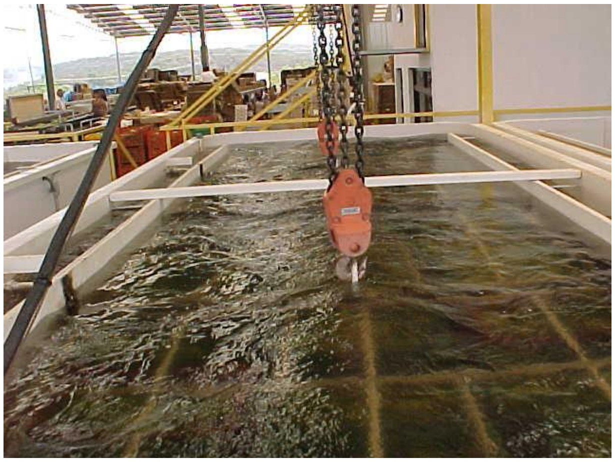
AGREEMENT INIFAP-NMB

DETERMINATION OF FRUIT INJURY BY QUARANTINE HOT WATER TREATMENT ON TOMMY ATKINS FRUIT GROWN IN MEXICO



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ABSTRACT

The Quarantine Hot Water Treatment (QHWT) is a mandatory norm to export mangos to the USA and it is largely attributed with the loss of the quality of the fruit. If this treatment is applied properly and other factors are taken care of such as ripening stage, temperature treatment, hydrocooling and careful management, the quality of the mangos exported to the US would be potentially greater than at present. The objectives of this study were: a. To determine the injury level of QHWT on the physicochemical characteristics and shelf life of the main mango varieties grown in Mexico; b. To quantify the effect of fruit ripeness, the duration and temperature of hydrothermal treatment on quality and shelf life of the main mango varieties grown in Mexico; c. To evaluate the potential seasonal differences of heat injury. Sixty two fruit per treatment were collected immediately after washing, and rated for 75 or 90 min for QHWT, separated by ripeness considering partially ripe fruit (flat shape without full cheeks and shoulders below the pedicel insertion; pulp color values between 1 and 2 and total soluble solids content < 7.3 °Bx) and ripe fruit (round shape with full cheeks and shoulders above the pedicel insertion; pulp color values between 2 and 3 and total soluble solids content of > 7.3 °Bx). Fruit were with excellent external appearance, free of mechanical damage, pests, and diseases**.** Then the fruit were divided into five lots for application of QHWT (the untreated control and the four mentioned temperatures using hydrothermal separate bins for each temperature or set point). At the end of the QHWT, fruit were immediately hydro cooled for 20 min. Fruit were transferred immediately to the postharvest lab at INIFAP-Santiago Ixcuintla Experimental Station for initial analysis and cold preservation (12 ± 1 °C, 90 ± 5% RH) for seven days and subsequent marketing simulation (22 ± 2 °C, 75 ± 10% RH) until ripening. Sampling was done at the beginning and at the end of the refrigerated period and then at consumption stage. A Factorial design was used with 20 replications for weight loss, 10 for fruit temperature and five replications for all the other variables. Results showed that external damage was mainly affected by the set point temperature. Fruit without QHWT did not show any injury while heat treated showed slight injury being those at 117.0 °F which showed slight to moderate injuries. The ripening stage and the hydrothermal time almost did not influence the external damage. The internal injury was almost absent at the end of the refrigerated period under the levels of the factors in study. However, at the consumption stage fruit showed very low and similar internal injury under all the factors. Firmness of the fruit was influenced for all the factors. Partially ripe fruit were firmer than ripe fruits. Fruit heat treated for 75 min were firmer than those for 90 min. The set point temperature significantly affected fruit firmness. The higher the set point temperature, the lower the fruit firmness at the end of the refrigerated period or at consumption stage. Pulp color was mainly influenced by the set point temperature. At the end of the refrigeration period the higher the temperature, the lower the pulp color intensity, while at consumption stage the fruit without QHWT showed the highest pulp color intensity. TSS content was mainly influenced by the ripening stage being the partially ripe fruit which showed less °Bx than ripe fruit. The set point temperature influenced the content of TSS in two ways. At the end of the refrigeration period, the higher the set point, the higher the TSS content. By contrast, at consumption stage, the fruit without QHWT showed the highest TSS content. The most important factor influencing external fruit damage and fruit quality was the set point temperature. The recommended set point between 115.5 and 116.5 °F showed slight damage while that at 117.0 °F showed moderated injury. Thus, if the mandatory QHWT is applied at the recommended set points only slight external injury will observed while maintaining adequate quality and shelf life.

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). With only some exceptions, most of the mangos grown around the world is established in areas having a high presence of fruit fly. For that reason, any mango intended for the US market must be treated with a quarantine hot water treatment (QHWT) to assure fruit fly control. The protocol requires exporters to submit the fruit to a quarantine treatment with hot water (115 °F for 65, 75, 90 o 110 minutes according to the size and weight of the fruit) [USDA, APHIS, PPQ, 2010]. Most of the packers believe that the QHWT is the main factor for fruit quality loss. However, even though some alternative treatments have been tested; the QHWT is still used since several studies demonstrate that fruit quality is not affected when the treatment is applied adequately and low initial investment (Mitcham and Yahia, 2008).

Requirements for the treatment with hot water

The work plan for treatment and certification of Mexican mangos (USDA-SAGARPA, 2012) specifies all the norms and conditions needed for packinghouses to fulfill the protocol for the QHWT. The most relevant points are as follows:

a. A packinghouse with a hot water system must have adequate water heating capacity and an automatic thermostatic control to meet or exceed the required temperature stated in the treatment schedule for the commodity. As well as an approved recording device to register: water temperature, at the beginning and end of every treatment.
b. An automatic size grader is required to separate mangos of different weights to be treated as scheduled during the plant certification tests.
c. The thermostatic control may be programmed at one or several temperatures (set point) depending on control equipment and type of system treatment. These

temperatures must be fixed and secured so that it cannot be changed after certification.

d. The QHWT will be applied to fruits with temperature at least 70 °F (21.1 °C).
e. For round varieties (Haden, Kent, Keitt or Tommy Atkins) fruit must weigh 900 or less for 110 minutes treatment, 700 g or less for 90 minute treatment and 500 g or less for 75 minute treatment without hydrocooling or 120, 100 and 85 minutes with hydrocooling.
f. For flat fruit varieties (Ataulfo or Manila) fruit must weigh 700 g or less for 90 minute treatment, and 570 g or less for 75 minute treatment, and 375 g or less for 65 minute treatment.
g. The actual water temperature after the first five minutes must be ≥ 115 °F (46.1 °C) and must be maintained during the whole treatment; Differences between the highest and lowest temperatures of 1.8 °F (1.0 °C) are allowed. However, if a temperature lower than 115 °F is registered, the treatment is rejected.
h. At the end of the treatment the pulp temperature of the fruit shall be at least 113 °F (45.0 °C).
i. Hydrocooling or other methods of rapidly cooling hot water fruit can be used just after finishing the treatment if additional 10 minute treatment was given. If not, it will be necessary to wait 30 minute until cooling the fruit. In either cases, water or air temperature must be not less than 70 °F (21.1 °C).

Effect of QHWT on quality and shelf life of mango fruit

There are conflicting reports in this regard, but in most cases when the specified time is exceeded and / or the temperature recommended for the control of insects and / or decay are so, heat damage is observed (blanching of skin, lenticel darkening, mottled and uneven ripening) [Kader, 1997; Paull and Armstrong, 1994]. Furthermore, it is documented that hot water treatment increases the respiration rate with a consequent increase in the rate of ripening and senescence; weight loss increases, firmness decreases, causes peduncle collapse, and modifies the structure of the cuticle waxes. These responses are dependent on ripening stage and variety (Becerra, 1989; Mitcham and McDonald, 1993, Ponce de León et al., 1997; Yahia and Fields, 2000; Petit et al., 2009). However, there are several studies showing that the quality of different mango varieties is not affected by the QHWT and instead this treatment helps to reduce the presence of anthracnose and stem rot (Spalding et al., 1988, Sharp et al., 1989a and 1989b; Zambrano and Materano, 1999, Baez et al., 2001, Moon et al., 2006).

Mechanisms to decrease the harmful effect of QHWT

Hydrocooling mango fruit after treatment with hot water decreases rapidly pulp temperature, slow metabolic activity and restore the cuticle of the fruit (Ponce de Leon et al., 1997; Shellie and Mangan, 2002). According to Mitcham and Yahia (2008) some of the following recommendations would help to improve the QHWT decreasing damage and maintaining quality:

1. Make sure the fruit is physiologically mature before treatment. The immature fruit is more susceptible to damage from the hot water.
2. Prevent the fruit surface from being in contact with the latex during harvest. It can exacerbate damage in hot water.
3. Improving the temperature control in the hot water tanks where needed to allow the treatment to be closer to the temperatures required. Even one degree above the required temperature can make the difference in tolerance of the fruit.
4. Always cool the fruit immediately after hot water treatment (after adding the 10 minutes according to the protocol), or after 30 minutes of delay following the hot water treatment, even if the fruit has to be packed immediately or needs to be packed later, and even for fruit that should take 12 hours rest to check for heat injury.
5. Hydrocooling time should be long enough to reach a temperature of 80 to 85 ° F (27 to 29.4 °C) in the center of the pulp (depending on the weight of the fruit, but is about 30 min).
6. Keep the water clean (ensure maximum hygiene) of hydro-cooling to 70-72 ° F (21-22.2 °C) with sufficient cooling capacity (condenser) to remove heat from the fruit.

Problem to solve

QHWT is a mandatory norm to export mangos to the US and it is largely attributed with the loss of the quality of the fruit. If this treatment is applied properly and other factors are taken care of such as ripening stage, temperature treatment, hydrocooling and careful management, the quality of the mangos exported to the US would be potentially greater than at present. For that reason, this project is submitted with the following objectives:

OBJECTIVES

- To determine the injury level of QHWT on the physicochemical characteristics and shelf life of the main mango varieties grown in Mexico.
- To quantify the effect of fruit ripeness, the duration and temperature of hydrothermal treatment on quality and shelf life of the main mango varieties grown in Mexico.
- To evaluate the potential seasonal differences of heat injury.

METHODOLOGY

a. **VARIETY:** Tommy Atkins.

b. **RIPENING STAGE:** Partially ripe and Ripe.

c. **TIMES FOR QHWT:** According to weight fruit and protocol USDA-APHIS: Ataulfo (65 and 75 min); Tommy Atkins and Kent (75 and 90 min) + 10 additional minutes since at the end of QHWT hydrocooling for 20 minutes will be applied.

d. **TEMPERATURES OF HYDROTHERMAL TREATMENT (SET POINTS):**

1. Control (without QHWT))
2. 115.5 °F
3. 116.0 °F
4. 116.5 °F
5. 117.0 °F

e. **HARVESTING DATES:** From March to June, 2013, every four weeks.

Hydrothermal Damage	Origen	Harvest Date	Treatment Date	Packinghouse
1	Chahuites, Oaxaca	23/03/13	26-27/03/13	FarmersBest
2	Cihuatlan, Jalisco	26/05/13	29-30/05/13	FarmersBest
3	18 de Marzo, Nayarit	16/06/13	19/06/13	FarmersBest

f. TREATMENTS

No.	Ripening stage	Hydrothermal time (min)	Hydrothermal Temperature (°F)
1	Partially ripe	75	Without QHWT
2	Partially ripe	90	Without QHWT
3	Partially ripe	75	115.5
4	Partially ripe	90	115.5
5	Partially ripe	75	116.0
6	Partially ripe	90	116.0
7	Partially ripe	75	116.5
8	Partially ripe	90	116.5
9	Partially ripe	75	117.0
10	Partially ripe	90	117.0
11	Ripe	75	Without QHWT
12	Ripe	90	Without QHWT
13	Ripe	75	115.5
14	Ripe	90	115.5
15	Ripe	75	116.0
16	Ripe	90	116.0
17	Ripe	75	116.5
18	Ripe	90	116.5
19	Ripe	75	117.0
20	Ripe	90	117.0

g. STORAGE: Simulation of refrigerated shipment (7 Days at 12 ± 1 °C; 90 ± 5 % RH) + Market simulation (22 ± 2 °C; 75 ± 10 %RH) until consumption stage.

h. SAMPLING: Initial, at the end of refrigerated period and then at consumption stage.

i. **VARIABLES TO MEASURE:** Fruit temperature (initial, at the end of QHWT, at the end of hydrocooling), weight loss, skin color, firmness, pulp color, total soluble solids, tritatable acidity, and hydrothermal injury.

Detailed description of methodology

For each variety in particular, specifically in the mango packinghouse **Agroservicios la 12 S. de R.L. de C.V.**, we got 62 fruit per treatment (2 boxes with 31 fruit each). The fruits were collected immediately after washing, and rated for 75 or 90 min for QHWT, separated by ripeness considering partially ripe fruit (flat shape without full cheeks and shoulders below the pedicel insertion; pulp color values between 1 and 2 and total soluble solids content < 7.3 °Bx) and ripe fruit (round shape wit full cheeks and shoulders above the pedicel insertion; pulp color values between 2 and 3 and total soluble solids content of > 7.3 °Bx). Fruit were with excellent external appearance, free of mechanical damage, pests, and diseases**.** Then the fruit were divided into five lots for application of QHWT (the untreated control and the four mentioned temperatures using hydrothermal separate bins for each temperature or set point). At the end of the QHWT, fruit were immediately hydro cooled for 20 min. The 40 boxes containing the 20 treatments were transferred immediately to the postharvest lab at INIFAP-Santiago Ixcuintla Experimental Station for initial analysis and cold preservation (12 ± 1 °C, 90 ± 5% RH) for seven days and subsequent marketing simulation (22 ± 2 °C, 75 ± 10% RH) until ripening. Sampling was done at the beginning and at the end of the refrigerated period and then at consumption stage.

Variables to measure

Fruit temperature. By using a digital thermometer model JR1 before and at the end of the hydrothermal treatment, and at the end of hydrocooling.

Weight loss. By using an analytical digital balance (Acculab VI-4800) with accuracy of 0.1 g (Ohaus Corp. Florham Park, NJ). Twenty fruit were weighed periodically throughout the evaluation period. The difference in weight with respect to initial weight was expressed as percentage weight loss.

Peel color. By a portable colorimeter CR-10 (Konica Minolta), reporting as L a b.

Firmness. Firmness was measured using a DFE-050 Chatillon penetrometer (Ametek Instruments, Largo, FL) with a 10 mm diameter head. A portion of the skin of approximately 5 mm was removed to expose the pulp and the probe inserted about 4 mm depth at a speed of 180 $mm \cdot min^{-1}$. Measurements should be taken at two opposite sites. Data were expressed in Newtons (N).

Pulp color. By a portable colorimeter CR-10 (Konica Minolta), reporting as Hue values.

Total soluble solids (TSS). By a digital refractometer with temperature compensator, ATAGO model PAL-1 calibrated with distilled water (AOAC, 1984).

Tritatable acidity. It was determined in 3 to 5 g of homogenized sample using phenolphthalein as an indicator with NaOH 0.1 N. Acidity will be reported as % of citric acid.

Injury due to QHWT (Bretch *et al*., 2011)

a. Skin discoloration based on a visual scale

0 = no discoloration (5% or less of the fruit surface affected).

1 = slight (6 a 15% of the fruit surface affected).

2 = Moderate (16 a 25% of the fruit surface affected).

3 = Severe (> 25% of the fruit surface affected).

b. Vascular browning based on a visual scale

0 = Absent.

1 = Slight (discoloration extending to a depth of no more than 5 mm into the flesh).

2 = Moderate (discoloration extending to a depth of more than 10 mm into the flesh).

3 = Severe (discoloration extending to a depth of 15 mm or farther into the flesh).

A Factorial design was used with 20 replications for weight loss, 10 for fruit temperature and five replications for all the other variables.

RESULTS AND DISCUSSION

In the Table 1 it is recorded the Analysis of variance showing the effect of ripening stage, hydrothermal time, and hydrothermal temperature on External and Internal damage, as well as on the main quality variable (weight loss, firmness, pulp color, Total Soluble Solids, and acidity) of Tommy Atkins fruit. It was observed that ripening stage affected significantly the quality variables but not the External and Internal damage. By contrast, the hydrothermal time factor affected significantly External and Internal damage but not quality variables. The Hydrothermal temperature was the most important factor since it affected significantly most of the damage and fruit quality variables.

Table 1. Analysis of variance for ripening stage, hydrothermal time, and hydrothermal temperature on the main quality variable of 'Tommy Atkins' variety. Nayarit, Mexico. Season 2013.

FACTOR	VARIABLES						
	External Damage	Internal Damage	Weight loss	Firmness	Pulp Color	TSS	Acidity
Ripening Stage	NS	NS	*	**	**	**	**
Hydrothermal time	*	*	NS	NS	NS	NS	NS
Hydrothermal Temperature	**	**	**	**	**	*	NS

NS = Non Significant   * Significant (P ≤ 0.05)   ** Significant (P ≤ 0.01)

In the Figure 1 it is illustrated the effect of hydrothermal temperature set point on initial temperature, temperature at the end of QHWT, and temperature after hydro cooling. The initial fruit temperature was around 83 °F, higher than 70 °F, which is the value indicated by the Norm. With respect to the set point treatment, a direct proportional increase was observed according to the specified temperature (115.5 a 117.0 °F). The higher the set point, the higher the temperature at the end of QHWT accomplishing the Norm that establishes the fruit temperature at that point must be higher than 113 °F. On the other hand, a similar respond was observed after the hydro cooling. The lower the set point, the lower the fruit temperature at the end of this process. However, none of the set point treatments was able to return the fruit to the initial values before QHWT. So, it is suggested to assure the 30 min for hydro cooling and be aware that water in the hydrocooling tank remains between 72 and 75 °F.

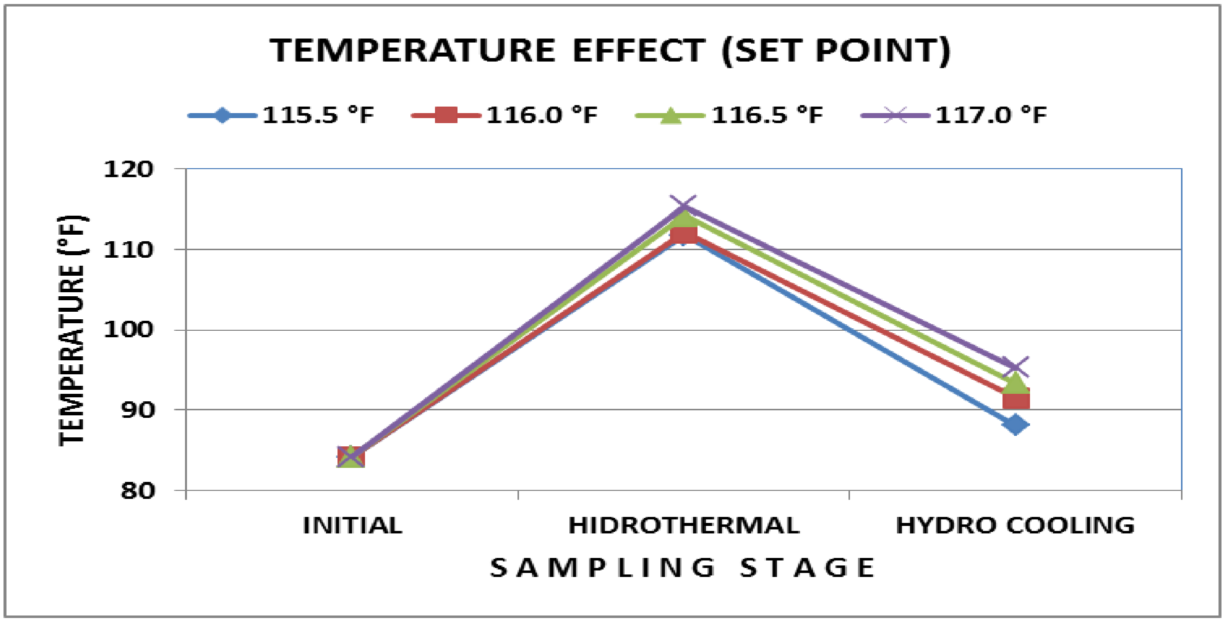

Figure 1. Effect of Hydrothermal Temperature (Set Point) on initial temperature, temperature after QHWT, and Hydro cooling temperature in 'Tommy Atkins' fruit submitted to QHWT. Nayarit, Mexico. Season 2013.

In Table 2 it is stated the effect of ripening stage, the temperature time, and the hydrothermal set point temperature on weight loss (%) of Tommy Atkins fruit at the end of refrigerated shipping simulation (a) or at consuming stage (b) during the three evaluation times. With respect to ripening stage, significant differences were detected only for the harvest in March in Oaxaca, where ripe fruit lost less weight than partially ripe fruit. Concerning to hydrothermal times, no significant differences were detected between 75 and 90 min for any of the sampling times or evaluation dates. However, the temperature set point affected significantly the cumulated weight loss at consumption. The control without QHWT lost less weight than any of the hydrothermal treatments.

Only in the sampling for Oaxaca (March), the recommended temperature (115.0 °F) was statistically equal then the control without QHWT. Both lost less weight than any of the fruit treated at temperature higher than 116.0 °F.

Table 2. Effect of ripening stage, hydrothermal time, and temperature (Set Point) on weight loss (%) of 'Tommy Atkins' fruit at the end of shipping simulation (a) or at consumption stage (b) during the three dates of evaluation. Nayarit, Mexico. Season 2013.

FACTOR	TOMMY ATKINS					
	MARCH (Oaxaca)		MAY (Jalisco)		JUNE (Nayarit)	
	a	b	a	b	a	b
Ripening stage						
a. Partially ripe	2.32 a	7.93 a	2.39 a	6.70 a	1.38 b	5.51 a
b. Ripe	2.22 b	7.15 b	2.59 a	6.68 a	1.46 a	5.65 a
Hydrothermal time						
a. 75 min	2.29 a	7.60 a	2.38 a	6.52 a	1.46 a	5.87 a
b. 90 min	2.25 a	7.47 a	2.60 a	6.87 a	1.38 b	5.29 b
Temperature (Set Point)						
a. Sin THC	2.21 b	6.82 c	1.86 b	5.80 b	1.49 a	5.77 a
b. 115.5 °F	2.16 b	7.30 bc	2.83 a	7.12 a	1.44 ab	5.77 a
c. 116.0 °F	2.38 a	7.91 a	2.65 a	7.07 a	1.33 c	5.24 b
d. 116.5 °F	2.36 a	7.90 a	2.56 a	6.79 a	1.43 ab	5.61 a
e. 117.0 °F	2.23 b	7.72 ab	2.54 a	6.69 a	1.41 ab	5.51 a

Means with the same letter within columns and Factors are statistically equal (Duncan P ≤ 0.05)

In Table 3 it is stated the effect of ripening stage, the temperature time, and the hydrothermal set point temperature on the external damage of Tommy Atkins fruit at the end of refrigerated shipping simulation (a) or at consuming stage (b) during the three evaluation times. No significant differences were found for this variable concerning to the effect of ripening stage or hydrothermal time at any sampling or evaluation date. The only factor affecting fruit external damage was the temperature set point. Fruit without QHWT did not show any symptom, while those treated at recommended temperature (115.5 °F) showed only slight damage, and those treated at 117.0 °F showed damage from slight to moderate. This strength the comments stated in the problematic; if the QHWT is applied according to the norm and other factors like fruit ripening stage, hydro cooling, and care handling are managed accordingly, the potential quality for mango fruit arriving to the USA may be potentially higher.

Table 3. Effect of ripening stage, hydrothermal time, and temperature (Set Point) on External Damage of 'Tommy Atkins' fruit at the end of shipping simulation (a) or at consumption stage (b) during the three dates of evaluation. Nayarit, Mexico. Season 2013.

FACTOR	TOMMY ATKINS					
	MARCH (Oaxaca)		MAY (Jalisco)		JUNE (Nayarit)	
	a	b	a	b	a	b
Ripening Stage						
a. Partially ripe	0.12 a	0.66 a	0.66 a	0.96 b	0.54 a	0.46 a
b. Ripe	0.04 a	0.72 a	0.92 a	1.44 a	0.60 a	0.32 a
Hydrothermal Time						
a. 75 min	0.08 a	0.62 a	0.56 b	1.06 a	0.48 a	0.38 a
b. 90 min	0.08 a	0.76 a	1.02 a	1.34 a	0.66 a	0.40 a
Temperature (Set Point)						
a. No QHWT	0.00 b	0.00 c	0.00 c	0.00 c	0.00 b	0.00 b
b. 115.5 °F	0.20 a	0.50 b	1.30 a	1.55 ab	1.00 a	1.14 a
c. 116.0 °F	0.05 ab	0.85 b	0.60 b	1.00 b	0.55 a	0.00 b
d. 116.5 °F	0.10 ab	0.80 b	0.90 ab	1.55 ab	0.80 a	0.25 b
e. 117.0 °F	0.05 ab	1.30 a	1.15 ab	1.90 a	0.50 ab	0.30 b

Means with the same letter within columns and Factor are not statistically different (Duncan P ≤ 0.05)

Scale values: 0 = No Discoloration 1 = Slight 2 = Moderate 3 = Severe

In Table 4 it is stated the effect of ripening stage, the temperature time, and the hydrothermal set point temperature on the internal damage of Tommy Atkins fruit at the end of refrigerated shipping simulation (a) or at consuming stage (b) during the three evaluation times. No significant differences were found for this variable concerning to the effect of ripening stage or hydrothermal time at any sampling or evaluation date. The only factor affecting fruit internal damage was the temperature set point. Fruit without

QHWT did not show any symptom, while those treated at recommended temperatures (115.5 - 116.0 °F) showed only slight damage. The treatment according to the norm was statistically equal than control fruit without QHWT only for the sampling done at the end of shipping simulation for fruit from Oaxaca. In general, the internal damage was almost imperceptible at the end of shipping simulation and slightly higher at consumption but the values were between absent and slight.

Table 4. Effect of ripening stage, hydrothermal time, and temperature (Set Point) on Internal Damage of 'Tommy Atkins' fruit at the end of shipping simulation (a) or at consumption stage (b) during the three dates of evaluation. Nayarit, Mexico. Season 2013.

FACTOR	TOMMY ATKINS					
	MARCH (Oaxaca)		MAY (Jalisco)		JUNE (Nayarit)	
	a	b	a	b	a	b
Ripening Stage						
a. Partially ripe	0.02 a	0.32 a	0.00 a	0.38 a	0.08 a	0.32 a
b. Ripe	0.04 a	0.38 a	0.00 a	0.26 a	0.12 a	0.22 a
Hydrothermal Time						
a. 75 min	0.04 a	0.30 a	0.00 a	0.18 a	0.02 b	0.20 a
b. 90 min	0.02 a	0.40 a	0.00 a	0.46 a	0.18 a	0.34 a
Temperature (Set Point)						
a. No QHWT	0.00 b	0.00 b	0.00 a	0.00 b	0.00 a	0.00 a
b. 115.5 °F	0.00 b	0.35 ab	0.00 a	0.35 ab	0.15 a	0.40 a
c. 116.0 °F	0.15 a	0.50 a	0.00 a	0.40 ab	0.25 a	0.30 a
d. 116.5 °F	0.00 b	0.50 a	0.00 a	0.50 a	0.10 a	0.35 a
e. 117.0 °F	0.00 b	0.40 ab	0.00 a	0.35 ab	0.00 a	0.30 a

Means with the same letter within columns and Factor are not statistically different (Duncan $P \leq 0.05$)

Scale values: 0 = No Discoloration 1 = Slight 2 = Moderate 3 = Severe

In Table 5 it is stated the effect of ripening stage, the temperature time, and the hydrothermal set point temperature on firmness (N) of Tommy Atkins fruit at the end of refrigerated shipping simulation (a) or at consuming stage (b) during the three evaluation times. This variable was practically affected for all the factors under study. Fruit partially ripe were firmer than ripe fruit; the fruit treated for 75 min were firmer than those treated for 90 min. In addition, the temperature set point significantly affected the fruit firmness. The higher the temperature, the lower the fruit firmness, especially at consumption stage.

Table 5. Effect of ripening stage, hydrothermal time, and temperature (Set Point) on Firmness (N) of 'Tommy Atkins' fruit at the end of shipping simulation (a) or at consumption stage (b) during the three dates of evaluation. Nayarit, Mexico. Season 2013.

FACTOR	TOMMY ATKINS					
	MARCH (Oaxaca)		MAY (Jalisco)		JUNE (Nayarit)	
	a	b	a	b	a	b
Ripening Stage						
a. Partially ripe	266.1 a	22.4 a	244.3 a	23.6 a	273.4 a	24.2 a
b. Ripe	250.8 a	21.0 a	200.6 b	17.2 b	252.3 b	23.3 a
Hydrothermal Time						
a. 75 min	269.0 a	21.9 a	221.8 a	21.6 a	278.9 a	25.6 a
b. 90 min	247.9 b	21.6 a	223.2 a	19.1 a	246.8 b	21.9 b
Temperature (Set Point)						
a. No QHWT	267.3 a	26.4 a	226.7 ab	21.5 a	274.8 a	26.4 ab
b. 115.5 °F	253.9 a	20.4 b	241.5 a	19.2 a	273.3 a	29.9 a
c. 116.0 °F	261.6 a	19.2 b	219.0 ab	20.0 a	253.3 ab	21.7 bc
d. 116.5 °F	262.1 a	20.7 b	241.3 a	20.6 a	277.2 a	20.2 c
e. 117.0 °F	247.3 a	21.9 b	184.0 b	20.5 a	235.7 b	20.5 c

Means with the same letter within columns and Factor are not statistically different (Duncan $P \leq 0.05$)

In Table 6 it is stated the effect of ripening stage, the temperature time, and the hydrothermal set point temperature on pulp color (Hue) of Tommy Atkins fruit at the end of refrigerated shipping simulation (a) or at consuming stage (b) during the three evaluation times. This variable was practically affected for all the factors under study. Partially ripe fruit had less pulp color intensity than ripe fruit; fruit treated for 75 min showed less pulp color intensity than those treated for 90 min. In addition, the temperature set point significantly affected the pulp color. At the end of refrigerated shipping simulation, at higher temperature less intensity of pulp color while at consumption the fruit without QHWT had the highest intensity of pulp color.

Table 6. Effect of ripening stage, hydrothermal time, and temperature (Set Point) on pulp color (Hue) of 'Tommy Atkins' fruit at the end of shipping simulation (a) or at consumption stage (b) during the three dates of evaluation. Nayarit, Mexico. Season 2013.

FACTOR	TOMMY ATKINS					
	MARCH (Oaxaca)		MAY (Jalisco)		JUNE (Nayarit)	
	a	b	a	b	a	b
Ripening Stage						
a. Partially ripe	82.8 a	77.0 a	86.0 a	74.3 a	85.7 a	69.0 a
b. Ripe	81.5 b	76.1 a	83.9 a	71.4 b	83.2 b	67.5 a
Hydrothermal Time						
a. 75 min	82.8 a	76.9 a	85.5 a	72.7 a	85.4 a	68.4 a
b. 90 min	81.4 b	76.2 a	84.4 a	73.0 a	83.5 b	68.0 a
Temperature (Set Point)						
a. No QHWT	82.5 a	74.7 b	86.2 a	71.1 b	86.4 a	66.9 b
b. 115.5 °F	80.8 b	77.0 ab	87.1 a	71.7 b	85.2 a	69.9 a
c. 116.0 °F	82.5 a	75.7 ab	85.4 a	73.4 ab	82.8 b	68.1 ab
d. 116.5 °F	82.4 a	77.2 ab	86.0 a	74.8 a	84.5 ab	67.2 b
e. 117.0 °F	82.4 a	78.2 a	80.1 b	73.3 ab	83.4 b	69.0 ab

Means with the same letter within columns and Factor are not statistically different (Duncan P ≤ 0.05)

In Table 7 it is stated the effect of ripening stage, the temperature time, and the hydrothermal set point temperature on Total Soluble Solids content (°Bx) of Tommy Atkins fruit at the end of refrigerated shipping simulation (a) or at consuming stage (b) during the three evaluation times. The TSS were influenced mainly for the ripening stage. Fruit partially ripe showed less °Bx than ripe fruit. The set point temperature affected in two ways the TSS content: at the end of refrigerated shipping simulation, at higher temperature, higher TSS content. By contrast, at consumption fruit without QHWT showed the highest values of TSS content.

Table 7. Effect of ripening stage, hydrothermal time, and temperature (Set Point) on Total Soluble Solids content (TSS, °Bx) of 'Tommy Atkins' fruit at the end of shipping simulation (a) or at consumption stage (b) during the three dates of evaluation. Nayarit, Mexico. Season 2013.

FACTOR	TOMMY ATKINS					
	MARCH (Oaxaca)		MAY (Jalisco)		JUNE (Nayarit)	
	a	b	a	b	a	b
Ripening stage						
a. Partially ripe	9.2 b	11.7 a	10.4 a	12.4 b	10.7 b	14.1 b
b. Ripe	10.4 a	12.1 a	10.9 a	13.5 a	11.2 a	14.7 a
Hydrothermal time						
a. 75 min	9.8 a	12.0 a	10.7 a	13.1 a	10.8 b	14.4 a
b. 90 min	9.8 a	11.8 a	10.7 a	12.8 a	11.1 a	14.3 a
Temperature (Set Point)						
a. Sin THC	10.0 a	11.4 b	9.7 c	13.9 a	10.3 c	14.4 a
b. 115.5 °F	10.2 a	12.7 a	10.8 ab	12.7 b	10.9 ab	14.1 a
c. 116.0 °F	9.8 a	11.9 b	10.6 b	13.1 ab	11.2 ab	14.4 a
d. 116.5 °F	9.6 a	11.6 b	10.7 b	12.3 b	10.8 ab	14.2 a
e. 117.0 °F	9.5 a	11.9 b	11.6 a	12.7 b	11.5 a	14.7 a

Means with the same letter within columns and Factor are not statistically different (Duncan $P \leq 0.05$)

In Table 8 it is stated the effect of ripening stage, the temperature time, and the hydrothermal set point temperature on Tritatable acidity (% of citric acid) of Tommy Atkins fruit at the end of refrigerated shipping simulation (a) or at consuming stage (b) during the three evaluation times. Acidity was influenced mainly by the ripening stage. Partially ripe fruit were more acid than ripe fruit. The time and temperature set point practically did not influence on acidity.

Table 8. Effect of ripening stage, hydrothermal time, and temperature (Set Point) on Tritatable acidity (% of citric acid) of 'Tommy Atkins' fruit at the end of shipping simulation (a) or at consumption stage (b) during the three dates of evaluation. Nayarit, Mexico. Season 2013.

FACTOR	TOMMY ATKINS					
	MARCH (Oaxaca)		MAY (Jalisco)		JUNE (Nayarit)	
	a	b	a	b	a	b
Ripening stage						
a. Partially ripe	0.90 a	0.18 a	1.00 a	0.21 a	0.59 a	0.20 a
b. Ripe	0.75 b	0.14 b	0.88 b	0.16 b	0.66 a	0.16 a
Hydrothermal time						
a. 75 min	0.79 a	0.18 a	0.94 a	0.17 a	0.67 a	0.18 a
b. 90 min	0.85 a	0.13 b	0.95 a	0.20 a	0.58 a	0.17 a
Temperature (Set Point)						
a. Sin THC	0.93 a	0.18 a	0.97 a	0.19 a	0.68 a	0.22 a
b. 115.5 °F	0.81 a	0.17 a	0.92 a	0.16 a	0.68 a	0.18 ab
c. 116.0 °F	0.74 a	0.12 a	1.01 a	0.18 a	0.48 b	0.14 b
d. 116.5 °F	0.78 a	0.17 a	0.94 a	0.18 a	0.62 ab	0.16 ab
e. 117.0 °F	0.85 a	0.14 a	0.87 a	0.21 a	0.64 ab	0.18 ab

Means with the same letter within columns and Factor are not statistically different (Duncan P ≤ 0.05)

CONCLUSIONS

- External damage was mainly affected by the set point temperature. Fruit without QHWT did not show any injury while that heat treated showed slight injury being those treated at 117.0 °F which showed slight to moderate injuries. The ripening stage and the hydrothermal time almost did not influence the external damage.
- The internal injury was almost absent at the end of the refrigerated period under the levels of the factors in study. However, at the consumption stage fruit showed very low and similar internal injury under all the factors.
- Firmness of the fruit was influenced for all the factors. Partially ripe fruit were firmer than ripe fruits. Fruit heat treated for 75 min were firmer than those for 90 min. The set point temperature significantly affected fruit firmness. The higher the set point temperature, the lower the fruit firmness at the end of the refrigerated period or at consumption stage.
- The pulp color was mainly influenced by the set point temperature. At the end of the refrigeration period the higher the temperature, the lower the pulp color intensity while at consumption stage the fruit without QHWT showed the highest pulp color intensity.
- The TSS content was mainly influenced by the ripening stage being the partially ripe fruit which showed less °Bx than ripe fruit. The set point temperature influenced the content of TSS in two ways. At the end of the refrigeration period, the higher the set point, the higher the TSS content. In contrast, at consumption stage, the fruit without QHWT showed the highest TSS content.
- The most important factor influencing external fruit damage and fruit quality was the set point temperature. The recommended set point between 115.5 and 116.5 °F with slight damage while that at 117.0 °F showed moderated injury. Thus, if the mandatory QHWT is applied at the recommended set points only slight external injury will be observed while maintaining adequate quality and shelf life.

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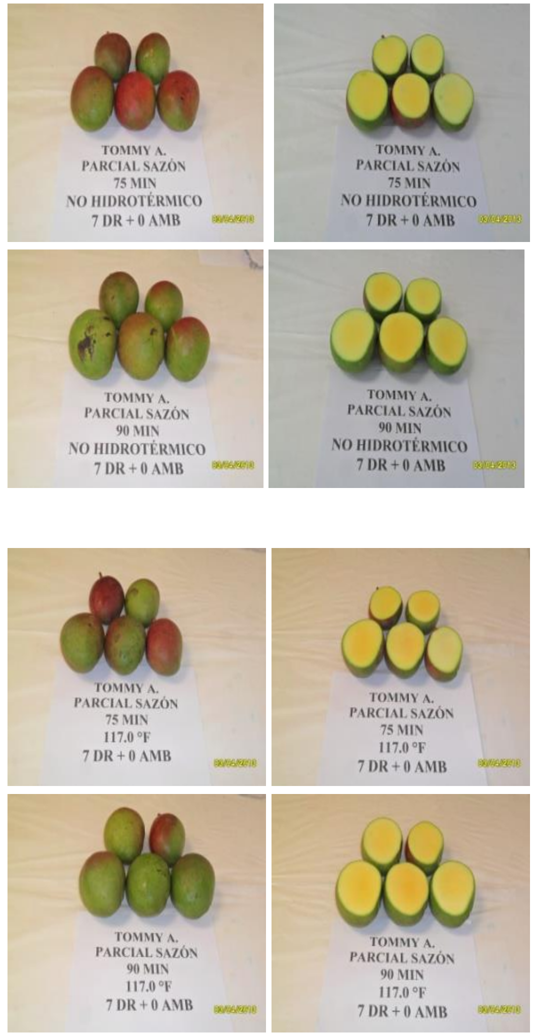
PHOTO GALLERY: a) PARTIALLY RIPE FRUIT (CONTROL WITHOUT QHWT AND SET POINT AT 117.0 °F)

INITIAL

END OF REFRIGERATION



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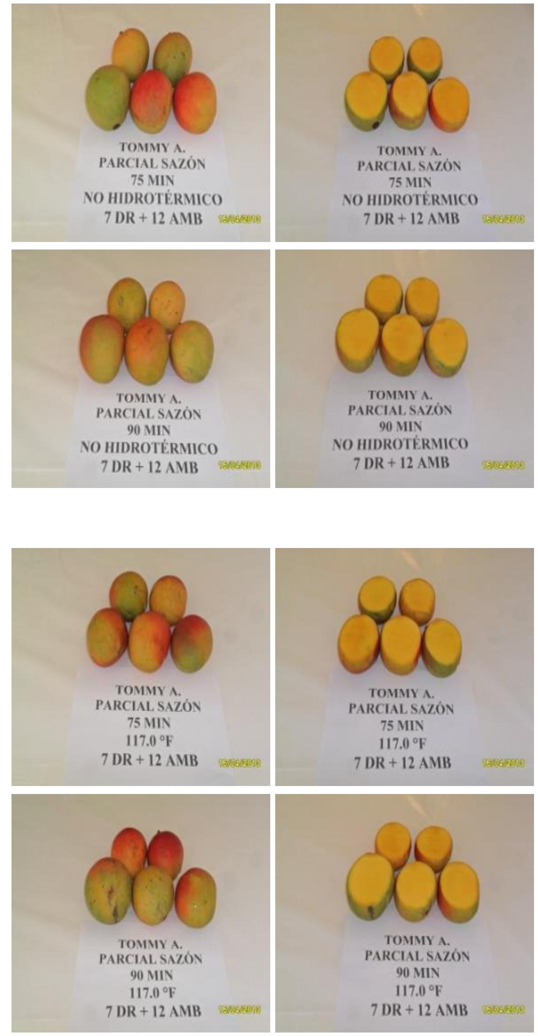
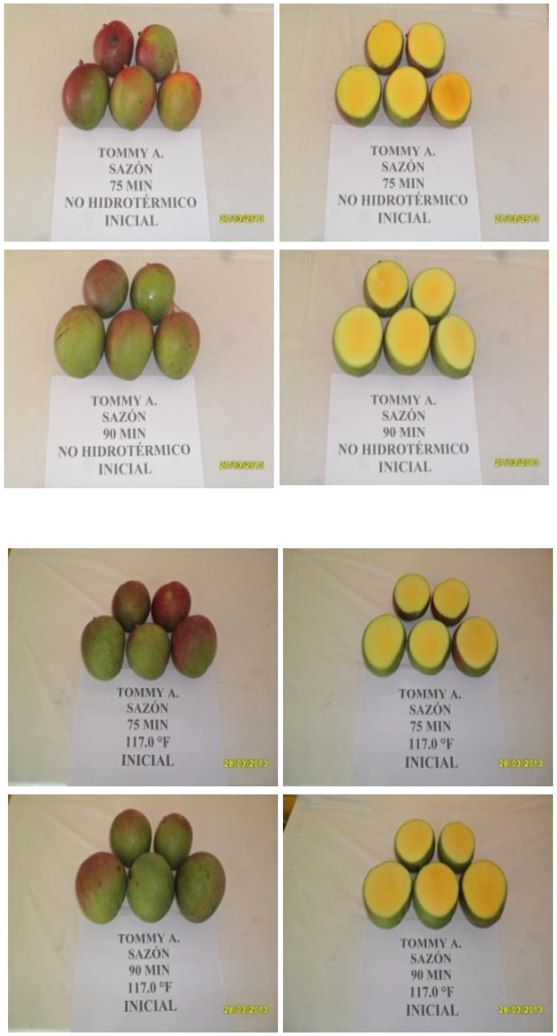


PHOTO GALLERY: a) RIPE FRUIT (CONTROL WITHOUT QHWT AND SET POINT AT 117.0 °F)

INITIAL



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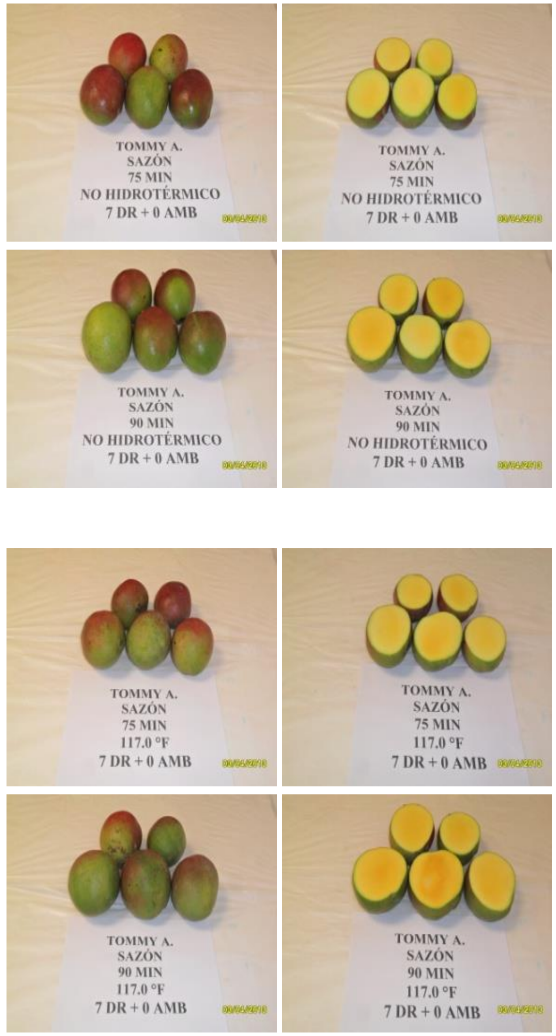

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