Hot Water Immersion Treatment of Nam Dorkmai Mango Infested with Oriental Fruit Fly, *Bactrocera dorsalis* (Hendel), for Export

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ABSTRACT

Hot water immersion treatment is a post-harvest treatment for fruit fly disinfestation and widely used as quarantine treatment in many countries. This technique has not been previously employed in Thai mango exports. The objectives of this research were to examine optimum temperature and exposure period of hot water immersion treatment to eliminate fruit fly, *Bactrocera dorsalis,* eggs and 1st instar larvae in mango variety Nam Dorkmai without affecting fruit quality. Procedures for hot water immersion treatments in small and large scale were arranged. Nam Dorkmai mangoes used for testing were infested with *B. dorsalis,* eggs or 1st instar larvae using artificial infestation and forced infestation methods. The results showed that hot water immersion treatment at the innermost of fruits at 46° C for 10 minutes was effective for elimination of both eggs and 1st instar larvae of *B. dorsalis* without impacting on fruit quality. This information can be applied to quarantine process of *B. dorsalis* infestation in exported Nam Dorkmai mangoes of Thailand.

Keywords: hot water immersion treatment; mango; *Bactrocera dorsalis*

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INTRODUCTION

Mango is one of economic crops of Thailand. According to the report from the Export Plant Quarantine Service Group, Office of Agricultural Regulation, Department of Agriculture; Thailand exported 98,140 tons of mangoes worth 1,694.43 million baht and 113,187 tons worth 2,027.63 million baht in 2015 and 2016, respectively. Among the cultivated mangoes, Nam Dorkmai variety is one of the best for domestic and export markets (Department of Agriculture, 1988). This variety is recognised as Queen of Thai mangoes with beautifully golden yellow pulp and sweet taste.

Fruit fly, *Bactrocera dorsalis* (Hendel), plays very important roles in the exportation of Thai mangoes because many countries have restriction for this insect in imported mangoes. Mango fruits imported from Thailand must be free from fruit flies because fruit flies can cause severe damage to many kinds of fruits. Jirasurat and Prachuabmoh (1998) reported that more than 1,000 million baht of Thai agricultural products were lost annually due to the damage caused by fruit flies. Fruit fly such as *Bactrocera dorsalis* (Hendel) is a quarantine pest of many countries as the eggs were laid in the fruits and the larvae feed inside the fruits that make them very difficult to detect and control. Fruit flies have very wide host ranges. Thus, many countries list them as quarantine pests. This constrains the exportation of agricultural products, especially fresh fruits including fruits of vegetables that are the hosts of these flies. Some countries required phytosanitary measures against fruit flies for importing fresh fruits from Thailand. The post-harvest treatments that are effective against fruit flies are such as irradiation, fumigation, vapor heat treatment and hot water immersion treatment.

In recent years, Thailand has successfully used vapor heat treatment (VHT) against fruit flies in mango and mangosteen that are exported to Japan and Korea and used irradiation for mangosteen, rambutan, longan and lychee that are exported to the USA. However, the investment and operating cost for vapor heat treatment and irradiation are very high. Hot water immersion treatment is another viable option because it is equally effective but comparing to the two methods already mentioned, hot water immersion treatment is less expensive because of its lower investment and operational cost. The rate of heating from the fruit skin to the center of the fruit with hot water immersion is substantially faster than those of VHT and FHAT (Forced hot-air heating) to achieve the same temperature (Couey, 1989; Stewart et al., 1990; Jordan, 1993). However, hot water immersion treatment has not been applied in Thailand because of the export regulations imposed by destination countries.

For examples, Japan requires mangoes from Thailand to be treated by vapor heat treatment, whereas the United States requires irradiation treatment.

Hot water immersion treatment to control fruit flies in mangoes is widely used in many countries, especially in Latin America to control Mexican fruit fly, *Anastrepha ludens* (Loew). It has been accepted as quarantine treatment by the Animal and Plant Health Inspection Service (APHIS), United State Department of Agriculture (USDA) since 1987. Hot water treatment for Mexican fruit fly is conducted at water temperature of 46.1 - 46.5° C for 65 - 110 min depending on weight and varieties of mangoes (Sharp et al., 1989).

The temperature and duration of hot water immersion treatment for disinfestation of fruit fly vary among types of fruits depending on weight and varieties. In order to apply hot water immersion treatment to meet plant quarantine standard for disinfestation of *B. dorsalis* in Nam Dorkmai mangoes for exportation, the efficacy of this treatment needed to be comprehensively investigated in both small-scale and large-scale experiments. The aim of this research was to determine optimum temperature and duration of hot water immersion treatment for complete disinfestation of fruit fly larvae, *B. dorsalis,* in Nam Dorkmai mangoes. The information obtained can be applied to quarantine process of fruit fly disinfestation for the exportation of Thai mangoes.

MATERIALS AND METHODS

1. Insects used in the experiments

Oriental fruit fly, *B. dorsalis,* used in this experiment was collected from infested mangoes, *Mangifera indica* L., in Pak Chong District, Nakhon Ratchasima Province and U Thong District, Suphan Buri Province. The insect colonies were reared at the laboratory of Pest Management Group, Plant Protection Research and Development Office, Department of Agriculture, Bangkok.

1.1 Fruit fly mass rearing technique

Rearing room condition: The colonies of oriental fruit flies were kept in temperature and humidity-controlled room at 26±1° C, with 69±3 % relative humidity (RH) and photoperiod of 12:12 (L:D) h.

Adult rearing: Adults of *B. dorsalis* flies were housed in each of the 16 mesh wire screen cages and fed with artificial diet (yeast : sugar = 1:1). About 5 cages (65.5x69x77 cm) with a population of approximately 20,000 flies per cage and 10 cages (35x50x35 cm) with a population of approximately 2,000 flies per cage were continuously maintained throughout the study.

Egg collecting: A perforated polyethylene container (17 cm in height, tapering downward from 7 to 5.5 cm. diameter) was used as an

egg receptacle inside each adult cage. Periodic checks on hatching rate were made by placing samples with a small camel hair brush on moist blotting paper held in petri dishes and recording the number of hatched eggs.

Larval rearing diet: Larval diet based on corn flour was used for rearing the *B. dorsalis* (Watanabe et al., 1973). The diet tray was covered by the inverted tray to maintain the humidity and was held for pupation.

Pupal handling: Mature larvae began leaving the diet at 6th day after egg transfer, and at this time the cover was removed, and trays were placed in pupae-collecting boxes (43x74x23 cm) containing moist sawdust (to encourage pupation). During pupal stage (8-10 days), at 2 days before expected adult emergence, the pupae were separated from the sawdust. Subsequently, 20,000 pupae were placed in plastic tray (23x32x5 cm.) and transferred to new cage for adult emergence.

Quality control of mass rearing: The laboratory colony of *B. dorsalis* have been routinely checked for quality in every generation. The hatching rate, emerging rate, pupae weight and sex ratio were examined for the quality of the flies.

1.2 Preparation of test insect

Two stages of fruit fly used in the experiment were egg stage and 1st instar larval stage.

1.2.1 Egg preparation: The 24 hours old eggs of *B. dorsalis* were used in disinfestation test. Eggs were collected from reared insect population by using previously mentioned techniques. Adult flies were allowed to lay eggs for 30 min. Eggs were then counted and one hundred eggs transferred to infest the mango pulp following experimental plan.

1.2.2 The 1st instar larvae preparation: The insects were obtained by collecting eggs 40 hours prior. After hatching, some 1st instar larvae burrowed through the muslin cloth into water and some remained on the cloth. The cloth was dipped in distilled water to collect more larvae. One hundred larvae were counted under magnifier and kept in petri dish containing water. The water with collected larvae were poured into fine mesh cloth and transferred into each tested fruit by using camel's hairbrush.

2. Mango fruits used in the experiments

Nam Dorkmai variety mangoes used in the experiment were from GMP farms. The 85% ripeness mango fruits were selected, cleaned, inspected for no symptoms or damage from fruit fly then sized and graded. After that, they were kept in the fruit fly free room. The fruits used in the experiment were of medium size (300 – 359 g) and large size (360 – 420 g), which aligns with the standard export sizes of Thai Nam Dorkmai mangoes.

3. Infestation methods

3.1 Artificial infestation method: This method followed the technique of Unahawutti et al. (1991). This technique was carried out by directly infesting certain developmental stage of fruit fly into the fruit flesh. Prior to artificial infestation, fruits were prepared by removing small piece of mango pulp using 1 cm diameter cork borer to pierce 1 cm deep into the fruit flesh (Figure 1). A thin layer of mango flesh was cut off from the plug so that there was some space for the eggs and larvae to be housed. The plug was inserted back into the hole after eggs or larvae had been transferred into the fruits. Then masking tape was put on the plug to prevent the larvae leaving the fruit. Each fruit was infested with one hundred eggs or one hundred larvae as per experimental plan.

In the case of egg infested fruits, they were kept in temperature-controlled room at 25-27° C until used. They were kept for 1 hour before subjecting to treatments of the experiment.

All larvae infested fruits were kept for 3 hours to allow larvae to burrow inside the fruit before subjecting to treatments.

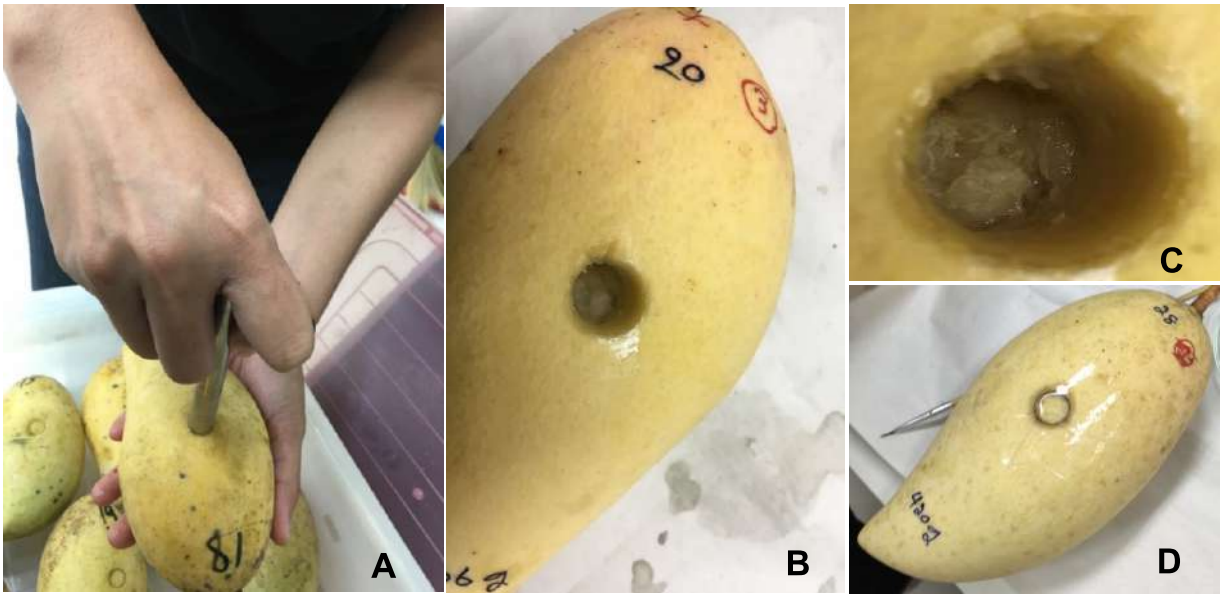

Figure 1 Preparation of infested mangoes by artificial infestation method; (A-B) Holes were made by 1 cm diameter cork borer at 1 cm depth, (C) Transfer eggs or larvae into the hole, (D) Close with masking tape

3.2 Forced infestation method: This method followed that of Unahawutti's technique (Unahawutti et al., 1991). Each test fruit was wrapped up with a clear plastic bag and five punctures were made by insect pin (Figure 2). Subsequently, the

Figure 2 Preparation of infested mangoes by forced infestation method; (A-B) Each mango fruit was wrapped up with clear plastic bag and five punctures were made by insect pin, (C-E) Egg laying of female fruit flies

10 test fruits were placed inside the fruit fly cage whereby puncture holes were exposed to the flies for oviposition. The oviposition was done 40 hours before subjecting to treatments and the exposure time for oviposition was 25 min. Upon completion of exposure time, the fruits were taken out from the cage. Infested fruits were held in temperature-controlled room at 25-27° C until used.

4. Hot water immersion treatments

4.1 Treatment facility

4.1.1 Water bath for small scale treatment: This treatment was conducted by using Memmert® water bath, model: WNB 22. They were electrically heated and electronically controlled. The temperature was measured by using a PT 100 (Class A) temperature sensor (4-wire circuit). The components of temperature control were controlled by integrated malfunction-recognition.

4.1.2 Water bath for large scale treatment: The procedure was conducted by using stainless steel tank (2.53x1.35 x0.6 m.) capable of holding twelve 20 Kg baskets. The temperature of the water was continuously controlled by a microprocessor-controller. The temperature was measured using a PT 100 (Class A). Water circulation system was managed by using water pump size 40 l/min for uniform temperature distribution.

4.1.3 Calibration of resistance thermometers: All sensors were calibrated periodically with a certified precision quality thermometer at a temperature of 47° C. Water temperature was allowed to stabilize for 20 min before data recording began. The actual temperature of water was confirmed with the standard thermometer. Temperature readings of all sensors were recorded every 5 min. Calibration was conducted regularly.

4.1.4 Monitoring of fruit temperature: Fruit temperatures were measured by using platinum resistance thermometer PT 100, protective tube length was 70 mm. and protective tube diameter was 3 mm. The sensors were connected to 6 points-multifunction hybrid recorders (Shinko, model: HR-700).

4.2 Hot water immersion treatments in small scale

This study was conducted at Crop Processing Research and Development Group, Postharvest and Processing Research and Development Division and Pest Management Group, Plant Protection Research and Development Office, from October 2013 until September 2018. The small-scale treatments were preliminary test to determine the temperature and exposure period of hot water immersion treatment to disinfest *B. dorsalis* in mangoes. The artificial infestation method for the tested fruits was prepared.

The stages of fruit fly tested were egg and 1st instar larval stage, based on the results from Kaneyuki et al. (2016) who reported that heat tolerance of *B. dorsalis* at 45° C decreased with increasing age of 1st and 2nd instar larvae, but increased with increasing age of 3rd instar, with 1st instar larvae being the most heat tolerant. The fruits used were medium and large sizes (310-420 g), which aligned with the standard export sizes of Nam Dorkmai mangoes.

The treatments were carried out in Memmert® water bath, model: WNB 22. Treatments temperatures at the innermost of tested fruits were 43° C, 44° C, 45° C, 46° C, 46° C+5 min, 46° C+10 min, 46° C+15 min and 46° C+20 min. The tested fruits were soaked in the water bath one treatment at a time. Five replications were performed. Each replication comprised of 3 treated fruits of egg infestation and 3 treated fruits of 1st instar larvae infestation. A total of 270 treated fruits was used in this experiment which 240 fruits were treated with various treatment temperatures and 30 fruits (15 fruits with egg infestation and 15 fruits with 1st instar larvae infestation) were non-treated control.

After the treatment, the fruit temperature was cooled down by force air cooling for 30 min. All fruits were individually placed in organdy bag separately kept in plastic container (33x41x12 cm) and covered with fine mesh clothes to prevent reinfestation. They were held in temperature-controlled room at 25-27° C until observation. To facilitate larval survival and pupation, test fruits which were obtained by forced infestation method were longitudinally cut 1 or 2 days after treatment. Insect mortality was determined by dissecting the fruits within 4-5 days after treatments and counting the number of dead and live larvae in each fruit. Corrected mortality was calculated by using Abbott's formula (Abbott, 1925). The data were analysed for Probit 9.

4.3 Hot water immersion treatment in large scale

This study was conducted at V.S. Freshco Company Limited. Large scale disinfestation test was carried out to assess the effectiveness of hot water immersion treatment for potential quarantine procedure to disinfest *B. dorsalis*. The treatment was based on preliminary test results from small-scale (4.2).

The tested treatment temperature and time were 46° C for 10 min in commercial water bath. Artificial and forced infestation tested fruits were prepared as described in 3.1 and 3.2. Three replications were performed. Each replication comprised 100 artificial infested fruits, 50 forced infested fruits and 144 filler fruits. The total hot water dipped fruits in each replication were 294. Two hundred and eighty-eight fruits were equally

divided and placed into 12 plastic baskets. Thus, one basket contained 8 artificial infested fruits, 4 forced infested fruits and 12 filler fruits. The remaining 4 artificial infested fruits and 2 forced infested fruits were randomly placed in the baskets to ensure the required number of insects for the experiment. There were also 20 artificial infested fruits and 10 forced infested fruits used as control (non-treated) in each replication.

The artificial infestation of 100 1st instar larvae were used per tested fruit and a total of 300 tested fruits were achieved. Approximately 28,270 larvae (estimated treatment population) were used. Besides, the forced infestation method was applied to 150 fruits for three replications, resulting in an estimated treatment population of approximately 27,580 larvae. Thus,n a total number of the treated fruit in hot water immersion treatment in large scale was 450 fruits or approximately 55,850 of treated 1st instar larvae and 90 fruits as-control (non-treated) or approximately 11,170 of control 1st instar larvae.

The procedure after finishing the treatments and observation of insect mortality were the same as those in hot water immersion treatments in small-scale test. To facilitate larval survival and pupation, tested fruits obtained by forced infestation were longitudinally cut 1 or 2 days after treatment. Number of live individuals was recorded by dissecting the fruits within 4-5 days after treatments.

5. Fruit injury test

This study was to examine the symptoms of thermal injury in treated mango fruits. The tests were carried out using medium to large size mangoes (310-420 g).

5.1 Fruit injury from small-scale treatment

The mangoes were placed in plastic basket (24x30x17 cm) then dipped in water bath, Memmert® WNB 22 at the temperature 48.5° C. Ten treated fruits and 10 control (non-treated) were used in each treatment. The treatments were done when the innermost temperature of fruits reach 48.5° C, 48.5° C +10 min and 48.5° C +20 min. Then, the treated fruits were air cooled for 30 min. The temperatures used for testing heat damage to mango fruits followed the method described by Unahawutti et al. (1991)

5.2 Fruit injury from large-scale treatment

The quality of treated fruits that simulated the situation for exportation by air and by sea were examined and compared the various quality characteristics with the non-treated fruits. Amount of 20 fruits of each were used in the study. The fruits were treated at the innermost temperature of 46° C for 10 min. This particular temperature

and duration were selected because insects had a 100% mortality rate when exposed to 46° C for 5 min. Therefore, the treatment duration was extended to 10 min at the same temperature setting as a precautionary measure to reduce the potential risk of human error during the treatment process. Treated mangoes were air cooled for 30 min after the treatment then put in foam net and placed in the box (32x45x13 cm) which had 4 holes (2.5 cm in diameter); two each on two opposite sides. The holes were covered with fine mesh. Fruits were kept in temperature-controlled room at 10° C for 7 and 14 days.

5.2.1 Percentage of weight loss of mango fruits: Comparison was made between 10 hot water immersion treated mango fruits and equal number of the non-treated (control) fruits. Each fruit was weighed at 0, 7 and 14 day after storage. The weights were recorded and percentages weight loss calculated using the following equation:

Percentage of weight loss = [(pretreatment fruit weight – post storage fruit weight)/pretreatment fruit weight] x 100

The percentages of weight loss of the fruits were averaged and statistically compared the mean using T-test

5.2.2 Brix value of mango fruits: Brix value of each method was measured into 3 replicates at 0, 7 and 14 days after storage. Comparison was made between 9 hot water immersion treated mango fruits and equal number of the non-treated (control) fruits. Measurement of brix value of mango fruit pulp was done using a digital refractometer (DBX-30, Atago Co., Ltd., Tokyo, Japan). Brix value of the fruits was averaged and statistically compared the mean by T-test.

5.2.3 Firmness of mango fruits: Each fruit was divided into 2 sides. Each side was subdivided into 3 parts: top, middle, and bottom. Firmness of each piece was measured into 3 replicates using penetrometer at 0, 7 and 14 day after storage. The firmness of the fruits were averaged and statistically compared the mean by T-test.

RESULTS AND DISCUSSION

1. Hot water immersion treatments in small scale

Preliminary test to disinfest *B. dorsalis* in Nam Dorkmai mangoes was done in small-scale experiment. Result showed that proper temperature of hot water immersion treatment can completely disinfest *B. dorsalis*.

One hundred percent insect mortality was found in mangoes infested with eggs after treatment of innermost temperature at 46° C and at 46° C with various holding times i.e., 46° C +5 min, 46° C +10 min, 46° C +15 min and 46° C +20 min (Table 1). In this experiment it took 61.50 min for the innermost part to reach the desired temperature 46° C.

One hundred percent insect mortality was also found in mangoes infested with 1st instar larvae when treated at the innermost temperature of fruits starting from 46° C with holding time for 5 min (46° C +5 min) and 20 min (46° C +20 min) (Table 1). At the temperature 43° C, 44° C, 45° C and 46° C the mortality was 78.29, 85.89, 98.16 and 99.93%, respectively. This result was similar to the findings of Kaneyuki et al. (2014) and Kaneyuki et al. (2016) that the 1st instar larvae of *B. dorsalis* were more tolerant than eggs and 1st instar larvae were the most heat tolerant at 45° C.

Heat tolerance of immature fruit flies is a concerned factor in hot water immersion treatment. Lapasathukul et al. (2002) conducted a study on the heat tolerance of immature stages of four fruit fly species in Thailand; *B. carambolae*, *B. dorsalis*, *B. papayae*, and *B. pyrifoliae*. The study revealed that 1st instar larvae of each fruit fly species had greater heat tolerance at 45° C than eggs, 2nd, and 3rd instar larvae. Estimated lethal dipping time for eggs and 1st instar larvae of *B. dorsalis* in hot water immersion treatment at 45° C was 17.73 and 29.58 min, respectively. The results were also consistent with Ndlela et al. (2017) who suggested that hot water treatment at a temperature of 46.1° C for 81.47 min could serve as a method for fruit fly disinfestation in mango. Likewise, mango variety Tommy Atkins when treated with hot water at a temperature of 46.1° C for 72.63 min could effectively disinfest fruit fly, *B. dorsalis* before exportation (Mwando et al., 2021).

According to the results, the 1st instar larvae of *B. dorsalis* were more tolerant than eggs. The appropriate temperature of hot water immersion treatment for complete disinfestation of *B. dorsalis* eggs and larvae in Nam Dorkmai mangoes should be at the innermost temperature of 46° C with holding times for 10 min (46° C +10 min) which was more assured for quarantine treatment than 46° C +5 min. The analysis result from Probit 9 also showed that temperature required to kill 99.99683% of *B. dorsalis* in egg stage should be at temperature 44.46° C and holding times for 57.43 min while that of 1st instar larval stage should be at temperature 45.07° C and holding times for 60.62 min. Thus, the temperature of innermost of mango at 46° C +10 min or immersion temperature at 46° C

Table 1 Mortality (%)[1/] of eggs and 1st instar larvae of the oriental fruit flies, *Bactrocera dorsalis* (Hendel), after treatment in hot water immersion at different temperatures and immersion periods in small-scale experiment

Temperature treatment[2/]	Time (min)[3/] of immersion	Number of treated eggs/insects	Egg infestation		1st instar larval infestation	
			Number of dead	Corrected mortality[4/] (%)	Number of dead	Corrected mortality[4/] (%)
Control	0	1,500	118	0	35	0
43°C	50	1,500	974	61.94	1,182	78.29
44°C	55	1,500	1,439	95.59	1,286	85.89
45°C	57	1,500	1,491	99.35	1,473	98.16
46°C	60	1,500	1,500	100	1,499	99.93
46°C+5 min	65	1,500	1,500	100	1,500	100
46°C+10 min	70	1,500	1,500	100	1,500	100
46°C+15 min	75	1,500	1,500	100	1,500	100
46°C+20 min	80	1,500	1,500	100	1,500	100

[1/] Combined data of 5 replications
[2/] Infestation of insects in each treatment was done by inoculation at egg stage with 100 eggs per fruit and at 1st instar larval stage with 100 individuals per fruit
[3/] Timing for immersion in hot water was initiated when the temperature of water in water bath stabilized until fruits were considered receiving required temperature
[4/] Mortality was corrected by using Abbott's formula

for 70 min was chosen for further investigation of hot water immersion treatment of Nam Dorkmai Mangoes for fruit fly disinfestation in large-scale experiment.

2. Hot water immersion treatment in large scale

Confirmatory test to disinfest *B. dorsalis* in Nam Dorkmai mangoes was done in large-scale experiment. The results showed that the treatment with hot water immersion at the innermost temperature of 46° C for 10 min can completely controlled 1st instar larvae of *B. dorsalis* in Nam Dorkmai mangoes because no survival insects were found in both insect infestation methods as shown in Table 2. The result was consistent with hot water immersion treatment of 46.1-46.5° C for 65-110 min depending on weight and varieties of mangoes to control Mexican fruit fly, *Anastrepha ludens,* in mangoes before exportation from Latin America to the USA (Sharp et al., 1989). Therefore, hot water immersion treatment in Nam Dorkmai mangoes at fruit innermost temperature of 46° C and maintained at this temperature for 10 min was effective for disinfestation of both eggs and the 1st instar larvae of *B. dorsalis*, which was the most heat tolerant stage.

Table 2 Survival of 1st instar larvae of the oriental fruit fly, *Bactrocera dorsalis* (Hendel), in mangoes "Nam Dorkmai" treated with hot water immersion at the innermost temperature of 46° C for 10 min in large-scale experiment

Exp.	Infestation method	No. of tested fruits		No. of alive individuals in control	Estimated treated population[1/]	No. of survivors[2/]
		Control	Treatment			
1	1st instar larval infestation	20	100	1,960	9,800	0
	Forced infestation	10	50	1,763	8,815	0
	total	30	150		18,615	0
2	1st instar larval infestation	20	100	1,940	9,700	0
	Forced infestation	10	50	1,699	8,495	0
	total	30	150		18,195	0
3	1st instar larval infestation	20	100	1,954	9,770	0
	Forced infestation	10	50	1,854	9,270	0
	total	30	150		19,040	0
	Total	**90**	**450**	**11,170**	**55,850**	**0**

[1/] The estimated treated populations were calculated from number of larvae in untreated fruits
[2/] Survival of larvae was determined 4 days after treatment

3. Fruit injury test

3.1 Fruit injury from small scale treatment

The quality of Nam Dorkmai mangoes treated at 48.5° C for 0, 10 and 20 min showed no differences from the control in terms of weight loss (Table 3) and Brix value (Table 4). Moreover, there was no symptom of spongy tissue in the treated mangoes which was similar to result of Unahawutti et al. (1991) which reported that modified vapor heat treatment mangoes at 48.5° C for 30 min did not show symptom of spongy tissue in mangoes variety Nam Dorkmai, Rad and Pimsaen Dang.

Table 3 Weight loss (%) of mangoes "Nam Dorkmai" after hot water immersion treatment at 48.5° C with holding times at 0, 10 and 20 min and 7- and 14-days storage at 26.10±1.35° C, 75±5% RH

Days of storage	Treatment	Weight loss (%)[1/]		
		0 min	10 min	20 min
7	48.5°C + holding time min	7.07	6.19	6.18
	control	5.25		
	T-test: 48.5°C vs. Control	ns	ns	ns
14	48.5°C+ holding time min	12.23	12.37	12.23
	control	11.78		
	T-test: 48.5°C vs. Control	ns	ns	ns

[1/] Values are mean of 10 fruits (treatment), and 10 fruits (Control), ns=non-significant

Table 4 Total soluble solid (°Brix) of mangoes "Nam Dorkmai" after hot water immersion at 48.5° C with holding times at 0, 10 and 20 min and 7- and 14-days storage at 26.10±1.35° C, 75±5 % RH

Days of storage	Treatment	Total soluble solid (^{0}Brix)[1/]		
		0 min	10 min	20 min
7	48.5°C + holding time min	16.73	16.83	16.87
	control	16.97		
	T-test: 48.5°C vs. Control	ns	ns	ns
14	48.5°C + holding time min	17.67	17.53	17.60
	control	17.29		
	T-test: 48.5°C vs. Control	ns	ns	ns

[1/] Values are mean of 3 fruits/time (treatment), and 3 fruits/time (Control), ns=non-significant

3.2 Fruit injury from large scale treatment

The quality of treated mangoes kept at temperature-controlled room at 10.05±1.35° C and 74.32±5.18% RH for 7 and 14 days showed no statistical difference from the control mangoes in terms of weight loss, Brix value and flesh firmness (Table 5).

In brief, hot water immersion has a number of advantages which include: relative ease of use by the industries, short treatment time, reliable and accurate monitoring of fruit and water temperatures (Sharp, 1994). Another important advantage of hot water immersion technology from an economic point of view is that the cost of a typical commercial system is approximately 10% of a commercial VHT system (Jordan, 1993). Data from this experiment pointed that hot water immersion treatment of Nam Dorkmai mangoes at innermost temperature of fruits at 46° C and maintained at this temperature for 10 min was effective for elimination of *B. dorsalis* eggs and 1st instar larvae, the most heat tolerant stage. This

Table 5 Weight loss (%), total soluble solid (°Brix) and firmness level (N) of mangoes "Nam Dorkmai" after hot water immersion at 46° C holding times at 10 min and 7 - 14 days storage at 10.05±1.35° C, 74.32±5.18 % RH

Day storage	Treatment	Weight loss (%) [1/]	Total soluble solid (°Brix) [2/]	Firmness level (N) [2/]
7	46°C +10 min	6.01±0.93	16.84±0.11	16.34±0.29
	control	5.57±1.26	16.42±0.53	17.58±0.37
	T-test: 46°C +10 min vs. Control	ns	ns	ns
14	46°C +10 min	13.32±0.19	17.97±0.13	10.33±0.21
	control	12.72±1.01	17.79±0.41	11.94±0.33
	T-test: 46°C +10 min vs. Control	ns	ns	ns

[1/] Value are mean of 30 fruits (treatment), and 10 fruits (Control), ns=non-significant

[2/] Value are mean of 9 fruits (treatment), and 3 fruits (Control), ns=non-significant

temperature caused no damage on fruit quality. Therefore, this method can be used as quarantine process to disinfest of *B. dorsalis* in Nam Dorkmai mangoes before exportation.

CONCLUSION

This research investigated hot water immersion treatment, a technique not previously employed in Thai mango exports, for disinfestation of *B. dorsalis* in Nam Dorkmai mangoes. The optimum temperatures and duration of hot water immersion treatment that can eliminate *B. dorsalis* without affecting fruit quality were examined in small and large-scale experiments. The results revealed that hot water immersion treatment at innermost temperature of fruits at 46° C and maintained at this temperature for 10 min was effective for elimination of the 1st instar larvae, the most heat tolerant stage. This temperature condition did not degrade fruit quality in terms of total soluble solids (Brix value), weight loss, or firmness level. Therefore, this approach can be considered as an alternative method for complying with quarantine regulations in countries that permit hot water treatment for imported Nam Dorkmai mangoes from Thailand.

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