

**Application of microwave and radio frequency energy to control *Sitophilus zeamais* (Coleoptera: Curculionidae) in maize grains**

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*To my Parents*

*Sisters*

*Wife and son*

*I dedicate this work*

*with love*



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## Symbols and abbreviations

$\tan\delta$	Loss angle.	DNA	Deoxyribonucleic acid.
$e$	Euler`s number = 2.718.	FCC	Federal Communications Commission.
$d_p$	The electrical field penetration depth.	FO	Fiber optic.
$^{137}\text{C}$	Caesium-137	GC	Gas chromatography.
$s$			
$^{60}\text{Co}$	Cobalt-60	HPLC	High-performance liquid chromatography.
$c$	The speed of the light in free space ( $3 \times 10^8$ m/s).	ICC	International Association for Cereal Science and Technology.
$f$	Frequency (Hz).	IMC	Initial moisture content (%).
$P$	Power (W).	ISTA	International seed testing Association.
$\Delta T$	The temperature rise ( $^{\circ}\text{C}$ ).	kGy	Radiation absorbed dose measurement unit.
$E$	Electric field ( $\text{V}\cdot\text{m}^{-1}$ ).	MW	Microwave.
$\Delta t$	Time increment (s).	RF	Radio frequency.
$\lambda$	Wavelength (m).	RH	Relative humidity.
$C_p$	The specific heat ( $\text{Jkg}^{-1} \text{ }^{\circ}\text{C}^{-1}$ ).	rpm	Revolutions per minute.
$\epsilon'$	Dielectric constant.	RVA	Rapid visco analyser.
$\epsilon''$	Dielectric loss factor.	RVU	Rapid visco unit.
$\epsilon *$	The relative permittivity.	K	Kelvin , $\text{K} = [^{\circ}\text{C}] + 273.15$
$\rho$	The density ( $\text{kgm}^{-3}$ ).		



# 1 Introduction

Infestation with the insect pests is a serious problem associated with raw and processed stored products. They can cause a variety of damage and economic loss to the stored food including physical and nutritional damage and they also lead to the contamination with insect's bodies and their products, dead insects, as well as encouragement of mould growth (Rees, 2004).

Among the stored product pests, maize weevil, *Sitophilus zeamais* (Coleoptera: Curculionidae), is one of the most economic primary pest of stored cereal grains, particularly maize. In stored maize, heavy infestation of *Sitophilus zeamais* may cause different types of damages which have a negative impact not only on the quantity of grains but also on its quality. Feeding activity of *S. zeamais* larvae and adults and development of its immature life stages inside the grains may result in producing a lot of heat and moisture, this encourage mould growth and growth of population of other insects species (Jood *et al.*, 1992a, 1992b; Jood and Kapoor, 1992; Rees, 2004).

Several control methods are currently being used for controlling store pests such as *S. zeamais*, including chemical and biological methods. The chemical method, for example, chemical insecticides such as malathion, chlorpyrifos-methyl, phosphine and methyl bromide are widely used to control the insects pests in stored grains (Arthur, 1996). However, the widespread uses of these chemical have a hazardous effects on human health and environment (Cherry *et al.*, 2005). Therefore, various effective and safe methods have been suggested and tested to control insect pests in agricultural commodities, such as ionizing radiation, dielectric heating, cold storage, controlled atmospheres, and combination treatments (Fleurat-Lessard, 1990; Heather *et al.*, 1997; Johnson *et al.*, 1997, 1998; Johnson and Marcotte, 1999).

Dielectric energies such as microwave and radio frequency energy have also been suggested as non-chemical treatment use in controlling stored-grain insects. As defined by Zhao (2006), microwaves (300 MHz to 300 GHz) and radio frequency (1 to 300 MHz) are non-ionizing electromagnetic waves generate heat in dielectric materials such as food through dipole rotation and/or

ionic polarization. Dielectric heating is based on the dielectrical properties of materials which are mainly affected by its moisture content. Hence, it is possible to heat the insects to the lethal temperature at faster rate than infested products, because they contain relatively higher water content (Hurlock *et al.*, 1979).

Several studies have been investigated the application of microwave and radio frequency energy on controlling stored-grain insects such as *Tribolium castaneum* in wheat (Vadivambal *et al.*, 2007), barley (Vadivambal *et al.*, 2008) and rye (Vadivambal *et al.*, 2010a); *Oryzaephilus surinamensis* (L.) in soft winter wheat (Khathir, 2011); *Sitophilus oryzae* L in rice (Zhao *et al.*, 2007); *Sitophilus granarius* in wheat (Vadivambal *et al.*, 2007); *Collosobruchus chinensis* in pulses (Singh *et al.*, 2011) and codling moth (*Cydia pomonella*), navel orangeworm (*Amyelois transitella*), and Indian meal moth (*Plodia interpunctella*) in walnuts (Wang *et al.*, 2001, 2002, 2003a, 2005a).

Application of microwaves and radio frequency heating in stored food product to control its insect pests, on the other hand, can play an important role in drying of food, because they offer a potential for rapid and uniform heating rate than conventional heating (Baldwin, 1983). It was reported that dielectric heating cause less thermal damage to the tested products than general heating methods such as hot water treatment (Wang and Tang, 2001; Wang *et al.*, 2003a). Results obtained by Vadivambal (2009) who determined the quality characteristics of wheat, barley and rye after disinfestation using microwave energy confirmed that microwave heating cause no significant changes in the grains quality. Similarly, radio frequency heat treatment is also able to heat insect pest to the lethal temperature while maintaining product temperature below the quality limit (Wang *et al.*, 2004).

### **Objectives**

The previous studies concluded that controlling insect of stored products by using dielectric heating such as microwave and radio frequency energy depends mainly on the differences between the dielectric properties of the insects and the host media. Many other factors including the frequency, heating rate, dielectric properties of the materials, moisture contents, and other characteristics are also affected the heating behaviour of materials. Therefore, different susceptibility of insects between the radio frequency and microwave has been expected. Furthermore, the moisture content of host medium has influence on its heating

ate. It was noted that increasing the moisture content of the material increased its heating rate in both of microwave and radio frequency treatments. Hence, the mortality of the insects might also be expected to influence by the moisture content of the grains.

In the present study, microwave and radio frequency energies were applied as non-chemical treatment to investigate their efficiency in controlling life stages (egg, larvae, pupa and adult) of maize weevil, *Sitophilus zeamais*, in maize grains at 10, 14 and 18% initial moisture content, at target temperatures 45, 50, 55 and 60°C, and for different holding times 0, 1, 3 and 5 min to full fill the following purposes:

1. To determine the lethal temperature and holding time to eradicate maize weevil, *Sitophilus zeamais*, in maize grains, as well as to study the influence of the initial moisture content of the grains on the mortality of the insects.
2. To study the germination rate of grains after microwave and radio frequency heat treatments.
3. To evaluate the flour quality of microwave and radio frequency treated maize.
4. To compare the efficiency of microwave and radio frequency in controlling *S. zeamais* as well as their effect on the quality of treated maize.



## 2 Literature review

### 2.1 Stored-products insects

Insects of stored- products have been associated with human food since human society started settled agriculture and began to produce and store their dried durable products (Rees, 2004). Insects pests that infested stored grains are grouped according to their feeding behaviour and the type of damage they caused into: primary and secondary pests (Hill, 2002).

Primary pests, internal developer, are able to penetrate and develop inside the kernel. Secondary pests, external developer, they tend to infest broken materials and grain dust created by primary invaders. They are found in grain but are more common in flour, meals and other processed foods. Primary pests include species such as maize weevil, *Sitophilus zeamais*, while secondary pests include species such as the red flour beetle, *Tribolium castaneum* (Hill, 2002).

Maize weevil, *Sitophilus zeamais*, belongs to family Curculionidae, which includes the rice weevil, *Sitophilus oryzae*, and the granary weevil, *Sitophilus granaries*. The females of *Sitophilus* spp. can drill a hole into kernels in the field or in storage and lay a single egg. The immature life stages of these species complete development inside the kernel, and their life cycle takes around 29 to 32 days under optimum conditions 30°C, 70% RH (Rees, 2004).

Among the widespread and destructive primary pest, *Sitophilus zeamais* is one of the most important primary pests in stored maize in the world, especially under tropical condition. The major effect of infestation by maize weevil is the grain damage due to feeding activities of the adults and the development of immature stages within the grain. This has a negative impact on both quantity and quality of the grains (Rees, 2004). Furthermore, it was reported that about 15% of harvested maize can be consumed by maize weevil in few months (Bergvinson, 2004).

## **2.2 Control methods of stored pest**

Post-harvest losses of stored grains due to the insects infestation is an annual common problem. Storage of grains under optimum condition (25-35°C), insects will multiply rapidly (Pederson, 1992) and can cause significant losses of grains quantity and quality, with decreased grain germination, nutritional value of seed, and contamination by insect's bodies and their waste products (Rees, 2004).

Prevention and control of insect pest in stored products are very important to the farmer, grain handler, grain processor and consumers (White and Leesch, 1996). There are various method used and tested to control insect pest, which can be grouped as chemical, biological and physical methods.

### **2.2.1 Chemical control**

Among the control methods, chemical control method is the easiest, rapid and economical one for controlling store pest. Chemical used to kill insects in stored grains relies on contact insecticides or fumigants (White and Leesch, 1996).

Contact insecticides kill the insects when they contact treated grains surface. Some of the common used contact insecticides around the world include bromophos, malathion and bioresmethrin (Sinha and Watters, 1985).

Fumigation is a process of killing insects by exposing them to toxic gas or mixture of gases. The most important fumigants used to control insects in stored grains are phosphine (PH<sub>3</sub>) and methyl bromide (CH<sub>3</sub>Br) (White and Leesch, 1996).

There are many disadvantages associated with using chemical insecticides to control stored pests. The resistance of insects to the chemical insecticides is a major limiting factor of their application. An early world-wide survey of stored-product insects found that 87% of 505 strains of red flour beetle, *Tribolium castaneum*, were resistant to malathion (Sinha and Watters, 1985). Furthermore, the conventional method of fumigation that is being used for disinfestations of grains is not suitable for sealed pouches because of non-penetration of the fumigant through the packaging material (Köksel *et al.*, 1998). Moreover, the widespread uses of these fumigants are harmful to human health and environment (Cherry *et al.*, 2005).