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Comparison of Coleoptera and Lepidoptera Response to Insect Control by Radio Frequency Heating

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Introduction

Insect pests of stored products are the major problem and the damage to crops. The moth insects in the order Lepidoptera and the beetle in the order Coleoptera currently controlled by insecticide (methyl bromide) fumigation management for trading and exporting. However, we have found that there is an increasing in concerning about the mentioned treatment, the use is reduced due to methyl bromide is a substance that is extremely harmful to the ozone layer and health. Its fumigating duration take about 24-48 hours. Later, there is a trying to switch to the other fumigant (phosphine), this substance has a toxic gas, it is flammable and can explosive in the air. The phosphine fumigation needs treatment duration 7-9 days. The report of insect resistance to phosphine is increasing (Chaudhry, 1997) coupled with banning the use of methyl bromide in agricultural products in developed countries from 2015 onwards and it is likely that in the future that would ban the use of chemicals in agricultural produce for consumption (USEPA, 2001). Therefore, it is very important to find a new alternative way to control and eliminate pests without using chemical methods such as the use of electromagnetic energy to cause heat that can build up in the pest body quickly within 2-3 seconds. Resulted effective with no toxic residues will be purchased as well as the shorter the duration of the treatment.

There has been researching the use of electrical energy into heat energy, which are physical methods used to control insects. The electromagnetic energy such as microwave (microwave: MW) and RF (radio frequency: RF) can transfer heat energy in dielectric materials. Agricultural products contain moisture which is dipolar molecule, qualifies as dielectric, a power transmission of electromagnetic energy from microwave and radio frequency will occur more quickly. Heating occurs, insects were controlled.

There were reports in control insects in grain processing by using a high frequency. They have studied the effects of the electromagnetic energy in controlling insects. (Frings, 1952; Baker *et al*, 1956; Nelson and Whitney, 1960; Watters, 1962; Kilgore and Doutt, 1967; Nelson,. 1996; Wang and Tang, 2001; Wang *et al*., 2003; Mitcham *et al*., 2004; Janhang *et al*., 2005; Vassanacharoen *et al*., 2007; Luechai, 2008; Sumeta, 2009; Bualoi, 2009; Na Pijit *et al*., 2011; Faikrajaypuan *et al.,* 2011). Besides that, RF can be applied in the medical field science and industry-related post-harvest insect control. The frequencies used are 13.56, 27.12 and 40.68 MHz. provided by the mass media of the United States (US Federal Communication Commission: FCC). RF currently was applied to the various facilities and can be used to control pest insects in storage as well due to increasing the thermal energy that can make insects die quickly with causes less physical changes (Lagunas-Solar *et al.*, 2006).

The principle of heat generated by the RF generator, qualified materials (material with dipolarity), the dielectric material, when the RF energy from a high voltage through the alternating current (AC) at a frequency of 27.12 MHz or 27,120,000 times per second, cause the material such as grain to induce molecular vibration at the same frequency of the wave. An object with two polar molecules such as water, the two hydrogen bonding vibrations cause the internal energy of the molecule. Intermolecular friction and hysteresis depended on the frequency and wavelength of the radio spectrum. The internal friction between the molecules of water inside the grain caused friction between the particles. The result is that the heat is going straight up water molecules. Heat occurrence is higher than any other point within this seed. It was heat transfer, generated. This energy was transferred by conduction through a medium such as solids and liquids with high viscosity. Therefore, the heat is starting to happen from where the water in the seeds. The heat from the water with a temperature higher transfer to the point where the temperature is lower in order to balance the temperature (equilibrium temperature) until reach the target temperature (Ryynänen, 1995; Nijhuis *et al.*, 1998; Birla *et al.*, 2004). Some research related to the use of RF to eliminate insects in many different crops such as Mitcham *et al.* (2004) have studied the use of RF for pest codling moth (*Cydia pomonella*), navel orangeworm (*Amyelois transitella*) and indian meal moth (*Plodia interpunctella*), a major pest infestation and damage the quality of the output walnuts. The frequency at 47, 50, 53 and 55°C for 1 minute can kill insects 32, 77, 99 and 100% respectively. Wang and Tang (2001) did a study on the use of RF to control codling moth attached to the inner shell of the walnut seed, found that at 53°C eliminate codling moth without affecting the quality of the inner shell and walnut seed. Wang *et al.* (2003) conducted a study on the frequency at 50°C for 3 minutes on pest control codling moth in the cotyledon inside the seed; found that this temperature and time duration could eliminate codling moth pests without affecting the quality of the walnut.

Researchers from the Chiang Mai University Thailand in cooperation with the Georg-August University of Goettingen, Germany studied on the use of radio frequencies for pest control in agriculture using of radio frequency to eliminate lesser grain borer (*Rhyzopertha dominica*) in rice var. KDML105 found that the frequency at 75°C for 3 minutes can get rid of the lesser grain borer so well. And affect less the quality of seeds as (Janhang *et al*. 2005). von Hörsten (2007) reported and presented the results of the use of radio frequency to eliminate rice weevil compared to the hot air oven, found that the adult rice weevil was controlled better than the hot air oven by using lower temperatures used and shorter duration. Anyhow, It was found that the research lack of compilation and comparison in grouping insects. This research therefore aimed to collecting data on the use of radio frequency in insect pest control, for use as guidelines in implementing such technology to selective insect control as well as to those who interested in this technique to build up their facilities.

Results and Discussion

Growth stages of insects that are resistant to RF

Insects in various stages, including eggs, larvae, pupae and adults of each insect species are response and resistant to different frequency by resulting in the percentage of dead insects in each treatment reported in Table 1. The insects in the order Lepidoptera such as rice moth (*Corcyra cephalonica* (S.)) found that egg stage was resistant to most RF followed by a pupal larva and egg stage, mortality rates were 100% respectively (Luechai, 2008). Angoumois grain moth (*Sitotroga* *cerealella* (O.)) in the pupal stage was strongly resistant to RF followed by egg and larvae stages respectively (Buapud, 2012).

Insects in the beetle group order Coleoptera, Faikrajaypuan (2011) found that maize weevil (*Sitophilus zeamais* (M.)) showed the highest tolerance of adult, followed by egg, larva and pupa stage respectively. Na Pijit *et al*. (2011) reported that cowpea weevil (*Callosobruchus maculatus* (F.)) pupae stage was resistant to most RF treatment, followed by eggs and larvae stage respectively. In addition, Red flour beetle (*Tribolium castaneum* (H.)) adult stage was resistant to most RF treatments, followed by egg and larval instars and larvae stage respectively (Bualoi, 2009). Lesser grain borer (*Rhyzopertha dominica* (F.)) in the adult stage was resistant to most RF treatment. Followed by the pupal stage larvae and eggs, respectively (Sumeta, 2009). Sawtoothed grain beetle (*Oryzaephilus surinamensis* (L.)) in the adult stage was resistant to most RF treatment, followed by the pupal larvae and egg stage, respectively (Srikam, 2014). Nutapong (2011) found that cigarette beetle (*Lasioderma serricorne* (F.)) adult stage showed the highest tolerance to RF treatments, followed by the pupal larvae and eggs stage, respectively.

From the experiments, it was seen that the growth stage of insects that are resistant to radio frequency treatment of insects in the order Lepidoptera, which are butterflies, such rice moth and Angoumois grain moth showed that the growth stage of eggs and pupae are resistant to radio frequency treatment, which may be stated that egg and pupae stages can withstand harsh environments better than larva to the adult. This may be because of insect eggs and pupae stages were in a range of activities in the lower respiratory than larva and the adult stages (Chapman, 1998).

The insects in the order Coleoptera, including maize weevil, mung bean weevil, saw-toothed grain beetle and cigarette beetle. Pupa and adult stages were the most tolerance stage to RF treatment. This might be the cause of larva and egg stages containing higher moister than pupae and adult stages, which is consistent with Wang *et al*. (2002) found that the heat from radio frequency caused by the response of the object to the frequencies, the ion compounds and the dielectric properties. The results of the overall response caused movement of water molecules, which resulted heat to build up inside the object. Cwiklinski and von Hoersten (1999) also stated that radio frequency can cause a lot of heat in an object with a water element. Therefore, to control storage pests by using radio frequencies, under the same conditions, insect species, each growth stage, the frequency response varies. Because of the different species, which biological, physical or body composition is different, when insects are exposed to heat from radio frequency, they achieve weight loss and may received more oxygen as a wounded larva. More protein may appeared (heat shock protein) to repair the damaged parts of the body. The insect may survive (Nelson, 1996).

Table 1 Mortality percentage of insect pest in various development stages after exposed to the radio frequency heat treatment at 27.12 MHz

Insect pest	Order	Commodity	Treatment	Mortality (%) ± SE				Reference
				Egg	Larva	Pupa	Adult	
Rice moth	Lepidoptera	Milled rice	60°C 180 sec	98.35±0.73	100	98.90±0.69	100	Luechai, 2008
Angoumois grain moth	Lepidoptera	Paddy rice	120 sec	80.04±1.90	88.82±4.33	68.75±3.14	n/a*	Buapud, 2012
Maize weevil	Coleoptera	Maize	120 sec	76.13±1.52	66.59±5.30	70.27±5.36	49.93±2.81	Faikrajaypuan, 2011
Cowpea weevil	Coleoptera	Mung bean	120 sec	30.88±8.73	30.90±4.60	22.91±4.97	n/a	Na Pijit, 2011
Red flour beetle	Coleoptera	Feed	50°C 180 sec	81.98±3.85	92.06±3.97	72.99±3.30	91.58±1.75	Bualoi, 2009
Lesser grain borer	Coleoptera	Milled rice	50°C 180 sec	99.10±0.80	92.30±2.50	86.56±4.30	38.33±6.70	Sumeta, 2009
Saw-toothed grain beetle	Coleoptera	Milled rice	55°C 90 sec	96.46±3.74	94.34±5.98	90.90±3.63	78.09±2.82	Srikam, 2014
Cigarette beetle	Coleoptera	Tobacco	60 sec	99.37±0.04	97.50±0.11	81.88±0.14	55.00±0.17	Nutapong, 2011

* n/a = not applicable or not available

Effect of frequency on the number of insects in the progeny

Buapud (2012) reported that egg, larval and pupae stage of Angoumois grain moth subjected through radio frequency 27.12 MHz power 700 watts at duration of 120 seconds, then stored for a period of 4 weeks, the number of progeny of eggs, larvae and pupae that survived from the radio frequency treatment was significantly decreased when compared to those from untreated samples in all stages. The result corresponding to Na Pijit (2011) who reported that the cowpea weevil progeny test after subjected the contaminated cow pea grain with eggs, larva, and pupae to the RF 27.12 MHz at a power level of 640 watts at 120 seconds and stored for a period of 4 weeks, the number of insect regenerate of cowpea weevil eggs larvae and pupae that survived after the treatment has decreased when compared to the insect number of the untreated progeny. Faikrajaypuan *et al*. (2011) reported that egg, larval, pupa and adult of maize weevil were subjected to RF 27.12 MHz with power of 670 W for 120 seconds, the numbers of their progeny were recorded and it was found that the number of progeny from the treated weevil differed from those from the untreated sample. This might be due to the effect of the adaptation of insects; insect may lay better number of eggs when the environment was not proper. This condition was known as ovipositor plasticity, which is consistent with reports of Danho (2002) reported that when the maize weevil to be raised in an abusive environment. Maize weevil can adapt and adjust their behavior to spawn as well (Table 2). Anyhow, report from Mahroof *et al*. (2005) stated that the flour beetle (*Tribolium casteneum*) when heated at 50°C can affect fertility and the rate of survival from egg to adult stage. The number of insect progeny decreased Nelson (1996) reported that the heat from radio frequency interference, damage cells of sperm and ovarian tissue. The fertilization and hatching rate decreased. It was also found that the eggs hatch out in a smaller size too. The heat can affect on the nervous system which control the endocrine system and other systems cause to unexpected functions such as inhibiting the formation of protein vitellin, which is important in the formation and development of insect eggs. Juvenile hormone (JH) is a hormone that controls the growth and differentiation of insects. The effect of JH reduction will result more in an insect larval molting. The abnormal growth increased. Or insect may response to heat by a change in behavior and development, draw out the heat shock proteins for its survival at elevated temperatures.

Table 2 Number of progeny of insect pest after exposed to the radio frequency heat treatment at 27.12 MHz for 120 second

Insect pest	Number of progeny ± SE								Reference
	Egg		Larva		Pupa		Adult		
	Untreated	RF	Untreated	RF	Untreated	RF	Untreated	RF	
Angoumois grain moth	45.75±5.22	5.25±3.09	154.75±12.84	13.75±11.83	169.50±10.69	84.75±12.70	n/a	n/a	Buapud, 2012
Cowpea weevil	24.60±1.49	18.10±1.19	65.6 0±3.61	47.80± 4.23	67.80±2.89	56.10 ±2.40	n/a	n/a	Na Pijit, 2011
maize weevil	9.60±1.63	5.40±2.06	26.40±18.21	27.80±10.87	26.40±6.67	34.40±6.61	22.00±5.91	58.8±24.98	Faikrajaypuan *et al*., 2011

n/a = not applicable or not available

Temperature and treatment duration of RF treatment to completely eliminate insect pest

Researchers from the Chiang Mai University reported the results using RF heat from RF 27.12 MHz to stored insects at their most tolerance stage. Temperature and time durable and level of energy used were demonstrated in Table 3. Insects that damage the external of the grain so called external feeder. Luechai (2008) reported that the radio frequency at 60°C for 3 minutes can get rid of a rice moth completely. Control Red flour beetle in pupa stage requires temperatures 70°C for 1 min (Bualoi, 2009) and to control saw-toothed grain beetle, power at 670 watts, temperature 70°C for 2 minutes were used (Srikam, 2014).

Table 3 Radio frequency heat treatment at 27.12 MHz for 100% insect mortality

Insect pest	Stage	Commodity	Power (W)	Treatment		Reference
				Temperature	Time	
External feeder						
Rice moth	Larva	Milled rice	n/a	60°C	3 min	Luechai, 2008
Red flour beetle	Pupa	Feed	n/a	70°C	1 min	Bualoi, 2009
Saw-toothed grain beetle	Adult	Milled rice	670	70°C	2 min	Srikam, 2014
Internal feeder						
Rice weevil	Adult	Milled rice	n/a	55°C	1 min	Vearasilp et al., 2009
Angoumois grain moth	Pupa	Paddy rice	700	72°C	3 min 40sec	Buapud, 2012
Cowpea weevil	Pupa	Mungbean	640	74°C	3 min 40 sec	Na Pijit, 2011
External and internal feeder						
Lesser grain borer	Adult	Milled rice	n/a	70°C	2 min 30 sec	Sumeta, 2009

n/a = not applicable or not available

Insects in the group of destroy or damage from inside the seeds so called internal feeder, rice weevil by using temperature 55°C for 1 min could control rice weevil in the most tolerance adult stage with100% mortality (Vearasilp *et al*., 2009). Control Angoumois grain moth at pupa stage requires power at 700 W, temperature 72°C for 3 minutes, 40 seconds (Buapud, 2012) and cowpea weevil, pupa stage requires power at 640 W, temperature 74°C for 3 min, 40 seconds (Na Pijit, 2011). Also Sumeta (2009) reported that the lesser grain borer which is an insect infestation both inside and outside the kernel by using the heat from the 27.12 MHz RF at 70°C for 150 seconds could control lesser grain borer 100%.

The amount of moisture contained in the insect and the feeding material are normally big difference. Insects contain water or humidity between 50-65%, while the grains moisture is between 11-16%, although low frequency radio frequency was applied, it can make a difference level of heat in the insects compare to the feed or grain. It was reported that the effective frequency will occur at approximately 30 MHz (Nelson and Charity, 1972), especially at the frequency 27.12 MHz was a level suitable for use in industry, in scientific research and in medical purposes. Although, the other frequencies were not available, it was known that those frequencies can affect the development and movement in insect growth (Halverson *et al*., 1996). According to Neven (2000) the heat affects the nervous system of insects that control the functioning of the endocrine system and other functioning organelles, lead to impossible to function normally, such as the level of juvenile hormone, a hormone that helps in the growth and differentiation or inhibit the formation of vitelline protein which is important in the formation and development of the eggs, the protein work defectively and the insects do not thrive.

Conclusions and Outlook

Growth stages of order Coleoptera insects which were most tolerance to RF of 27.12 MHz were pupa and adult stages. The insects in the order Lepidoptera, which showed the most tolerance to radio frequency, were eggs and larvae. The temperature used and duration of RF heat treatment for effective insect control, differed from insect varieties. The temperatures used for pest control were in the range of 55-74°C for a period from 1 to 3.40 minutes.

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