*Journal of Applied Horticulture, 12(2): 107-112, July-December, 2010*

# Vapour heat quarantine treatment for Taiwan native mango variety fruits infested with fruit fly

Thi-Nghiem Le[1a], Ching-Chang Shiesh[2b], Huey-Ling Lin[2] and Elsa Lee[2]

*[1]Graduate School of Horticultural Department, Chung Hsing University, 250 Kuo Kang Road, Taichung, Taiwan. [a]Email: nghiemkn12gv@yahoo.com. [2]Horticultural Department, Chung Hsing University. 250 Kuo Kang Road, Taichung, Taiwan. [b]Email: ccshiesh@dragon.nchu.edu.tw*

## Abstract

The objective of the research was to evaluate the efficacy of Vapour heat treatments (VHT) to disinfest the Taiwan native mango variety fruits (Tuu Shien) from the oriental fruit fly (*Dacus dorsalis* Hendel) and the effect of the treatments on the quality of mango fruits. The three stage treatment of forced air at 30°C for 30 minutes, 30 to 48°C for 60 minutes, and then 48°C forced hot air with saturated humidity over the mango fruit surface until the fruit centre temperature reached 46.5°C and fruit was held for 40 minutes. Survival tests showed that both second and third generation instars were more susceptible to the VHT than eggs and there were no surviving oriental fruit fly after 46.5°C for 40 min. The quality of local mango fruits treated with VHT and stored at ambient temperature (28 ± 3°C) for 6 days was not significantly different from the control.

**Key words**: Vapour heat, oriental fruit fly, quarantine pests, 'Tuu Shien' mango

## Introduction

Mango (*Magifera indica*) is one of the most economically important tropical fruits in the world in term of both worldwide production and cultivated area (Castrillo *et al.*, 1992). In Taiwan, mango is a major fruit crop with high potential for export. The oriental fruit fly, *Dacus dorsalis,* is a direct pest of the mango. Quarantine heat treatment to disinfest oriental fruit fly is required by Taiwan's developing mango industry. Taiwan's mango exports to Japan increased from 481 metric tons in 2005 to 787 metric tons in 2007 and export value was increased from 78.4 million NT$ in 2005 to 131.3 million NT$ in 2007 (COA, 2008).

There are some methods to heat fruit to temperatures beyond the target quarantine pest thermal tolerance limit. Hot air has been used for both fungal and insect control and to study the response of commodities to high temperature. Heat is transferred from the air to the fruit by condensation of water Vapour (heat of condensation) on the relatively cooler fruit surface. The technique consists of a period of warming which can be faster or slower depending on a commodity's sensitivity to high temperatures. Fruit may be gradually heated over time to a desired temperature that may be either the treatment end temperature, or a holding temperature maintained for a specific time required to kill all target pests. For mango disinfestation, treatments can only utilize heat, because of the strong sensitivity of this fruit to cold temperatures. The heat treatments, in general, consist of using an immersion in hot water by a system of batches or an uninterrupted bath. Heat can also be obtained by use of forced hot air or hot vapour, because temperatures higher than 45°C kills fly eggs and larvae (Marie-Noëlle *et al.*, 2007). These treatments may then be followed by a fast cooling fruit system which can be carried out by ventilation with cold air or hydro-cooling.

Beside, a commercial 800 watt-microwave oven was used to heat on export-graded 'Chokanan' mango (average mass of 0.32 kg/ fruit). It was found that mango heated at 50% microwave power for 40 seconds yielded an internal temperature of 45°C at 23 mm underneath the skin (Varith *et al.*, 2006). However, even though a drawback of microwaves is non-uniform heating, knowing nature of the microwaves and where the waves concentrate in the mango will help overcome uneven heating problem and assist with the process design (Varith *et al.*, 2006). On the other hand, the treatment of mangoes with microwaves depends much on fruit shape and size. The mango fruit is more or less a compressed, fleshy drupe. It varies considerably in size, shape, colour, flavour, taste, presence of fiber and several other characteristics. The shape of the fruit varies from rounded to ovate-oblong or longish, with the length varying from 2.5 to 30 cm according to variety. So the efficiency of microwave treatment will depend on how the fruit is placed.

The latest technology to control fruit fly infestations in mangoes is the extended hot water treatment (EHWT), a cheaper alternative to the expensive vapour heat treatment (VHT). In EHWT, the fruits are dipped 10 cm below the surface of the heated water at a temperature of 48°C. Pulp temperature at 46°C is held up to 15 minutes and a calibrated thermometer sensor - is used to monitor the pulp and water temperature. Four sensors are attached from the computer to the fruits to record at what time the 48°C-fruit fly killing temperature was reached (Golez, 2009).

The common method used to control fruit fly in mangoes is VHT. However, VHT was developed specifically for insect control. VHT of fruit is air saturated with water vapour at temperatures of 43 to 46.5°C at which insect eggs are killed. This procedure was first used to kill Mediterranean (*Ceratitis capitata* Wiedemann) and Mexican (*Anastrepha ludens* Loew) fruit fly (Hawkins, 1932; Baker, 1952) in a chamber without forced air. In modern facilities, the vapour heat includes forced air which circulates through the pallets and heats the commodity more quickly than vapour heat without forced air.

'Tuu Shien', a Taiwan native mango variety, is a green skin, yellow flesh and small-sized fruit. It has the longest history of cultivation and the largest cultivation area in Taiwan. It was introduced into Taiwan 400 years ago. When 'Tuu Shien' mango fruit are exported to Japan, it is necessary to subject fruit to quarantine heat treatment. This study is to find an optimum procedure of vapour heat treatment for 'Tuu Shien' mango fruit.

## Materials and methods

**Plant material:** The test Taiwan native mangoes (Tuu Shien) were purchased from a local market during the mango season in 2009, and then brought to the Horticultural Research Laboratory, Department of Horticulture, National Chung Hsing University, the night before vapour heat treatment. Mangoes were infested with oriental fruit fly and used in vapour heat treatment tests. Fruits that were of an uniform size, weighing an average of 120–130 g, at horticultural maturity stage (based on external visual colour and size) with an absence of visible wounds were selected.

**Vapour heat treatment:** The VHT is a quarantine method of heating fruit with air saturated with water vapour at temperatures in the range of 40-50°C, according to the procedure developed by Animal and Plant Health Inspection Service (APHIS, 1985). The three stage treatment of forced air at 30°C for 30 minutes, 30 to 48°C for 60 min, and then 48°C forced hot air with saturated humidity is circulated over the mango fruit surfaced until the fruit centre temperature reaches 43 or 46.5°C, depending on treatment aims. In the heat tolerance test of oriental fruit fly in mango fruit inoculated for 0, 2, 4, and 6 days were subjected to the VHT until fruit centre temperature was 43°C for 15 and 30 minutes. In the small-scale disinfestation test inoculated mangoes were subjected to VHT until fruit centre temperature was at 46.5°C for 10, 20, 30, 40, and 50 minutes. In the large-scale disinfestations test, inoculated mangoes were subjected to VHT until fruit centre temperature was 46.5°C for 40 minutes.

**Eggs of oriental fruit fly:** Fruit fly species used in fruit infestations were the oriental fruit fly. The oriental fruit flies were collected annually from infested guava orchards in Chang-hua county (central Taiwan) guava orchards. Wild oriental fruit flies were mixed in with them in order to sustain the population's natural characteristics. The fruit flies used in this study had been kept in the Taichung branch office, APHIS, for 9 generations and fruit fly eggs used to infest mango were collected. The collected eggs were placed in a beaker and provided with water and oxygen for preservation before use in testing. Some of the collected eggs were also preserved for 20 to 30 hours by evenly spreading them over a wet, black cotton cloth and keeping them at room temperature 25 ± 2°C. Eggs were kept on a wet black cotton cloth and were placed in Petri dish in groups of 50 eggs. Then groups of 50, 100, 150, 200 eggs were determined by a chronometer and injected into mango fruits.

**Oriental fruit fly eggs infestation method:** A knife was used to slice a 1.5 cm triangular cut on the face of each mango. A piece of pulp of the same volume was removed, but the peel of the mango was retained to recover the hole. Oriental fruit fly eggs were injected below the fruit surface in each triangular hole. After the process of egg injections was finished, a piece of sticking-plaster was used to cover the hole. The infested mango fruits were enclosed in loosely tied white nets to prevent the escape of maggots. They were placed in plastic baskets (35 x 30 x 7 cm) then the baskets were put into plastic trays. Lastly, the top of trays were tightly covered by black cloths. The trays were placed in room temperature for incubation until the larvae developed to the desired stage.

**The test for density of oriental fruit fly in mango:** Oriental fruit fly eggs (50, 100, 150, and 200 per hole) were separately inoculated into the triangular hole cut into mango fruits. Seven days after the inoculation, 3 mango fruits from every batch were selected to determine the number of live larvae. Larvae were counted to determine the number hatched during the 7 day incubation period.

**The test for development of oriental fruit fly in mango:** Fifty oriental fruit flies were separately inoculated into the triangular hole on mango fruits. On each of the 8 days after the inoculation, the 5 mango fruits were cut to collect larvae and the developing stages were identified. First and second-instar larvae were distinguished according to the presence of a front spiracle. Second and third-instar larvae were identified by the size, shape, and length of their oral hooks. For each day, the results were counted and recorded for larvae rate and growth stage.

**Heat tolerance test of oriental fruit fly in mango fruit:** To test the heat tolerance of oriental fruit fly, vapour heat treatment was used. A batch of 100 oriental fruit fly eggs was inoculated into mango. All of the fruits were placed in baskets according to the time duration of its VHT treatment. The infested mangoes were divided into 5 groups and incubated at room temperature for 0, 2, 4 or 6 days. Then they were subjected to VHT until fruit centre temperature held at 43°C for either 15 or 30 minutes. Control was no heat treatment. After VHT finished, the baskets were taken out, wrapped in white netting, cooled, and kept at room temperature. Finally, mortality rates for each treatment were calculated, vapour resistance for each immature stage was compared.

**The test for small-scale disinfestations:** The mango fruits were treated with 48°C vapour heat until the fruit centre temperature reached to 46.5°C and then held for 10, 20, 30, 40 and 50 min, respectively. In the small-scale test, each fruit was artificially inoculated with 100 eggs, the then placed into groups of thirty fruits for each treatment. There were 6 treatments for time including control. After vapour heat, the fruits were kept at room temperature for 7 days. The larvae were then collected by rinsing the fruits with water over screen filters. The larvae were counted after development to the third-instar. The number of survivor and mortality rate were counted and recorded. The results of the disinfestation test were determined.

**The test for large-scale disinfestations:** This test for large-scale disinfestation follows the method as the same small-scale disinfestations tests. However, a mango fruit was inoculated with 200 oriental fruit fly eggs in two holes. They were divided into a control and one large test group. The large test group was subjected to vapour heat treatment until fruit centre temperature was 46.5°C for 40 minutes, removed to room temperature for 7 days and then counted. The number of survivor and mortality rate also were counted and recorded.

**Quality analysis:** Ninety sample mangoes were taken from the

original seven hundred ninety three mangoes for quality analysis. They were placed into 2 jars, ten mangoes each and, 0, 3, and 6 days after VHT, were evaluated for colour, firmness, and total soluble solid.

**Colour and decay:** Decay development was assessed by viewing the mango fruits' skin. A colour index was recorded according to the following rating scale (Shorter and Joyce, 1998): 1 = 100% green; 2 = 75% green; 3 = 50% green and 50% yellow; 4 = 75% yellow; 5 = 100% yellow.

**Firmness (N):** Firmness measurements were taken by Rheo meter (Sun Rheo Meter, Sun Scientific, Japanese) as the force required for a 3 mm stainless steel probe to penetrate the cut surface of mango fruit held perpendicular to the probe. Firmness was reported as force in newtons (N).

**Total soluble solid (TSS):** Immediately after firmness and colour measurements were made, samples were stored at room temperature (25°C) till TSS analysis. Juice samples were prepared by throughly mixing mango slices (two slices for every mango fruit). Total soluble solid was assessed with a Digital Hand-held "Pocket" Refractometer PAL-1 and expressed as a percentage.

**Statistical analysis:** The experiments were conducted in a completely randomized design. The mean values were analyzed by SAS version 9.1 (SAS Institute Inc., Cary, NC, USA). Analysis of variance was performed; means were compared by the least significant difference and Tukey tested at $P$=0.05 and 0.01.

## Results and discussion

**Effect of artificial inoculation density of eggs on the hatch rate of oriental fruit fly:** Different densities of oriental fruit fly eggs were used to test for hatch rate (from 50, 100, 150, and 200 eggs, respectively). After artificial inoculation and incubation at 25°C for 7 days, the highest hatch rate was about 73% in 100 eggs/hole treatment (Table 1). There was no significant difference of hatch rate between treatments (eggs/hole). However, when inoculation density was increased the hatch rate decreased. The results indicated that 100 eggs/hole is optimum density. The rates of oriental fruit fly larvae development were not significantly different between treatments. After 7 days, all larvae had developed to the 3rd stage (Table 1).

**The development of oriental fruit fly in 'Tuu Shien' mango fruit:** Forty mangoes were divided into 8 groups of 5 fruits and each mango was injected with 50 oriental fruit fly eggs. Table 2 shows that according to the rearing time for each group of 'Tuu Shien' mango fruit, larvae rate varied from day to day. The results were used as a basis for distinguishing eggs stage and larvae stage, including the first (1st), second (2rd), and third (3nd) instar larvae. The eggs quickly hatched and those that did not immediately hatch to larvae were reduced from 61.6 to 3.6% on the first day and the second day after inoculation, respectively. On the 1st day after incubation, 38.4% of the eggs had hatched and developed to first instar. The hatching rate increased to 96.4% on the second day. The instar developed to second stage after 3 days of incubation and reached third stage on the fourth day. By the seventh day, 26.7% of the eggs became pupa. However, the rate was only 1.9% on the sixth day. In all groups, over half of the inoculated eggs developed into larvae (Table 2).

Table 1. Effect of density of eggs in artificial inoculation on the hatch rate of oriental fruit fly, in which the inoculated mango fruits were stored at 25±2 °C for 7 days

| Treatments[y] (Eggs/hole) | Larvae (Numer of hole) | Hatch rate (%) | Development stage |
|---|---|---|---|
| 50 | 36.0 | 72.0 | 2.93 |
| 100 | 73.0 | 73.0 | 3.00 |
| 150 | 92.3 | 61.6 | 2.83 |
| 200 | 93.3 | 50.7 | 3.00 |
| Mean | | 64.3 | 2.94 |
| F-value[z] | | NS | NS |
| CV (%) | | 14.2 | 5.58 |

[z]F-value for main effect or interaction significant at $P$>0.05. [y]Fly eggs were placed inside the hollowed area (1 cm$^2$) of the fruit.

According to growth conditions in which the oriental fruit flies were reared, the duration of the egg stage was determined more than 24 hours after egg inoculation. On the other hand, both 1st and 2rd-instar larvae were found on the third day after inoculation. Similarly, the larvae rate for 2rd and 3nd-instar were increased, and it was the highest after 5 days of inoculation of oriental fruit fly eggs. It must be noted that the number of 3rd-instar larvae was higher than other developmental stages after 6 days of egg inoculation. The number of pupa was highest after 8 days of egg inoculation (Table 2). This demonstrated that, after injection of oriental fruit fly eggs into mango fruit, approximately 6 days was needed in order for eggs to change to pupae (Table 2). The development stage for the 3rd-instar larvae of oriental fruit fly on carambola fruits was determined after 5 days of inoculation (Chang *et al.*, 2009).

In addition, there was no difference in larva length after 5, 7, and 8 days, while in the other treatments larva length increased with rearing time (data not shown). The highest degree of larva

Table 2. The development stages of oriental fruit fly in 'Tuu Shien' mango fruit, the infested fruits were inoculated with 50 eggs per fruit and stored at 25±2 °C for 8 days

| Rearing time | Egg (rate) | 1st instar (rate) | 2rd instar (rate) | 3rd instar (rate) | Pupa (rate) | Larva length (mm) |
|---|---|---|---|---|---|---|
| 1 day | 30.8 (61.6) | 19.2 (38.4) | | | | 0.24c[x] |
| 2 days | 0.8 (3.6) | 21.2 (96.4) | | | | 0.54b |
| 3 days | | | 24.6 (100) | | | 0.70b |
| 4 days | | | 2.0 (7.4) | 25 (92.6) | | 0.90a |
| 5 days | | | 3.0 (9.0) | 30 (91.0) | | 0.98a |
| 6 days | | | | 31 (98.1) | 0.6 (1.9) | 1.08a |
| 7 days | | | | 27.4 (73.3) | 10 (26.7) | 1.00a |
| 8 days | | | | 10.4 (44.1) | 13.2 (55.9) | 0.96a |
| Mean | | | | | | 0.80 |
| F-value | | | | | | *** |
| CV (%) | | | | | | 11.68 |

[x]Values in columns followed by the same letter are not significantly different according to the Tukey test of transformed data. F-value for main effect or interaction significant at $P$<0.001

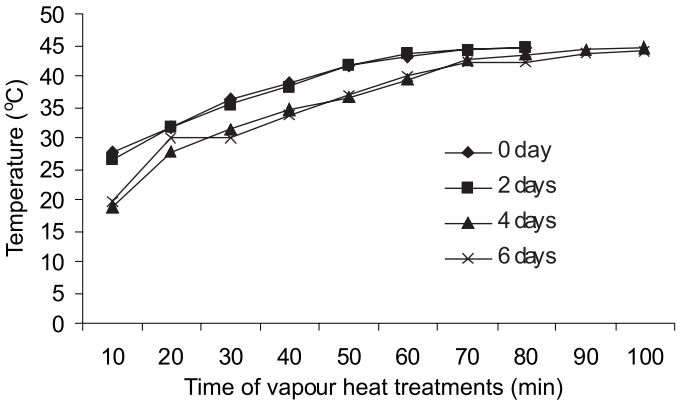


Fig. 1. Fruit centre temperature of mango fruits and air temperature during vapour heat treatment

length was observed at the 6th day. Ronald *et al.* (2007) found that the larva has three stages, and the third instar is about 2/5 inch long and similar results were recorded in this study. This result focused on the importance of identifying rearing time during which eggs change to pupae. The rearing time could attribute to positive effect on larval length because it could determine time for larvae development.

**Heat tolerance test of oriental fruit fly in 'Tuu Shien' mango fruit:** Time of VHT increased with the numbers of days following infestation. The values ranged from 70 to 100 min (0, 2, 4, and 6 days) for mango fruit centre temperature to arrive at 43°C (Fig. 1). At 0 d group, the treatment time was the shortest. But for the 6 d group, the treatment was prolonged to 70 min before mango fruit centre temperature reached 43°C. This proves that, total time of VHT is affected by ripening stage.

The alive instar percentage and mortality rate are shown in Table 3. There were significant differences in the alive instar rate between 15 and 30 min treatments. The mortality rates were increased when samples were treated with vapour heat for a longer time, except that the egg stage for 30 min. At the egg stage, the alive instar percent was different between treatment times, while mortality rate was higher when fruit centre temperature was at 43°C (53.17 and 40.00% for egg stage at 15 min and 30 min, respectively). This was because the VHT at 43°C for 30 min, killed the eggs before they could develop, so the alive instar rates were low. Additionally, for 1st, 2nd, and 3rd instar stage, the alive instar rate was reduced from 37.74 to 10.31% when treatment time was 30 min. For example, the 1st instar with increase of time the mortality rate increased from 32.18 to 62.26%. The 3rd instar with increase of time the mortality rate also increased from 45.59 to 89.69%. On the other hand, all stages with VHT, the mortality rates were increased negative when fruit temperature was at 43°C for 15 min except that the mortality rate decreased positive from the egg stage to the 1st instar stage. The mortality rates were increased negative when fruit centre temperature was at 43°C for 30 min. The alive instar rate was the highest in the control (no VHT), 96.79%, and mortality rate was the lowest. The data showed that the egg stage was the most tolerant to heat (Table 3).

Table 3. Heat tolerance test of oriental fruit fly in 'Tuu Shien' mango fruit

| Stage | Treatments | Alive instar rate (%) | Mortality rate (%) |
|---|---|---|---|
| Egg (24 hrs)[y] | 43°C, 15 min | 46.83ab[x] | 53.17ab |
| | 43°C, 30 min | 60.00ab | 40.00ab |
| 1st-instar (2 days) | 43°C, 15 min | 67.82ab | 32.18ab |
| | 43°C, 30 min | 37.74ab | 62.26ab |
| 2rd-instar (4 days) | 43°C, 15 min | 64.66ab | 35.34ab |
| | 43°C, 30 min | 33.30ab | 66.70ab |
| 3nd-instar (6 days) | 43°C, 15 min | 54.41ab | 45.59ab |
| | 43°C, 30 min | 10.31b | 89.69a |
| 6 days | Control[z] | 96.79a | 3.21b |
| Mean | | 52.43 | 47.57 |
| F-value | | * | * |
| CV (%) | | 69.87 | 77.01 |

[x]Values in columns followed by the same letter are not significantly different according to the Tukey test of transformed data. F-value for main effect or interaction significant at $P>0.05$. z: no heat treatment.
[y]: The number in parenthesis is rearing time.

Vapour heat has been used worldwide to disinfest mangoes from fruit flies (Gaffney *et al.*, 1990). Sein (1935) reported that all immature fruit flies were killed in mangoes from Puerto Rico after exposure to vapour at 43°C for 4 h. Vapour heat was used by Koidsumi (1937) to disinfest mangoes in Taiwan. Sunagawa *et al.* (1987) reported that immature melon fruit fly, *Bactrocera cucurbitae* (Coquillett), in mangoes in Okinawa were killed with vapour heat at 44 ± 0.3°C, >90% RH when the pulp centre reached 43°C and remained at that temperature for 3 h.

Animal and Plant Health Inspection Service (1992) reported that vapour heat treatment at 43°C for 6 h was used on mangoes exported from Mexico. In addition, mangoes that were to be imported from the Philippines or Thailand to Japan had to be treated for fruit flies using vapour heat until fruit centre temperatures were 46.0°C (Philippines) or 46.5°C (Thailand) and held at the respective temperature for 10 min (Anonymous, 1975, 1987).

**The small-scale disinfestations test of oriental fruit fly:** One hundred oriental fruit fly eggs were inoculated per fruit and one hundred eighty mango fruits were used in small-scale test. Table 4 shows that the larvae survival rate after vapour heat treatments where the fruit centre temperature was 46.5°C for different time

Table 4. The small-scale disinfestation of oriental fruit fly in mango fruits

| Treatments | Hatching rate (%) | Survival rate (%) | Mortality rate (%) |
|---|---|---|---|
| Control[y] | 100.00a[x] | 83.43a | 16.56c |
| 46.5° C, 10 min | 100.00a | 64.80b | 35.20b |
| 46.5° C, 20 min | 0.00b | 0.00b | 100.00a |
| 46.5° C, 30 min | 0.067b | 0.00b | 100.00a |
| 46.5° C, 40 min | 0.00b | 0.00b | 100.00a |
| 46.5° C, 50 min | 0.00b | 0.00b | 100.00a |
| Mean | 33.34 | 24.70 | 75.29 |
| F-value | *** | *** | *** |
| CV (%) | 0.45 | 93.89 | 30.80 |

[x]Values in columns followed by the same letter are not significantly different according to the Tukey test of transformed data. F-value for main effect or interaction significant at $P< 0.001$. y: no heat treatment

intervals. There were significant differences in hatching, survival, and mortality rate between the treatments. After eggs inoculation, mangoes were kept for exactly one day at 25 ± 2°C; they were treated with vapour heat; then returned to room temperature for 7 days.

In the control (untreated with vapour heat) the larvae survival rate was 83.43%, while VHT at 46.5°C for only 10 min had 64.80% surviving larvae, a mortality rate of 35.20%. However, VHT for 20 to 50 min left no survivors. It must be noted that there was no difference in VHT besides the time of exposure. However, two eggs did hatch into larva in the batch that underwent to 30 min VHT. The hatching rate was 0.067% in VHT at 46.5°C for 30 min. This demonstrates that VHT with a fruit centre temperature of 46.5°C killed eggs completely after 40 min. Therefore, the treatment of 46.5°C at 40 min can be used for quarantine heat treatment for 'Tuu Shien' mango fruit.

Vapour heat treatments have been reported for Taiwan mangoes which infested with melon fly can be disinfested with vapour heat at 47.5°C until the fruit centre temperature was >46.5°C for 45 min (Kuo *et al.*, 1987). Vapour heat was also approved by Japan in 1986 to allow the import of mangoes from the Philippines (Merino *et al.*, 1985). Currently, Japan requires mangoes from the Philippines and Thailand to be treated with vapour heat until temperature of fruit centre is 46 and 46.5°C, respectively, and held at the respective temperature for 10 min (Anonymous, 1975, 1987). Australia Quarantine and Inspection Service (AQIS) (2008b) reported approval of a vapour heat schedule against Queensland fruit fly (*Bactrocera tryoni*) of 47°C for 15 min, in 'Kensington Pride', 'R2E2', 'Keitt', 'Palmer' and 'Kent' from Australia bound for the Japanese market. Additionally, vapour heat treatment was approved as quarantine treatment for *Anastrepha* species in 'Manila'; oriental fruit fly from Taiwan; and for Mexican fruit fly [(*Anastrepha ludens* (Loew)]. AQIS (2008a) also showed that mangoes from Taiwan imported into Australia must be treated until the pulp temperature has been held at 46.5°C for 30 min.

**The large-scale disinfestation test of oriental fruit fly:** Probit analysis was used to examine the results of the small-scale disinfestation test of oriental fruit fly. As recorded, in the Table 4, there was a mortality rate of 99.93% (data not shown) after 30 min VHT. However, this is unacceptable under probit 9, whose security requires a mortality rate of 99.9968%. Therefore, 40 min VHT was chosen for large-scale disinfestation tests. The results in Table 5 show that there were no survivors when fruit centre temperature was 46.5°C for 40 min. So, the mortality rate for oriental fruit fly eggs was 100%. This documented that, with VHT for fruit centre temperature exposed at 46.5°C for 40 min was sufficient to kill eggs in mango fruit.

**Effect of vapour heat treatment on colour, firmness and total soluble solid of 'Tuu Shien' mango fruits**: The colour of the skin of whole mango fruit was estimated and measured before and after VHT by optic subjective at three different times (0, 3d, 6d). Compared to the control, heat-treated fruit had higher value on the index, indicating yellowing of the skin as previously reported by Segarra-Carmona *et al.* (1990).

The colour by optic subjective for VHT treatments was significantly higher than for the control. These results emphasized

Table 5. Large-scale disinfestation of oriental fruit fly in mango fruits

| Treatments | Number of tested eggs | Number of survivor | Mortality rate (%) |
|---|---|---|---|
| Control (without heat treatment) | 6.000 | 1.511 | 32.68 |
| 46.5°C, 40 min | 60.000 | 0 | 100 |

Table 6. Effect of vapour heat treatment (VHT) on colour, firmness, and total soluble solid (TSS) of mango fruits

| Treatments | Colour | Firmness (N) | TSS (%) |
|---|---|---|---|
| At treatment | 1.8b[x] | 27.3a | 16.3a |
| CK-3d | 2.1ab | 17.6bc | 14.5ab |
| CK-6d | 2.6ab | 13.6c | 14.4ab |
| VHT-3d | 2.8ab | 21.4ab | 14.5ab |
| VHT-6d | 3.2a | 12.6c | 13.7b |
| Mean | 2.5 | 18.50 | 14.69 |
| F-value | * | *** | * |
| CV (%) | 40.22 | 28.85 | 11.23 |

[x]Values in columns followed by the same letter are not significantly different according to the Tukey test of transformed data. F-value for main effect or interaction significant at $0.01<P<0.05$ (*), or $P=0.001$ (***). CK: No heat treatment. VHT: Vapour heat treatment

the influence of the duration of treatment on the VHT (Table 6). For each treatment, the colour value increased during storage time. Table 6 shows that after 6 d, all the treatments showed a rise in colour from 2.6 to 3.2. This was within the threshold 50% yellow and 50% green of the colour index. It was determined, that with a 3 d VHT treatment, the colour of mango fruit was maintained significantly better than with the other treatments. In addition, firmness value decreased during storage for all conditions except for VHT-3 d (Table 6). These results suggest that VHT-3 d maintained the best quality of mango fruit. Total soluble solid percent (TSS %) (Table 6) for CK and VHT was similar whatever the treatment conditions. However, there was a slight decrease of TSS which did not match characteristics of the normal ripening process. The VHT also induced a slight decrease of TSS until after day 6. Compared with the control treatments, VHT-6d treatment decreased the TSS% of mangoes. However, the post treatment changes in TSS% did not appreciably affect the quality of mangoes up to 6 days.

Sein (1935) reported that using VHT to prevent West Indian fruit fly infestation during refrigerated storage for 8 h at 43°C in a circulating atmosphere saturated with moisture did not alter the flavour, texture, and storage quality of 'White' mangoes. Furthermore, vapour heat at 43.5 ± 0.5°C for 3 h for melon fly disinfestations did not injure the mangoes (Sunagawa *et al.,* 1987). The susceptibility of the fruit to storage decay was reported by Hallman *et al.* (1990) in which vapour heat at 46-46.4°C for 3 hours and 45 min resulted in darkening of the oil glands in the peel of 'Marsh' grapefruit. Vapour heat treatment for quarantine security against Caribbean fruit fly at 43.5°C for 260 min on 'Marsh' and 'Ruby' grapefruits did not develop symptoms of quality deterioration (Miller *et al.*, 1991).

Hundred percent of eggs inoculated in 'Tuu Shien' mango fruits were killed with vapour heat treatment at 46.5°C for 40 min. Under this condition, no heat injury occurred and there was no affect on quality. Overall, vapour heat treatment may be used

as a quarantine and disinfestation technique for 'Tuu Shien' mangoes.

## Acknowledgments

We thank Miss Ming-Hui Wang, Mrs Chun-Fen Lin (Department of Horticulture and Taichung Quarantine Center, Taiwan, respectively) for assistance with rear work for preparing fruit fly eggs. We are grateful to Prof. Adel A. Kader (University of California, U.S.A), Prof. Zora Singh (Curtin University, Australia) for their critical reading and valuable comments in improving the contents of the paper.

## References

Animal and Plant Health Inspection Service, 1985. Section III, 9 and section VI-T106. *Plant protection and quanrantine manual*. US Dept. Agric., Wash. DC.

Animal and Plant Health Inspection Service, 1992. T106 (a), (b), and (c): Vapour heat treatment of grapefruit, orange, tangerine, and mango from Mexico for Anastrepha ludens; bell pepper, eggplant, pineapple (other than smooth Cayenne), squash, tomato, and zucchini for *Ceratitis capitata*, *Bactrocera dorsalic*, and *B. cucurbitae*; and mangoes from Taiwan for *Bactrocera dorsalic*. In: *Plant Protection and Quarantine Manual*. US Department of Agriculture, Hyattsville, Maryland, Pp.5.52-5.53.

Anonymous, 1975. Standard established by the Ministry of Agriculture, Forestry and Fisheries on fresh Manila Super variety of mangoes from Phillipines, Notification No. 693. In: *Collection of Ministry Notifications of Plant Protection Laws and Regulations*. Plant Protection Division, Japan Plant Quarantine Association, Tokyo, Pp. 162-163.

Anonymous, 1987. Standard established by the Ministry of Agriculture, Forestry and Fisheries on Fresh Nang Klarngwun variety of mangoes from Thailand, Notification No. 187. In: *Collection of Ministry Notification of Plant Protection Laws and Regulations*. Plant Protection Division, Japan Plant Quarantine Association, Tokyo, Pp. 177-178.

Australia Quarantine and Inspection Service (AQIS), 2008a, AQIS import conditions database. < *http://www.aqis.gov.au/icon32/asp/ex_querycontent.asp*>.

Australia Quarantine and Inspection Service (AQIS), 2008b, <*http://www.aqis.gov.au/phyto/asp/ex_search.asp*>.

Baker, A.C. 1952. The vapour heat process. *The Yearbook of Agriculuture.* pp. 401-404.

Castrillo, M., N.J. Kruger and F.R. Whatley, 1992. Sucrose metabolism in mango fruit during ripening. *Plant Sci.*, 84: 45-51.

Chang, F.C., H.Y. Chen, J.S. Lin, C.L. Chen and S.C. Chen, 2009, Elimination of oriental fruit fly (*Bactrocera dorsalic* Hendel) and melon fly (*B. cucurbitae* Coquillett) infestation in carambola (*Averrhoa carambola* L.) with cold treatment. <*http://stuinfo.nchu.edu.tw/cofsys/plsql/vocscrd_techp*>.

Council of Agriculture (COA), 2008, Taiwan mangoes becoming popular at home and abroad, <*http://www.chinapost.com.tw/taiwan/%20business/2008/06/04/159426/Taiwan-mangoes.htm*>

Gaffney, J.J., G.J. Hallman and J.L. Sharp, 1990. Vapour heat research unit for insect quarantine treatments. *Journal of Economic Entomology*, 83: 1965-1971.

Golez, H. 2009. External Hot Water Treatment: A Cheaper Alternative to Costly Vapour Heat Treatment in Mango. <*http://www.agribusinessweek.com/external-hot-water-treatment-a-cheaper-alternative-to-costly-vapour-heat-treatment-in-mango* >.

Hallman, G.J., J.J. Gaffney and J.L. Sharp, 1990. Vapour heat treatment for grapefruit infested with Caribbean fruit fly (Diptera: Tephritidae). *J. Econ. Entomol*., 83: 1475-1478.

Hawkins, L.A., 1932. Sterilization of citrus fruit by heat. *Citriculture*, 9: 7-22.

Koidsumi, K. 1937. Heat sterilization of Formosan fruits for fruit flies (III). *Japanese Society of Tropical Agriculture*, 9: 275-286.

Kuo, L.S., C.Y. Su, C.Y. Hseu, Y.F. Chao, H.Y. Chen, J.Y. Liao and C.F. Chu, 1987. Vapour heat treatment for elimination of *Dacus dorsalis* and *Dacus cucurbitae* infesting mango fruits. *Taiwan Burean of Commodity Inspection and Quarantine*. Ministry of Economical Affairs, Taipei, Taiwan, October 1987.

Marie-Noëlle, D.C., A. Cecile, K. Valerie and D. Christian, 2007. Fruit flies: disinfestation, techniques used, possible application to mango. *Fruits*, 62: 223-236.

Merino, S.R., M.N. Eugenio, A.U. Ramos and S.T. Hermandez, 1985. Fruit fly disinfestations of mangoes (*Mangifera indica* Linn. var. 'Manila Super') by vapour heat treatment*. Report from the Bureau of Plant Industry*. Ministry of Agriculture and Food, Manila, Philippines to the Ministry of Agriculture, Fisheries and Forestry, Japan, 89 pp.

Miller, W.R., R.E. McDonald, G.J. Hallman and J.L. Sharp, 1991. Condition of Florida grapefruit after exposure to vapour heat quarantine treatment. *HortScience*, 26: 42-44.

Ronald, F.L. Mau and Jayma L. Matin, 2007. *Bactrocera dorsalis* (Hendel). Department of Entomology, University of Honolulu, Hawaii.

Sein, F., Jr. 1935. Heat sterilization of mangoes and guavas for fruit flies. *Journal of Agriculture of the University of Puerto Rico*, 19: 105-115.

Segarra-Carmona, A.E, R.A. Franqui, L.V. Ramirez-Ramos, L.R. Santiago and C.N. Torres-Rivera, 1990. Hot-water dip treatments to destroy *Anastreppha obliqua* larvae (Diptera: Tephritidae) in mangoes from Puerto Rico. *Journal of Agriculture of the University of Puerto Rico*, 74: 441-447.

Shorter, A.J. and D.C. Joyce, 1998. Effect of partial pressure infiltration of calcium into 'Kensington' mango fruit. *Australian Journal Experimental Agriculture*, 38: 287-294.

Sunagawa, K., K. Kume and R. Iwaizumi, 1987. The effectiveness of vapour heat treatment against the melon fly, *Dacus cucurbitae* Coquillett, in mango and fruit tolerance to the treatment. *Research Bulletin of Plant Protection Japan*, 23: 13-20.

Varith, J., W. Sirikajornjaru and T. Kiatsiriroat, 2006. Microwave-vapour heat disinfestations on oriental fruit fly eggs in mangoes. *Journal of Food Processing and Preservation*, 31: 253-269.

Received: May, 2010; Revised: September, 2010; Accepted: October, 2010