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

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Introduction

The thermal radiofrequency (RF) has been studied continuously (Nelson and Payne, 1982), however one of the main problems is the consistency of heat in the material (Tang et al., 2000). Many researches have been developed, both of methods and techniques to control insect infestation with agricultural products such as codling moth (Wang et al., 2001) 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, 2008; Boaloi, 2009; Janhang, 2005). 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 pulp due to specific heat point contacted with each other or with RF parallels 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 are play an importance role to support the largest area of radio frequency power in the homogeneous form. The medium having 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 pulps are 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. Then, dipping the fruit in a medium can solve the problem of necrotic point on fruit and improve heat uniform internal fruit especially the energy absorbs area in large fruits and medium due to the difference in electro magnetic field from radio frequency energy. The hypothesis in this study was to support regularly move of fruit around the absorb areas of radio frequency energy to improve the uniformity of the large size fruit. In addition, a rotating container was developed and filled with a

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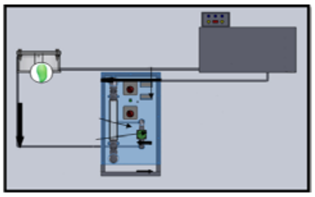
medium to support a homogeneous movement and uniformity of electromagnetic energy. The objective of this research was developed of container and fruit mover in the laboratory scale to determine and improve the uniformity of heat in mango fruit. Comparison of heat uniformity in mango fruit treated by several thermal methods based on the import of mangoes to the U.S (USDA-APHIS-PPQ, 2002) was also investigated.

Material and Methods

Design of rotating container combined with RF applicator

The size of container was designed to provide the rate of heat dissipation when full filled with water (Fig 1). After operating with radio frequency generator, the energy was created and some of them were lost as heat to heat up water within the container until proper temperature. 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. 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.


A

B

Fig 1. Schematic scheme of fruit rotating chamber (A); Mango sample cut in half lengthwise before treating (B)

Experimental processes

1) Investigation of flow rate and the velocity affected on movement of mango fruit

Three different weights (360, 330 and 250g) of mango (*Magnifera indica* L.) were taken samples. Each fruit of mango was flood in the water to determine the flow rate of mango 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 (SX 8) analysis program. 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) Comparison of heating method between RF, hot water and hot air on mango fruit

2.1) Radio frequency heating

After fruit mover combined with radio frequency application, a sample mango fruit was put into the rotating container and filled with the exact volume (5 liter) 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 sample were cut in half lengthwise (Fig 2). The thermal dissipation inside the fruit was measured by using an infrared camera (ThermaCAM™ Researcher 2001, FLIR system, Portland, Oregon).Then, the water was heated with the radio frequency generator with the temperature of 48°C for 8 minutes, then cut and thermal dissipation inside the fruit was measured by using an infrared camera

2.2) Hot air dryers heating

Hot water was prepared in a water bath with a flow rate of 1 meter per second. Mango fruit was dip into the hot water at the constant temperature of 46°C by steam heat in hot water for different periods of 10, 20, 30 and 40 minutes. After that the treated mango were cut in half lengthwise and measured the thermal dispersion by using an infrared camera.

2.3) Hot water heating

Hot water was prepared in a water bath with a flow rate of 1 meter per second. Mango fruit was dip into the hot water at the constant temperature of 46°C by steam heat in hot water for different periods of 10, 20, 30 and 40 minutes. After that the treated mango were cut in half lengthwise and measured the thermal dispersion by using an infrared camera.

Results and Discussion

Water flow rate and the velocity affected on movement of mango fruit

The result from comparison of different weights of mango movement in water showed that the rate of injection was 11.5 L min^{-1} affected on the rotation in round per minute of mango as shown in Table 1. Mango with weight of 366 g showed the lower velocity (32 rpm) than 330 and 250g (35 and 41 rpm, respectively). Statistic 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=-0.9363, ($P \leq 0.05$). It can be implied that increasing size of fruit reduced the motion rate.

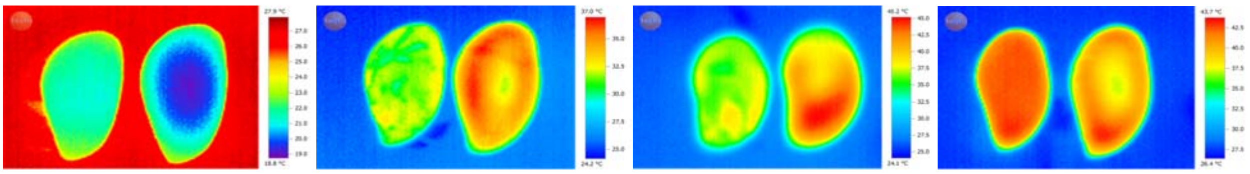
Table 1 Rotational speed of mango at different weight in rotating chamber filled with water

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 column indicate that means are significantly different ($P \leq 0.05$) by LSD

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

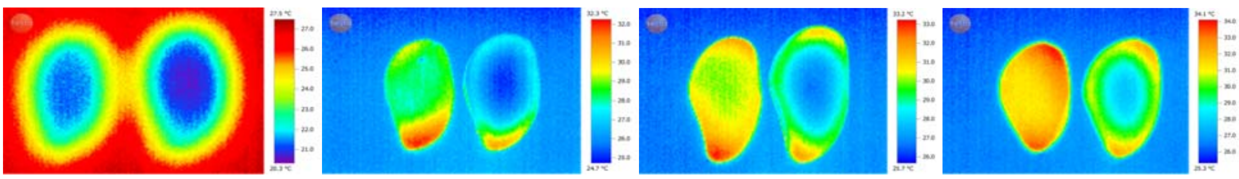
Fig 3A show temperature variations of mango fruit without heating which the temperature of skin was 22°C and inside the fruit was 20°C. When the mango was heated with RF heat energy for 5 min (Fig 3B), the mean temperature varied from 30 to 35°C while the non-uniform heating was observed at the core of fruit. The hot patch on the end of mango fruit (Fig 3C) was observed when exposure time was 10 min and the temperature ranged from 35 to 45°C. Findings of Birla (2006) reported 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 supported the movement of fruit rotation but also water was flowed in three dimensions.



A B C D

Fig 3 Thermal image with temperature legend showing heat distributions in untrated mngoes (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)

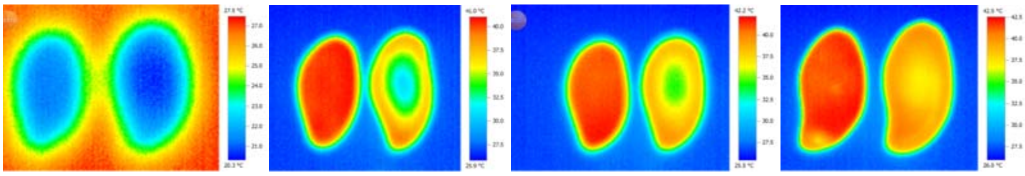
After treating hot air drier at 10 min of exposure time, the fruit skin temperature remained at 23°C (Fig 4E) because of the occurrence of evaporative cooling on the fruit surface during hot air treatment at lower relative humidity (Shellie and Mangen, 2000). For 20 min, mango temperature showed more variation from 25 to 31°C (Fig 4F). 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. When the treated period expand to 30 and 40 min (Fig 4G, H) the temperature of surface and within fruit also expressed thermal deviation. 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).



E F G H

Fig 4 Thermal image with temperature legend showing heat distributions in treated mango with hot air for 10 min (E) 20 min (F) 30 min (G) 40 min (H)

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 min depending on fruit weight and variety for export to the U.S (USDA-APHIS-PPQ, 2002). In pararell, the temperature of mango submerged into hot water at temperature of 46°C for a short period of 10 min was varied 21 to 24°C (Fig 5I). When dipping for 20 min, 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 (Fig 5J). The non-uniform of heat was reduced when the tempering duration increased to 30 minute (Fig 5K) and temperature range from 35 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 (Fig 5L).



I J K L

Fig 5 Thermal image with temperature legend showing heat distributions in treated mango with hot water for 10 min(I), 20 min(J), 30 min(K) 40 min (L)

Conclusions and Outlook

The result confirmed that 1000watt 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. The RF heating process required shorter time than immersion into hot water and exposure to hot air. The result were recorded also that there were no contacted damage observed since the movement of mango fruit were freely moved in water fulfilled chamber

Acknowledgement

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