CHAPTER 6

Improving of Thermal Uniformity of Mango during Radio Frequency Heat Treatment for Insect Control

Abstract

Hypothesis in this study was to improve the distribution of electromagnetic energy from radio frequency (RF) heating of mango fruit. Therefore, a rotating container was developed and filled with a medium (water) to support a homogeneous movement and uniformity of electromagnetic energy. The experiment was to compare the uniformity of heat inside mango fruit treated by several thermal methods based on U.S (USDA-APHIS-PPQ, 2002) regulation for control fruit fly in mango. Design of rotating container combined with RF applicator was done. The indicator affected on movement of mango fruit then was investigated by using three different weight (360, 330 and 250g) of mangos (*Magnifera indica* L.) to determine the flow rate as well as the velocity of the movement of fruit around the container per time was also measured. Comparison of heating method between radio frequency, hot water and hot air on mango fruit were evaluated by infrared camera for the uniformity of heat in treated mango fruit. The result was found that 1000 watt RF heating energy applied to container of fruit-roll could provide a consistent distribution of thermal treatment in mango with exposure period for 5-10 minutes equivalent to the result from dipping in hot water for a period of 40 minute. Besides that the thermal distribution in mango treated with hot air showed non-uniform heat distribution inside flesh fruit. Moreover, the RF heating operation process required shorter time than immersion into hot water and exposure to hot air. The results were recorded also that there were no contacted damage since the movement of mango fruit was freely moved in water fulfilled chamber.

6.1 Introduction

The thermal radiofrequency has been studied continuously (Headlee and Burdette, 1929; Frings, 1952; Nelson and Payne, 1982), however one of the main problems is the consistency of heat in the material (Tang *et al*., 2000). Many researchers have been developed, both of methods and techniques to control insect infestation with agricultural products such as codling moth (Wang *et al*., 2001a) and navel orange worm (Wang *et al*., 2002) in walnuts without adverse effect to the quality of raw materials. Recently, The study from the postharvest technology research institute, Chiang Mai University also reported the possibility of RF heat treatment to control rice weevil (*Sitophillus oryzae* L.), angoumois grain moth (*Sitotroga cerealella* (Ollivier)), rice moth (Corcyra cephalonica (Stainton)) and lesser grain borer (*Rhyzopertha dominica* F.) infested in paddy rice and animal feed (Luechai *et al*., 2008; Krisna, 2009; Boaloi, 2009). These study focused on those materials which were orthodox seed and resistant to heat better than fresh fruit. Practically, when the fruits exposed to RF heat treatment, it show a damage both on the peel and flesh due to specific heat point contacted with each other or with RF parallel plate. The damage resulted from the excessive heat since high concentrations of electric field around the area of contact.

Therefore, to avoid the impact of contact between fruits, the medium plays an importance role to support the largest area of radio frequency power in the homogeneous form. The medium has a property of dielectric closed to the fruit should be selected as an intermediary in the process. Moreover, supporting resembles between fruit gap and fruit flesh as much as possible is necessary to decrease difference of dielectric property (Wang *et al*., 2003). Ikediala *et al*. (2002) revealed that using water as a medium in RF heat process showed the improvement of uniformity of heat in cherry fruit; however distribution of the heat in large fruits such as orange and apple expressed thermal fluctuations in temperature both outside and inside fresh fruit. Therefore, dipping the fruit in a medium can solve the problem of necrotic point on fruit, however a heat uniform internal fruit have to be improved especially the energy absorbs area in large fruits and medium due to the difference in electromagnetic field from radio frequency energy. The hypothesis in this study was to support regularly move of mango fruit around the absorb areas of radio frequency energy to improve the uniformity of the large size fruit. Therefore, a rotating container was developed and filled with a medium to support a homogeneous movement and uniformity of electromagnetic energy in the laboratory scale. After that, the uniformity of heat in mango fruit treated by several thermal methods was compared by base on the import of mangoes to the U.S (USDA-APHIS-PPQ, 2002).

6.2 Materials and methods

6.2.1 Design of rotating container combined with RF applicator

The inconsistency of the heat may be caused by irregularities in the distribution of the electromagnetic wave and result to heat transferred at some point of material due to the uneven power between the two poles of the magnetic field. Thus, the movement or rotation of the fruit and fill the gap between them with the solution showing features similar to the dielectric material may help to increase the consistency of heat (Ikediala *et al*., 2002; Wang *et al*., 2003). Dielectric heating is generated from electromagnetic energy at radio frequency (13.56, 27.12 and 40.68 MHz). A high frequency is converted from oscillating electromagnetic field to RF power. As polar molecules in the material continually arrange in a line and reorient them to change electric field. Therefore, the water content of the matter is an important factor for these heating performances. In addition the heat is generated inside out and distributed throughout its mass within the container often hot rapidly. The measurement of dielectric constant over the fruit was higher and heat rate of the magnetic field faster than ordinary water. However, fruit sank in water solution as medium must be expressed electro-conductivity equal to the fruit to avoid the necrotic on the skin and over heat inside the core of fruit (Ikediala *et al*., 2002). The sample fruit should be rotated along the axis to reduce non-uniformity of electromagnetic field within the containers. During rotate, the fruit should not be exposed to the container to avoid the overheating from consolidation of the electromagnetic energy. The container was equipped with a radio frequency generator (Sairem, France) that provides 600 Watts of heat which the RF applicator was established and developed by Institute of Agricultural Engineering, Goettingen University, Germany.

The size of container was designed to provide the rate of heat dissipation when full filled with water. After operating with radio frequency generator, the energy was created and some of them were lost as heat to the environment that heat up water within the container to higher temperature. The transfer of heat to the fruit was calculated from the formula as followed:

$$\rho V C_p \underline{\Delta T} = P \eta \Delta t$$

Where;

η	input power (%)
C_p	specific heat capacity of water at room temperature (4186 $J.kg^{-1}.^{o}C^{-1}$)
ρ	water density (1000kg.m^{-3})
V	capacity of container (m^3)
ΔT	different of the water temperature (ºC)
Δt	time to heat temperature of water up (second)
P	absorbed energy of water to heat temperature up from radio frequency

6.2.2 Improving of thermal uniformity of mango during radio frequency heat treatment for insect control

1) Investigation of the indicator affected on movement of mango fruit

Before the experiment, the containers or fruit mover was filled with clean water and then heated by the RF energy. The temperature of water was measured in 5 positions (4cornersof the container and in the middle) at 1 cm above the hole from the bottom and 1 cm below the surface by measuring the temperature immediately after heating by RF. Then, the uniformity of temperature inside the container was compared with no water rotation by measuring with 3 replications3 times.

Took a sample of mango (*Magnifera indica* L.) three different weight (360, 330 and 250g) mangos to determine the flow rate and the velocity by measuring from the movement of middle fruit around the container per time. Mean values and standard deviations were calculated from 10 replications for each mango weight. Different mango weights were compared using the Statistix program (SX). Where ANOVA showed significant differences ($P \leq 0.05$) and means were separated using least significant difference (LSD) as well as the correlation between weight and rotation was also calculated.

2.) Evaluation the uniformity of heat in treated mango fruit

After fruit mover combined with radio frequency application, a sample mango fruit was put into the rotating container and filled with the exact volume of water at temperature of 25°C. Then, the water was heated with the radio frequency generator with the power of 1000 watt for 5 and 10 minutes. After that the untreated and treated mango samples were cut in half lengthwise. The thermal dissipation inside the fruit was measured by using an infrared camera (Therma CAM^{TM} Researcher 2001, FLIR system, Portland, Oregon).

6.2.3 Comparison of heating method between radio frequency, hot water and hot air on mango fruit

To ensure consistency of heat in mango fruit, the mango (weight 350 g) was heated by several methods. After that the treated mango sample was cut in half lengthwise (Figure 6.1).

Figure 6.1 Mango sample cut in half lengthwise

The thermal dissipation inside the fruit was measured by using an infrared camera (Therma CAM^{TM} Researcher 2001, FLIR system, Portland, Oregon). The methods of heating processes were as followed:

1) Radio frequency heating

Fruit mover was combined with radio frequency application. A sample mango fruit (with a temperature of 19°C) was put into the rotating container and filled with the exact volume of water at temperature of 25°C. Then, the water was heated with the radio frequency generator with the temperature of 48°C for 8 minutes.

2) Hot air dryers heating

A fruit (with a temperature of 19°C) was put into dryer that heat up by blowing from heated coil at a constant temperature of 46°C using embedding ventilator (at 1 meter per second) to control. A sample mango fruit was placed in the middle of the cabinet to allow the hot air blowing throughout the fruit for 10 minutes.

3) Hot water heating

Hot water was prepared in a water bath with a flow rate of 1 meter per second. Mango fruit was dipped into the hot water at the constant temperature of 46°C. The temperature of the mango was dipped and heated with steam heat in hot water for different periods of 10, 20, 30 and 40 minutes.

6.3 Results

6.3.1 System of RF generator combined with rotating container and procedure

RF energy was used as the main source of heating dispersal in fruit rotating chamber in all treatment methods and used in combination with RF energy (Figure 6.2). The RF power was supplied by 6 kW, 27.12 MHz pilot scale RF system (Sirem, France). The gap between electrode plates was adjusted, then the samples were treated with 0.1 kW RF energy.

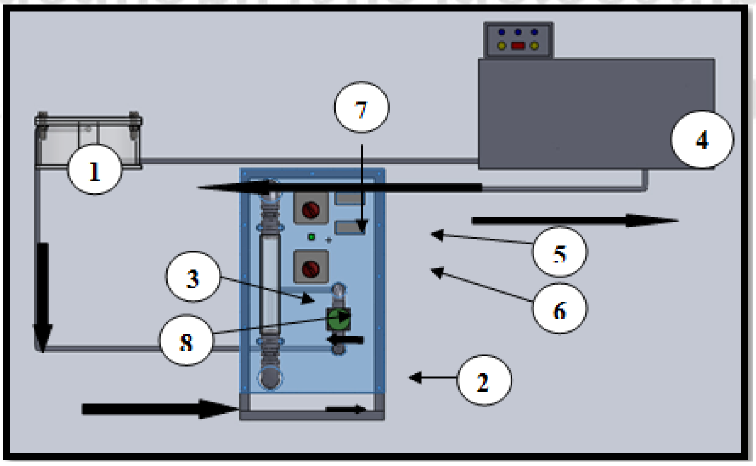

Figure 6.2 Schematic diagram of fruit chamber

6.3.2 Indicator affected on movement of mango fruit

Comparison of the three different weight of mango movement in fruit rotating container filled with water showed that the rate of injection was 11.5 liters per minute affected on the rotation in round per minute of mango as shown in Table 2. Mango with weight of 366 g showed the lower velocity (32 rpm) than 330 and 250g (35 and 41 rpm, respectively). Statistics analysis showed that different in mango weight significant affected on rotation of mango in rotating chamber ($P \leq 0.05$). The correlation between mango weight and rotation also showed significant different (r=-9363, ($P \leq 0.05$). It can be implied that increasing size of fruit reduced the motion rate.

Table 6.1 Velocity of different mango weight in rotating chamber filled with water

Weight of mango (g)	**Water flow rate (Liter/min)**	**Mango rotation (rpm)**
366	11.5	32±1.47 a*
330	11.5	35±1.49 b
250	11.5	41±1.48 c

*Different letters within row indicate that means are significantly different ($P \leq 0.05$)

6.3.3 Evaluation the uniformity of heat in treated mango fruit

Figure 6.3 shows temperature variation in RF heating of mango without heating (Figure 4A) which the temperature of skin was 22°C and inside the fruit was 20°C while the core of fruit was lower (19°C). When the mango was heated with RF heat energy for 5 minute (Figure 6.3B), the mean temperature of individual mango varied from 30 to 35°C while the non-uniform heating was observed at the core of fruit which temperature was 30°C. The consistent hot spot on the end of mango fruit (Figure 6.3C) was observed when exposure time for 10 minutes and raised the temperature range from 35 to 45°C. On the other hand. When expose mango to RF heating at the temperature of 48°C for 8 min, overheating was observed since at the fruit surface and non-uniform heat was expressed inside the fruit while the temperature rage from 35 to 42.5°C.

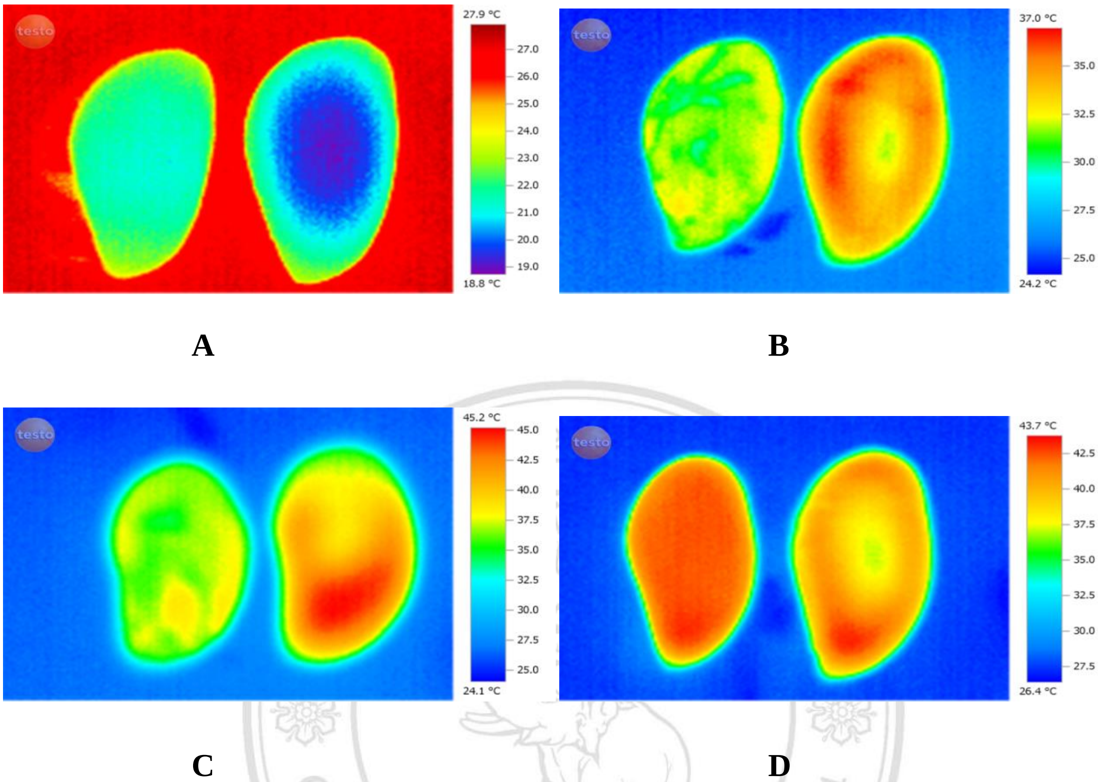

Figure 6.3 Thermal image with temperature legend showing heat distributions in untreated mangoes (A) and treated mango with radio frequency 1000 watt for 5 minute (B) 10 minutes (C) and exposed with temperature of 48°C for 8 min (D)

6.3.4 Comparison of heating method between radio frequency, hot water and hot air in mango fruit

Figure 6.4 shows temperature distribution in a mango fruit as measured by an infrared thermal imaging camera immediately after the mangos were placed in hot air drier at 46°C for 10, 20, 30 and 40 minutes. The fruit skin temperature remain cooler (23°C) when exposed to hot air treatment for 10 minute (Figure 6.4A) while the tissue just below the skin heat (21°C) because of the occurrence of evaporative cooling on the fruit surface during hot air treatment at lower relative humidity (Shellie and Mangen, 2000). When the mango exposed to same condition for longer period for 20 minutes (Figure 6.4B), the fruit showed more variation of temperature from 25 to 31°C. The exposure time of thermal to product influence the overheating at the end of fruit at which the point of overheat at temperature of 31°C was found while the upper skin surface was 28 to 29°C. When the treated period expand to 30 and 40 minute (Figure 6.4C, D) the temperature of surface and within fruit still showed deviation. Which tempering period for 40 minute, the flesh inside the fruited also exhibited non-uniform and the core temperatue was lower at 28°C while mango skin was 34°C. Because the moisture diffuse toward the surface from more to less moist layers, the redistribution of water was held in the material, then the drying rate improved due to water availability close to evaporation surface that increase the concentration gradient at the surface (Shellie and Mangen, 2000).

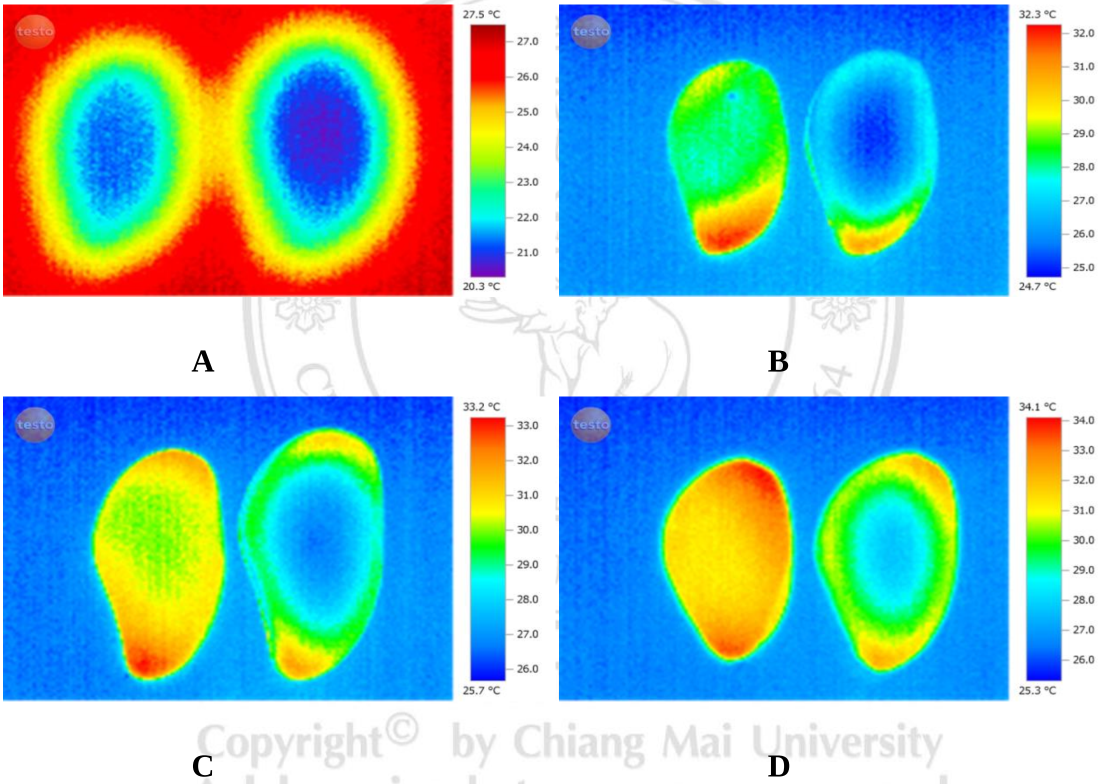

Figure 6.4 Thermal image with temperature legend showing heat distributions in treated mango with hot air for 10 minutes (A) 20 minutes (B) 30 minutes (C) 40 minutes (D)

The principle of the dipping mango fruit in hot water method was done according to the USDA Animal and Plant Health Inspection Service (APHIS) approved the hot water immersion quarantine treatment for Tephritidae fruit flies in mangoes in 1987. Large commercial hot water treament facilities are routinely used to treat mangoes with hot water immersion at a temperature of 46.1 to 46.5°C for 65-110 minutes depending on fruit weight and variety for export to the U.S. Figure5.5

shows thermal picture and temperature legend to compare the distribution of heat in mango after immersion into hot water at temperature of 46°C. The temperature of mango submerged for a short period of 10 minute was varied 21 to 24°C (Figure 6.5A). When dipping for 20 minute, the skin of mango showed uniform of thermal distribution with temperautur of 40°C, while the inside flesh and core was non-uniform and the heat expressed from 30 to 37°C (Figure 6.5B). The non-uniform of heat was reduced when the tempering durration increased to 30 minute (Figure 6.5C) and temperature range from35 to 37.5°C. The uniformity of thermal inside the fruit was improved when resting time for exposure was 40 minute showing temperature at 37.5°C (Figure 6.5C).

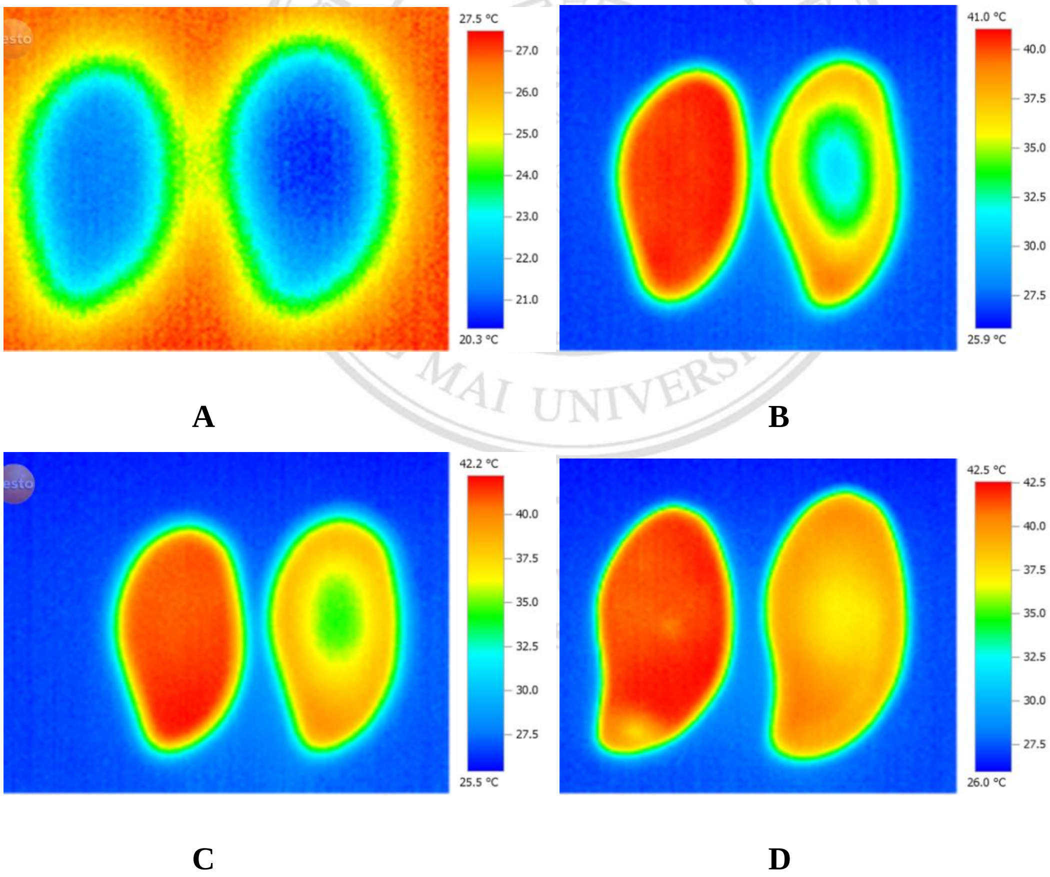

Figure 6.5 Thermal image with temperature legend showing heat distributions in treated mango with hot water for 10 min (A), 20 min (B), 30 min (C) 40 min (D)

6.4 Discussion

Development of container combined with RF heating to improve the uniformity of heat by the movement and rotation of the mango found that with RF heating energy applied to container of fruit-roll can provide a consistent of thermal treatment in mango with exposure period since 1000 watt for 5-10 minutes, compared with dipping in hot water which regularly heat took a period of 40 minute. While the thermal distribution in mango treated with hot air showed non-uniform inside flesh fruit. It can be implied that RF applications combined with fruit rotating container can provide consistency in the heat and spent lesser time than dipping fruit in hot water. This study parallel with the findings of Birla (2006) noted that thermal treatment for fresh fruits by combination of fruit mover with RF hating energy improved the uniformity of thermal distribution because not only the mover support the movement of fruit rotation but also water was flowed in three dimensions. Moreover, the RF heat operation required shorter time process than immersion into hot water and exposure in hot air and it was not limited even in thickness skin fruit such as orange. While the fruit dimension was not limited to rotate in the chamber because the movement was full filled with water without contacting damage.

6.5 Conclusion

The RF heating operation process required shorter time than immersion into hot water and exposure to hot air. The results recorded also that there were no contact damages observed since the mango fruit moved freely in water filled chambers.

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