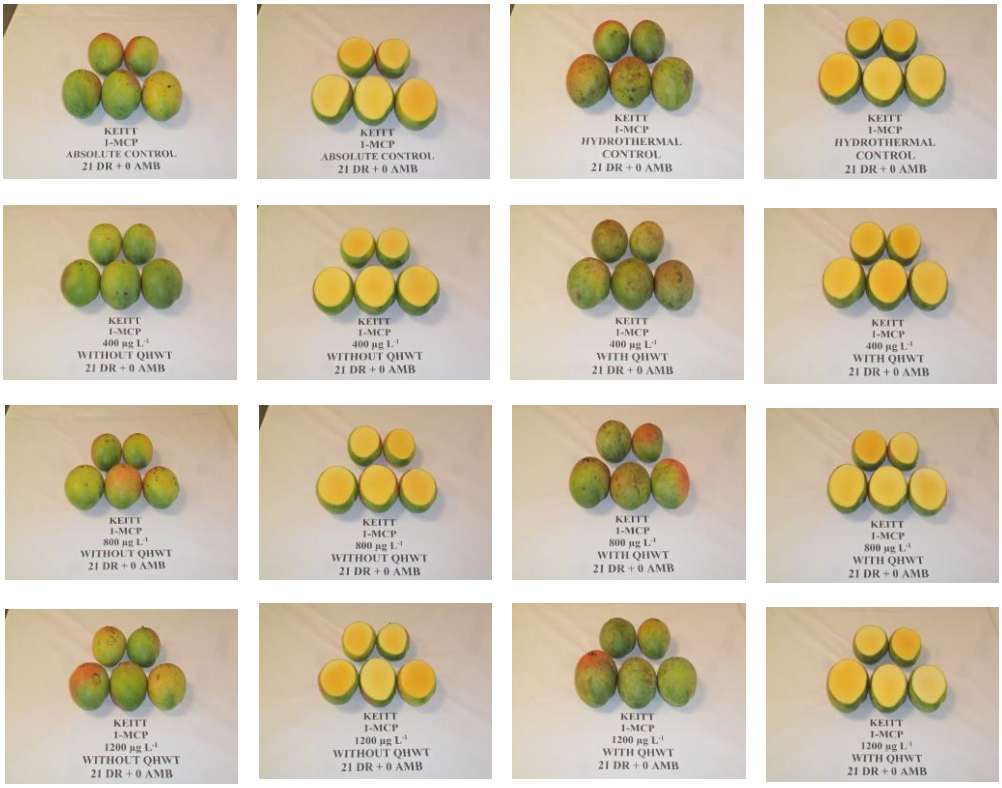


Figure 13. Effect of QHWT (A) and 1-MCP doses (B) on Firmness (N) on 'Keitt' fruit. Nayarit, Mexico. 2014 season.

PHOTO GALLERY KEITT 2014

a. Pictures at the beginning of the experiment

b. Pictures at the end of refrigerated period



c. Pictures at consumption

CONCLUSIONS

- Differences among varieties in response to aqueous 1-MCP were detected. 'Ataulfo', 'Tommy Atkins', and 'Haden' didn't show any significant difference for all variables except for external appearance.

- 'Kent' and 'Keitt' retained firmness longer during shipping simulation; however, the external appearance was negatively affected for the 1-MCP in combination with the QHWT in the five varieties, showing surface spots and lenticel blackening.

- At the end of shipping simulation or at consumption stage fruit treated with 1-MCP before or after QHWT showed fair to poor external appearance while the absolute control (No 1-MCP; No QHWT) or the 1-MCP control (1-MCP without QHWT) had an excellent to good external appearance.

- Aqueous 1-MCP had a good performance in 'Kent' and 'Keitt' fruit since caused delay of fruit ripening as shown by maintenance of fruit firmness, attenuation of pulp color development, and delayed increase of total soluble solids. However, it had a negative interaction with QHWT, causing surface spots and lenticel blackening to develop during shipping simulation (3 weeks at 12 ± 1 °C; 90 ± 5 % RH) and final ripening (7 days at 22 ± 2 ºC; 75 ± 10 % RH).

- It seems that 1-MCP is not a good alternative for mangos exported to the USA, but it may be most useful for mango markets that do not require mandatory QHWT.

REFERENCES

Alves R.E., Filgueiras H.A.C., Almeida A.S., Pereira M.E.C., Cocozza F.M. and Jorge J.T. 2004. Postharvest ripening of 'Tommy Atkins' mangoes on two maturation stages treated with 1-MCP. Acta Horticulturae 645:627-632

Blankenship S.M. and Dole J.M. 2003. 1-Methylcyclopropene: a review. Postharvest Biology and Technology 28: 1–25.

Bretch J.K., Sargent S.A., Kader A.A., Mitcham E.J. Arpaia M.L. 2009. Monitoring and evaluation of the mango supply chain to improve mango quality. Final report. National Mango Board. 19 p.

Contreras-Martínez R., Báez-Sañudo M., Muy-Rangel D., Siller-Cepeda J., Contreras-Angulo L. 2007. Respuesta del mango 'Tommy Atkins' a la aplicación del 1-Metilciclopropeno (1-MCP) en solución acuosa. Efecto de dosis y tiempos de inmersión. XII Congreso nacional SOMECH. p. 68.

Cheng S., Wie B., Ji S. 2012. A novel 1-methylcyclopropene treatment for quality control in Nangou pears at ambient temperature. African Journal of Agricultural Research 7(14):2236-2242.

Choi S.T. and Huber D.J. 2008. Influence of aqueous 1-methylcyclopropene concentration, immersion duration, and solution longevity on the postharvest ripening of breaker-turning tomato (Solanum lycopersicum L.) fruit. Postharvest Biology and Technology 49: 147-154.

Choi S.T., Trouvaltzis P., Lim C.I., and Huber D.J. 2008. Suppression of ripening and induction of asynchronous ripening in tomato and avocado fruits subjected to complete or partial exposure to aqueous solutions of 1-methylcyclopropene. Postharvest Biology and Technology 48: 206-214.

Chaiprasart P. and Hansawasdi C. 2009. Effect of 1-Methylcyclopropene on the shelf life of mango (*Mangifera indica* Linn.) Cv. Nahm-dawg-mai-sri-tong. Acta Horticulturae 820:725-730.

Coêlho de Lima M.A., Luciana da Silva A., Nunes Azevedo S.S.; De Sá Santos P. 2006. Postharvest treatments with 1-methylcyclopropene in 'Tommy Atkins' mango fruit: effect of doses and number of applications. Rev. Bras. Frutic. 28(1):64-68.

EPA. 2002. Federal Register, July 26. Environmental Protection Agency. 67 (144: 48796-48800).

Hofman P.J., Jobin-Décor M., Meiburg G.F., Macnish A.J. and Joyce D.C. 2001. Ripening and quality responses of avocado, custard apple, mango and papaya fruit to 1-methylcyclopropene. Australian Journal of Experimental Agriculture 41:567-572.

Huber D.J. 2008. Suppression of ethylene response through application of 1-Methylcyclopropene: A powerful tool for elucidating ripening and senescence mechanisms in climacteric and nonclimacteric fruits and vegetables. HortScience 43(1): 106-111.

Jiang Y. and Joyce D. 2000. Effects of 1-methylcyclopropene alone and in combination with polyethylene bags on the postharvest life of mango fruits. Ann. Appl. Biol. 137(3):321-327.

Mitcham E and Yahia E. 2009. Alternative treatments to hot water immersion for mango fruit. Final report. National Mango Board. 50 p.

Penchaiya P., Jansasithorn R. and Kanlavanarat S. 2006. Effect of 1-MCP on physiological changes in mango ´Nam Dokmai´. Acta Horticulturae 712:717-722

Pereira-Bomfim M., Pereira-Lima G.P., Rebouças-São José A., Vianello F., Manoel de Oliveira L. 2011. Post-harvest conservation of 'Tommy Atkins' mangoes treated with 1-metilciclopropeno. Rev. Bras. Frutic. 33(1):290-297

Osuna García J.A. y Beltrán T. 2002. SmartFresh™ (1-MCP) for extending the postharvest quality of mangoes, under semicommercial conditions in Mexico. Proceeding of the VII International Mango Symposium. Septiembre 22-27. Recife, Brasil. p. 328.

Osuna García J.A. y Beltrán J.A. 2004. El SmartFreshTM (1-MCP): Una nueva tecnología para exportar mango 'Kent' a Europa o Japón. Desplegable técnica No. 1. Centro de Investigaciones del Pacífico Centro. C.E. Santiago Ixc. 2 p.

Osuna-García J.A. y Muñoz-Ramírez A. 2004. Estrategia de Transferencia de Tecnología del SmartFresh™ (1-Metilciclopropeno) en mango Kent para exportación. Congreso Estatal de Ciencia y Tecnología. Tepic, Nayarit, México. 11 p.

Osuna García J.A., Beltrán J.A. y Urías-López M.A 2005. Influencia del 1-Metilciclopropeno (1-MCP) sobre la vida de anaquel y calidad de mango para exportación. Revista Fitotecnia Mexicana 28(3):271-278.

Osuna García J.A. 2006. Validación semicomercial del SmartFresh™ (1-MCP) en mango 'Kent' y 'Keitt' para exportación. Congreso de Ciencia y Tecnología Nayarit 2006. 256-264.

Osuna García J.A., Cáceres Morales I., Montalvo González E., Mata Montes de Oca M. y Tovar Gómez B. 2007. Efecto del 1-Metilciclopropeno (1-MCP) y tratamiento hidrotérmico sobre la fisiología y calidad del mango 'Keitt'. Revista Chapingo Serie Horticultura 13(2):157-163.

Osuna-García J.A., Pérez-Barraza M.H., Vázquez-Valdivia V., Beltrán J.A. 2009. Methylcyclopropene (1-MCP), a new approach for exporting 'Kent' mangos to Europe and Japan. Acta Horticulturae 820:721-724.

Silva S.M., Santos E.C., Santos A.F., Silveira I.R.B.S., Mendonça R.M.N. and Alves R.E. 2004. Influence of 1-Methylcyclopropene on postharvest conservation of exotic mango cultivars. Acta Horticulturae 645:565-572.

Sisler E.C. and Serek M. 1997. Inhibitors of ethylene responses in plants at the receptor level: Recent developments. Physiologia Plantarum 100(3): 577-582.

Sisler E.C. and Serek M. 1999. Compounds controlling the ethylene receptor. Bot. Bull. Acad. Sin. 40: 1-7.

U.S. Department of Agriculture. Animal and Plant Health Inspection Service. Plant Protection and Quarantine. 2010. Treatment manual. http://www.aphis.usda.gov/import_export/plants/manuals/ports/downloads/treatment.pdf.
USDA Foreign Agricultural Service. Three years trends for U.S. mango imports. 2012. http://www.fas.usda.gov.

Warren O. 2009. Quality of carambola fruit (*averrhoa carambola* L.) as affected by harvest maturity, postharvest wax coating, ethylene, and 1-Methylcyclopropene. M. Sc. Thesis. Horticultural Science Department. University of Florida. Gainesville, FL. 137 p.

Watkins C.B. and Miller W.B. 2005. A summary of physiological processes or disorders in fruits, vegetables and ornamental products that are delayed or decreased, increased, or unaffected by application of 1-methylcyclopropene (1-MCP). http://www.hort.cornell.edu/mcp/.

Watkins C.B. 2006. 1-Methylcyclopropene (1-MCP) based technologies for storage and shelf life extension. Int. J. Postharvest Technology and Innovation 1(1):62-68.

Watkins C.B. 2008. Overview of 1-Methylcyclopropene trials and uses for edible horticultural crops. HortScience 43(1): 86-94.