OPTIMISATION OF MICROWAVE SYSTEM FOR RICE TREATMENT

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ABSTRACT

Microwave heating has a potential to disinfest insect in rice grain. This method can be an alternative and a safe method to replace the current used of fumigant. Microwave leaves no chemical residue to hazard human health and safe for environment. A microwave system were developed using domestic microwave oven, an Arduino microcontroller, a switching circuit to study the effect of microwave energy applied to the infested rice grain. The microwave frequency used in the study is a standard 2.45MHz magnetron. The microcontroller is programmed to maintain the temperature at 55 – 65 ºC and duration is set at 2 – 3 mins. The experiments were carried out to monitor the effect of microwave on spawning process and the mortality of adult insect. There are two samples with and without microwave are stored at room temperature to monitor the activity of insect periodically. From the study, it was found that the use of microwave system gives positive result on the rice treatment where the effect caused the insect and eggs colonies activities reduced.

ABSTRAK

Pemanasan gelombang mikro menpunyai potensi untuk menghapuskan pembiakan serangga di dalam beras. Kaedah ini boleh menjadi altenatif dan selamat mengantikan kaedah pengunaan racun makhluk perosak. Pemanasan gelombang mikro tidak meninggalkan sisa-sisa kimia yang mengancam kesihatan manusia dan menggangu alam persekitaran. Satu sistem gelombang mikro telah dibangunkan untuk tujuan ini. Sistem yang dibangunkan ini adalah terdiri dari sebuah ketuhar gelombang mikro, satu peranti pengawal mikro Arduino dan satu litar pensuisan geganti untuk mengawal bekalan kuasa kepada ketuhar gelombang mikro. Frekuensi piawai bagi gelombang mikro yang digunakan adalah 2.450MHz. Sistem pengawal mikro akan diprogramkan untuk menetapkan suhu pada 50-60 °C dalam tempoh 2-3 minit. Ujikaji dijalankan untuk melihat kesan gelombang mikro ke atas aktiviti peneluran dan tahap kematian serangga dewasa di dalam beras. Oleh itu dua set sampel disediakan untuk tujuan pemantauan berkala iaitu saru set sampel beras tanpa pemanasan gelombang mikro dan satu set sampel dengan didedahkan pemanasan gelombang mikro. Daripada kajian, didapati, penggunaan sistem gelombang mikro memberikan keputusan positif dalam mengurangkan pembiakan serangga dewasa dan perkembangan telur serangga di dalam beras.

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LIST OF SYMBOLS AND ABBREVIATIONS

ARF	-	Agriculture Research Foundation
CO2	-	Carbon dioxide
DNA	-	Deoxyribonucleic acid
DIP		Dual-in package
EM	-	electromagnetic
GHz	-	Gigahertz
Hz	-	Hertz
ISM	-	Industrial, Scientific and Medical appl.
ICSP	-	In Circuit Serial Programming
LCD	-	Liquid crystal display
MHz	-	Megahertz
PC	-	Personal computer
PIC	-	Peripheral Interface Controller
PWM	-	Pulse width modulation
USB	-	Universal Serial Bus
pH	-	Measurement of acidity or basicity
π	-	Pi
mho	-	siemens
m	-	meter
s	-	second
mm	-	milimeters

°C	-	Degree centigrade
mg	-	milligram
MeBr	-	methyl bromide

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CHAPTER 1

INTRODUCTION

1.1 Research Background

Agricultural commodities produced on the fields have to undergo a series of operations such as harvesting, threshing, winnowing, bagging, transportation, storage, and processing before they reach the consumer, and there are appreciable losses in crop output at all these stages. Various estimates have been made to assess the postharvest food grain losses. The losses are caused either by environmental factors such as temperature, moisture, and type of storage structure or by biological agents, namely, insects, rodents, birds, and fungi. The major losses during production, storage and marketing of food grain are being attributed to infestation by insect pests, microbiological contamination, and physiological changes. Insect infestations can occur just prior to harvest or during storage or in-transit in a variety of carriers. The occurrence and numbers of stored grain insect pests are directly related to geographical and climatic conditions (S. Lal et al., 1985). Almost all species have remarkably high rates of multiplication and, within one season, may destroy 10–15% of the grain and contaminate the rest with undesirable odors and flavors. Insect pests also play a pivotal role in transportation of storage fungi (A. K. Sinha, 1990).

Therefore, preventing economic losses caused by stored-product insects is important from the field to the consumer’s table (B. Subramanyam, 2000). The losses during storage are classified as quantity losses and quality losses. Quantity losses occur when the grain is consumed by insects, rodents, mites, birds and microorganisms. Quality losses are reflected as reduced economic value of the crop. The stored-grain insects affect not only the quantity of grain but also the quality of grain. Infestation causes decreased nutritional value, reduced seed germination, and lower economic value and also causes changes in chemical compositions such as increase in moisture, free fatty acid levels, non-protein nitrogen content, and decrease in pH and protein contents in food grain (R. I. Sanchez-Marinez, 1997).

They reduce the product quality directly by damage through feeding and indirectly by producing webbing and frass (F. S. Nasab, 2009). Also the grain quality has been found to decrease with time with increasing levels of infestation (J. P. Edward, 1991). It is estimated that more than 20,000 species of field and storage pests destroy approximately one-third of the world's food production, valued annually at more than 100 billion dollar (Y. Rajashekar, 2012).

Furthermore, quality deterioration of rice grains intended for seedling purposes may cause further losses in quality and viability (germination) thus affecting yields in crop production. Under the current storage (bulk) conditions and long times, the presence of even a few viable colonies of insect pests may result in the emergence of much larger populations as the storage conditions are favorable to propagation due to the abundant presence of nutrients.

1.2 Problem Statement

There is interest worldwide in reducing the quantities of pesticides and chemical fumigants used in agricultural commodities (Ipsita Das et. al, 2013). The major problem associated with the chemical methods is that, even if they are applied with care and in limited quantity, there is a possibility that these chemicals may remain in the food grains and have adverse effects on humans. Fumigation causes fatal to larvae and adult insect but fail to sterilize the insect eggs inside the grain kernel (S. J. Langlinais). Conventional chemicals, grain protectants, and fumigants are extensively used around the world to control insect pests in stored commodities because of low cost, fast processing, and easy application. Greater regulation and restriction of methyl bromide use will likely increase the cost of the fumigant, as well as reduce its availability (E.Mitcham, 2001).

The used of lime, as an alternative to the chemical fumigants, where the lime is misting during the rice movement in the process will create a thin layer of lime for the rice to slower the activity of the insect pests. According to a study from Faiza (Sdn. Bhd.), this method could increase the number of days for the egg to hatch for 25 to 40 days compared to 4 to 14 days without lime misting. The effectiveness of this method can be low as after certain duration the activity of the insect pests will start to hatch. A method to eliminate the entire egg of insect pests is needed to ensure the quality of the rice in storage to the consumer is maintained with a minimal loss in economic value. So there is clearly a need to develop non-chemical treatment methodologies.

The use of electromagnetic heat treatment or microwaves is selected as a new method for post-harvest treatment of agriculture commodities. This method leaves no chemical residues with acceptable quality of the commodities and minimal impact to the environment.

1.3 Objectives

Microwaves can be used to control insects in stored- rice products. The objectives of this project are:

- To develop a microwave system for rice treatment.
- To determine the optimum temperature and duration for the rice treatment.
- To investigate the quality of rice grain maintained at an acceptable condition.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter is divided into two parts. The first part attempts to discuss generally about rice commodities, infestation on the rice grain and available method to disinfestation. The second part intends to discuss a proposed method with the basic concept and principle involved.

As an overview, this is a project to develop a microwave system to treat the infested rice grain as an alternative method. Microwave treatment has a potential to provide a continuous process to allow large quantities of products to pass in a short period of time. It is considered as a safe and competitive method to fumigation to avoid problem on food safety and environmental pollution. Microwave has a good penetrability can kill insect inside and outside the rice kernel.

2.2 Rice

Rice (genus *Oryza*) is the staple food for more than half of the human population i.e. three billion people. In Asia alone, more than two billion people obtain 60 to 70 percent of their calories from rice and its products. With the average person in much of Asia eating rice 2 to 3 times a day, the per capita annual consumption in Asia is many times that of Europe or America. For example, the per capita annual consumption is 195 kg in Myanmar and 160 kg in Cambodia, in contrast with 3 kg in Europe and 7 kg in America (ARF 2004).

A plant of the grass (*Poaceae*) family, rice is tolerant to desert, hot, humid, flooded, dry and cool conditions and can survive in saline, alkaline and acidic soils. As such it is the world's third largest crop, behind maize and wheat. Of the 23 *Oryza* species, only two are cultivated: *Oryza sativa* which originated in the humid tropics of Asia, and *Oryza glaberrima*, from West Africa. There are more than 140,000 varieties of cultivated rice and so far more than 90,000 samples of cultivated rice and wild species are stored in the International Rice Genebank. The three commonest rice cultivars are *indica*, *japonica* and *javanica* and they are often classified by their grain shapes, with the long-grain variety generally containing less starch than the short-gain variety. Figure 2.1 shows the photo of real paddy plant in the field.

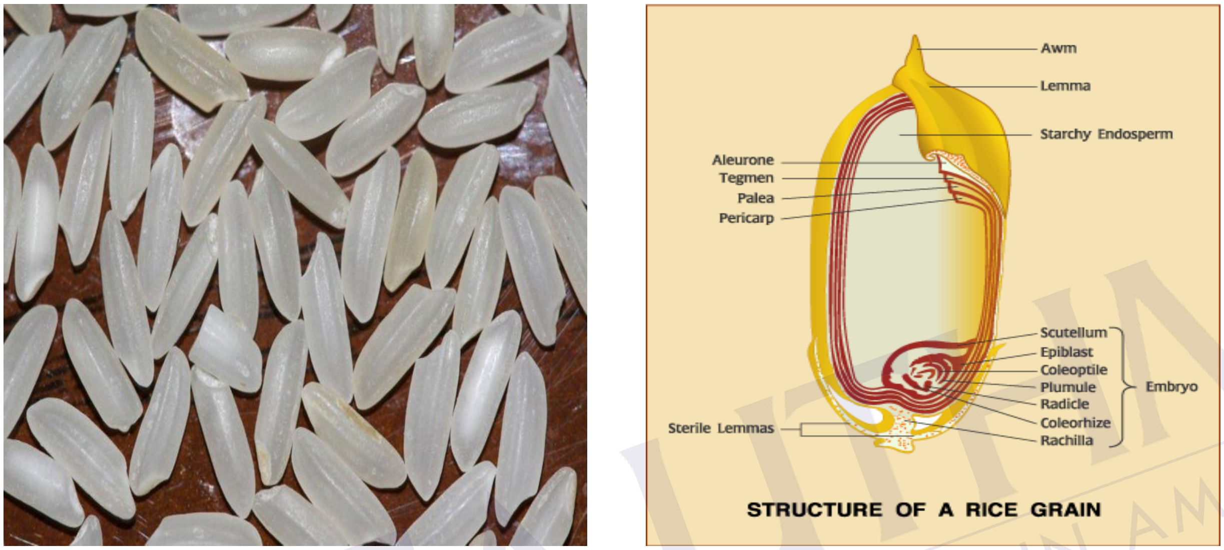
Figure 2.1: Rice paddy plant. Adapted from (http:// http://www.kew.org, 2014)

After harvesting, the seeds of the rice plant are milled to remove the outer husks of the grain and the processed seeds are usually boiled or steamed to make them edible.

However, beside of being a food for the almost 3 billion people around the world, it grows in Asia for at least 10,000 years, rice has become deeply embedded in the cultural heritage of Asian societies and it has entered into their lives in many other aspects, namely, in religion and beliefs, culture and tradition, politics and business, at religious festivals and wedding parties, in paintings, poems and in songs. Many religious rituals are tied to the rice cycle, and social and cultural behavior tied to rice production.

In remote villages of South-east Asia, farmers still compare a grain of rice to a "grain of gold". In modern Japan, people see rice as the very heart of their culture. Rice cultivation has changed landscapes and cuisine, and provided farmers with new sources of income. It has become the most rapidly growing source of food in Africa, and is of significant importance to food security in an increasing number of low-income food-deficit countries.

It is for all these reasons that in 2002, the United Nations General Assembly took the unprecedented step of declaring 2004 as the International Year of Rice with "*Rice is Life*" as the theme, reflecting the importance of rice as a primary food source. Rice was first cultivated in ancient China and India. Figure 2.2 shows the rice grain and its grain structure.



(a) (b)

Figure 2.2: Rice grain (a) Physical rice grain (http://www.21food.com)/ and (b) grain structure (http://www.teksengricemill.com/)

From China rice growing was brought to neighboring countries in East and South-east Asia, while from India it spread to southern Europe and Africa. From its Asian homeland, rice is now cultivated in 113 countries and on all continents except Antarctica. It is often grown in paddy fields i.e. fields with small boundary earth bunds to maintain a shallow water depth (typically from 100 to 200 mm depth) as the plant itself is an aquatic plant capable of "breathing" through its hollow stem. The main reason for flooding the rice fields is that most rice varieties maintain better growth and produce higher yields when grown in flooded soils than when grown in dry soils. The standing water layer provides for water storage to tide over the vagaries of weather, helps to suppress weeds and allows for breeding of fish and ducks. Such a paddy system facilities increased productivity, although rice can also be grown on dry land (including on terraced hillsides). Rice cultivation is well suited to poor countries as it can grow fairly well even with rudimentary or no water infrastructure. About 80 percent of the world's rice is grown by small-scale farmers in low-income and developing countries where rice-based production systems and their associated post-harvest operations employ nearly 1,000 million people in the rural areas. Only about 5 percent of the world's production is exported with Thailand exporting 5.3 million tons a year, Vietnam 3.3 million and the United States 2.3 million tones. Efficient and productive rice-based systems can lead to economic development and improved quality of life, particularly in rural areas, as well as help in the efforts to eradicate hunger and malnutrition (Keizrul Abdullah, 2004).

Rice grows in diverse soils and climates but it is best adapted to a warm, humid environment. In that environment, insects are more prolific than in a cooler, dryer environment. In addition, where year-around continuous cropping is practiced, there are overlapping insect generation throughout of the year.

2.2.1 Infestation of rice grain

Insect infestations in rice can occur just prior to harvest or during storage or in-transit in a variety of carriers. This caused the losses during storage that classified as quantity loses and quality loses. Quantity loses occur when the rice grain is consumed by insect and quality losses are reflected to the reduced economic value of the crop. The stored-grain insects affect not only the quantity of grain but also the quality of grain. Infestation causes decreased nutritional value, reduced seed germination and lower economic value and also causes changes in chemical compositions such as increase in moisture, free fatty acid levels, non-protein nitrogen content, and decrease in pH and protein contents in food grain (Sanchez-Marinez et al. 1997).

The most common stored-grain insects in Malaysia rice are *Prostephanus Truncates* and *Rhyzopertha dominica*. Most stored-product insects have a wide range of food habits and they can feed on several different dry food products. This wide range allows them to move from one food product to another during storage and transportation leading to cross-infestations and residual infestations. The distribution of insects in bulk grain is typically non-uniform and is determined by gradients of temperature and moisture, distribution of dockage and broken grain, and inter and intra-species interactions of insects.

Larger Grain Borer (*Prostephanus truncatus*)(photo:www.agrsci.dk)

(a)

Lesser Grain Borer (*Rhizopertha dominica*) of sorghum: (A) adult and (B) larva in the grain (photos: ICRISAT)

(b)

Figure 2.3: Type of insect found in stored rice grain. (a) *Prostephanus truncates;* (b) *Rhizopertha dominica*

Prostephanus Truncates is a long-lived species with an extended oviposition period and a relatively rapid larval development stage. Its development pattern is similar to the closely related *Rhyzopertha dominica*, lesser grain borer, which is from the same insect family. The species has a potential life span of several months, during which adults continue to feed and infest the host. Optimum conditions for development on maize are 32^{o} C and 70-80% relative humidity, and under these conditions, the life cycle can be completed in 24 - 25 days (Hodges, 1986).

Adults bore into maize grains making neat round holes, generating large quantities of dust as they tunnel from grain to grain. After mating, adult females lay most eggs within the grain in blind ended chambers bored at right angles to the main tunnel. Eggs are laid in batches of 20 and covered with finely chewed maize dust. Oviposition begins 5 - 10 days after adult emergence, reaching a peak at 15 - 20 days (Bell &Watters 1982). The same process occurs in rice grain. Figure 2.4 shows a Granary weevil which attacks rice grain by laying their eggs inside whole kernels. Damage is caused by the larvae feeding in whole grain and the adults feeding in and on whole or broken grain.

Figure 2.4: Rice stem borer (Granary weevil). (a) Adult and its larvae (http://agebb.missouri.edu/), (b) Effect on rice with rice stem borer (http://co-opstop.blogspot.com/).

Another Rice stem borer is *Scirpophaga.* This is a type of yellow stem borer of rice attacks only rice and has wide distribution in all Asian countries. This insect cause the nature of damage by its larva feeds inside the stem causing drying of the central leaving a hollow husk. The month from October to December has been found conducive for the multiplication of this insect. This insect commonly attacks in paddy stage.

The female lays 15 - 18 eggs in a mass near the tip on the upper surface of tender leaf blade and covers them with buff coloured hairs and scales. A female lays about 2 - 3 egg masses and the incubation period ranges from 5 - 8 days. The newly hatched pale white larva enters the leaf sheath and feeds for 2 – 3 days and bores into the stem near the nodal region. Usually only one larva is found inside a stem but occasionally 2 - 4 larvae may also be noticed. The larva becomes full grown in 33 - 41 days and measures about 20 mm long. It is white or yellowish white with a well-developed prothoracic shield. Before pupation it covers the exit hole with thin webbing and then forms a white silken cocoon in which it pupates. The pupa is dark brown and measures 12 mm long. The pupae period varies from 6 -10 days and may get prolonged depending on the weather conditions. The entire life-cycle is completed in 50 - 70 days (A.V Navarajan Paul, 2007)

Figure 2.5: A Genus Scirpophaga (www.knowledgebank.irri.org/).

There are various methods are used in an effort to control these insect pests in rice paddies and in the harvested rice.

2.2.2 Available Method of Disinfestation

The efficient control and removal of stored grain pests from food commodities have long been the goal of entomologists throughout the world. Various methods of insect control have been practiced to save the grain. In recent years, technology has made marked progress in the study of disinfestation of stored-grain insects and of finding improved ways to control them especially to detect latent forms of infestation (R. Vadivambal et al., 2006). The various methods of insect control can be grouped as physical, biological and chemical methods.

2.2.2.1 Physical Method

Insects in stored grain can be controlled by manipulating the physical environment or by applying physical treatments to the grain and insect species. Physical methods to control insects include different types of traps (probe traps, pheromone traps), manipulation of physical environment (Sinha and Watters, 1985), mechanical impact, physical removal, abrasive and inert dusts and ionizing radiation (Muir and Fields, 2001). The physical variables that are usually manipulated are: temperature, relative humidity or grain moisture content, and composition of atmospheric gases in the inter-granular air spaces. Low temperatures are usually obtained by aeration with cold ambient air. Methods to obtain high grain temperatures are more diverse, including: microwaves, infrared, hot air and dielectric heating (Banks and Fields, 1995). Physical control methods tend to be slow and some may not give high levels of mortality even when well managed. They can be used where the infestation is low. Microwave disinfestation is a physical method to control insects in stored grain (Muir and Fields, 2001).

2.2.2.2 Biological Method

The biological method is to use living beneficial organisms, as natural enemies, to control pests. There are many approaches to biological control of pests in stored products, including the use of predatory insects and mites, parasitoids and species-specific pathogens. Unlike chemicals that need to be applied to a wide area, natural enemies can be released at a single location and they find and attack the pests in a grain mass. There are no chemicals involved and these methods do not pose serious risk to the consumers or to the environment (Subramanyam et. al., 2000). Biological control agents are usually species-specific. Since most infestations comprise multiple species, several different isolates or species of biological control agents may be needed. Biological control methods act slowly and consequently much damage may occur before control is effective. It is not usually suitable for dealing with heavy infestations (Subramanyam et. al., 2000).

2.2.2.3 Chemical Method

The chemical method uses insecticides to kill the insects. Since the 1950s, chemical insecticides have been used extensively in grain storage facilities to control stored-product insect pests due to low cost, fast speed in processing, and ease of use. Most postharvest pest management programs, therefore, rely heavily on fumigants. The chemicals used to control insects in the bulk stored-grains are composed of two classes, namely, contact insecticides and fumigants.

Contact insecticides kill insects when they contact treated surfaces. Some of the commonly used insecticides are *Malathion*, *pirimiphos-methyl*, *chlorpyrifos-methyl*. These types of insecticide are sprayed directly on grain or structures which provide protection from infestation for several months. Fumigants are gaseous insecticides applied to control insects in grains that are inaccessible by contact insecticide. Fumigants are gaseous insecticides applied to control insects in grains and processed foods that are inaccessible by contact insecticide. Some of the commonly used fumigants are methyl bromide and phosphine (Sinha and Watters 1985).
Methyl bromide is involved in the depletion of the atmospheric ozone layer. Hence it has been banned effective 2005 in developed countries, except for quarantine purposes (Fields and White 2002). Many alternatives have been tested as replacements for methyl bromide, from physical control methods such as heat, cold and sanitation to fumigant replacements such as phosphine, sulfur fluoride and carbonyl sulfide (Fields and White 2002). Among the physical, chemical and biological control methods, the chemical method is widely used to control insects (Sinha and Watters 1985). Chemical control methods are essential for efficient production and preservation of food products. For the past three decades, efforts have been devoted to the study of possible alternative insect control methods that might be helpful in minimizing the environmental hazards associated with chemical insecticides (Nelson and Stetson 1974).

The most commonly used fumigants are *methyl bromide* (MeBr) and *phosphine* which could eliminate live insect insects in food product (E. J. Bond, 1984). In Malaysia, a mixture of *pirimiphosmethyl* (12.0 mg of the active ingredient), *permethrin* (1 mg),and *piperonyl butoxide* (5.0 mg) is used as one liter per ton of paddy to achieve complete prevention of infestation (100% insect control) throughout the grain storage period (Manjur Ahmed et al., 2011). However, the used of methyl bromide is under control because of ozone depletion (J. G. Leesch et al., 2000). It has already been established that the use of *methyl bromide* has led to serious environmental damage and hazards to people's health. For these reasons, the Montreal Protocol constituted by the United Nations Environment Program agreed on a phasing out of methyl bromide in the developed countries by 2005 and in the developing countries by 2015 (United Nations Environment Programme, 1997). As a result, *phosphine* has been used as a replacement of methyl bromide for a long time (S. Rajendran et al., 2001). Phosphine is increasingly used as a treatment to replace methyl bromide but the major drawback is the rapid increase in resistance of insects tophosphine (Taylor 1994, Fields and White 2002). Another limiting factor is that insects develop resistance to some particular chemical fumigants. Some of the contact insecticides have become ineffective because of wide-spread resistance in insect populations. The other major problem associated with the chemical methods is that, even if they are applied with care and in limited quantity, there is a possibility that these chemicals may remain in the food grains and have adverse effects on humans. Fumigation often only kills live larvae or adult insects but does not sterilize the eggs which are still alive in the grain kernels (S. J. Langlinais, 1989). The consumption of organic products is also increasing each year. There is, therefore, interest in developing an alternative, nonchemical process method to control insect pests in food grains so as to minimize the environmental hazards associated with chemical insecticides while retaining acceptable product quality.

2.2.2.4 Controlled Atmosphere Storage

In this method, normal composition of atmospheric air, that is, 21% oxygen, 0.03% carbon dioxide, and 78% nitrogen is altered appropriately for disinfestation process. An atmosphere containing more than 35% CO2 known as carbon dioxide atmosphere and the atmosphere containing less than 1% are lethal to insects (J. Banks and J. B. Fields, 1995). Controlled atmospheres are mainly based on the establishment of a low-oxygen environment which kills pests. Insects in all stages are eliminated because of the lack of oxygen which causes the insect to dry out and suffocate. Another study on 15% to 100% CO_2 effect on wheat flour at 25ºC found that pupae were most the tolerant stages for all CO_2 concentrations and eggs were the only 100% mortality at 20% CO_2 in duration of less than 30 days (P. C. Annis and R. Morton, 1997).

This controlled atmosphere storage has been shown to be promising in creating lethal conditions for insects and fungi in stored food commodities. Controlled atmospheres are always being seen as average alternative such as longer treatment time, usability and availability, and being not suitable for dealing with high level of infestation.

2.2.2.5 Ionizing radiation

It is a process where infested food products are being exposed to ionizing radiation so as to sterilize, kill, or prevent emergence of insect pests by damaging their DNA. The most commonly used of ionizing radiation is gamma rays from radioactive cobalt- 60 .Irradiation with high energy electrons is usually safer and easier to work with because it can be turned on and off while an isotope is always radiating and humans must be shielded from it (P. G. Fields and W. E. Muir, 1996). The ability of gamma rays to deeply penetrate pallet loads of food makes it one of the most commonly used in postharvest pest control. Sterilization of many species of insects can be accomplished at lower doses. However for the purpose of rice disinfestation requires high doses of energy to the level of insect mortality. Higher the doses of energy could lead to damage to the sample and more radiation may cause hazardous to human being. Besides, this method has not received wide recognition because of high power consumption and irradiation has not been accepted by many countries.

2.2.2.6 Lime Misting

This is a non-chemical method as an alternative to protect rice grain from infestation. T During storage, the insect lays egg outside rice grain and between the grains. In the process of packaging, the lime is misting during the movement of the conveyor for uniform coverage to the rice. This provides a thin layer for the rice will produce a small electrical charge that enough to make insect move away. This method will affect the insect activity to slower. The number of days for the egg to hatch increases more than 2 week. This implementation will reduce number of claim more than 50% (Faiza sdn. Bhd. 2012). However, after some times the insect is expected to start again. They start to create new colony by laying egg in the rice grain.

With all above method discussed, there is interest worldwide to develop a new method especially to reduce the use of chemical and pesticides in food commodities. Therefore, a propose method will be discussed in the part two.

2.3 Method of microwave system

2.3.1 Properties of Microwave

Microwave is the region range in the electromagnetic (EM) wave spectrum in the frequency range from about 1 GHz to 100 GHz. This corresponds to a range of wavelengths from 30 cm to 0.3 cm in free space. The free space is characterized by the electrical medium parameter permittivity $\varepsilon_o = 10^{-9}/36\pi$ farad/m, permeability ↑ $\mu_o = 4\pi \times 10^{-7} henry/m$, and conductivity $\sigma_o = 10^{-14} mho/m$ [10]. Microwaves are invisible waves of energy that travel at the speed of light, 3×10^8 m/s. In the electromagnetic spectrum, microwave lie between radio frequencies and infrared radiation. From the broad range of microwave frequencies available, a few are designated for industrial, scientific and medical applications (ISM). Microwaves are reflected by metals, transmitted through electrically neutral materials such as glass, most plastics, ceramics and paper, and absorbed by electrically charged materials (Decareau 1972; Mullin 1995).

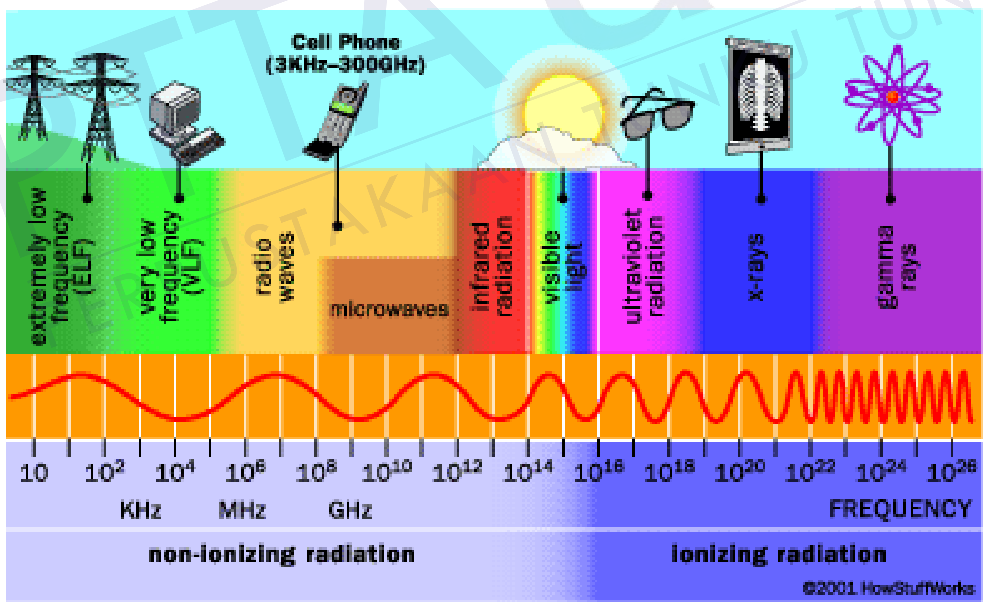


Figure 2.6: Electromagnetic spectrum
(http://electronics.howstuffworks.com/cell-phone-radiation1.htm)

2.3.2 Principle of Microwave heating

Microwave heating is based on the transformation of alternating electromagnetic field energy into thermal energy by affecting polar molecules of a material. All matter is made up of atoms and molecules and some of these molecules are electrically neutral but many are bipolar. When an electric field is applied, the bipolar molecules tend to behave like microscopic magnets and attempt to align themselves with the field. When the electrical field is changing millions of times per second (e.g. 915 or 2450 million times per second), these molecular magnets are unable to withstand the forces acting to slow them. This resistance to the rapid movement of the bipolar molecules creates friction and results in heat dissipation in the material exposed to the microwave radiation. Biological material placed in such radiation absorbs an amount of energy which depends on the dielectric characteristics of the material and heat is produced (Mullin 1995). Microwaves are not heat. Microwave fields are a form of energy and microwaves are converted to heat by their interaction with charged particles and polar molecules, their agitation is defined as heat (Buffler 1993). The most important characteristic of microwave heating is volumetric heating which is different from conventional heating. Conventional heating occurs by convection or conduction where heat must diffuse from the surface of the material. Volumetric heating means that materials can absorb microwave energy directly and internally and convert it into heat. The conversion of microwave energy to heat is expressed by the following equation (Mullin 1995; Linn and Moller 2003):

$$P = 2\pi E^2 f \varepsilon_o \varepsilon'' V$$

Where $P = power, W$

$E = the\ electric\ field\ strength,\ V/m$

$f = the\ frequency, Hz$

$\varepsilon_o = the\ permittivity\ of\ free\ space, F/m$

$\varepsilon'' = the\ dielectric\ loss\ factor$

$V = volume\ of\ material, m^3$

2.3.3 Principle of microwave in rice treatment optimization.

The use of microwaves for killing insects is based on the dielectric heating effect produced in grain, which is a relatively poor conductor of electricity. Since this heating depends upon the electrical properties of the material, there is a possibility of advantageous selective heating in mixtures of different substances. In a rice disinfestation or treatment, it is possible to heat the insects to a lethal temperature because they have high moisture content while leaving the drier rice with slightly warm. Raising the temperature of infested materials by any means can be used to control insects if the infested product can tolerate the temperature levels that are necessary to kill the insects.

Dielectric properties are the electrical characteristics of materials that are poor conductors of electricity (dielectrics). The dielectric properties of the materials depend on the frequency of the applied electric field and the temperature of the material (Nelson 1973a, 1991). If the material is hygroscopic, dielectric properties also depend on the amount of water in the material (Nelson 2001). The first reported measurements of insect dielectric properties were for bulk samples (insect and air space) of rice weevil and confused flour beetle, Tribolium confusum (J. duVal) at 40 MHz frequency. The dielectric constants were 6.6 and 7.8 for rice weevil and confused flour beetle, respectively, and loss factor was 2.2 for both the species (Nelson and Whitney 1960; Nelson et al. 1966; Nelson 1967). The insect permittivity data at 25^{o}C for 2.47 GHz frequency reported by Nelson et al. (1998) are shown in Table 1.1.

Table 1.1: Dielectric properties of insects at 20 - 25 ℃ (Nelson et. al. 1998)

Adult insect species	Frequency (GHz)								References
	0.2		2.4		9.4		20		
	ε′	ε″	ε′	ε″	ε′	ε″	ε′	ε″	
S. oryzae	28	12	17	3	17	3	-	-	Nelson 1972b
L. decemlineata	53	81	38	12	30	16	19	17	Colpitts et al. 1992
S. oryzae	42	28	32	9	25	12	18	13	Nelson et al. 1997
S. oryzae	55	48	42	13	31	16	23	16	Nelson et al. 1998
T. castaneum	61	56	47	15	34	19	25	19	
O. surinamensis	70	68	53	17	40	21	28	22	
R. dominica	63	55	43	15	34	19	25	18	

ε′- Dielectric constant; ε″- Dielectric loss

The dielectric properties obtained by measuring bulk samples containing insects were different from the dielectric properties of whole insect body (Nelson et al. 1998; Nelson 2001). The dielectric properties of whole insect bodies of various insect species are shown in Table 1.2.

Table 1.2: Adult body dielectric constant and loss factor for stored grain insect (Nelson et. al. 1998)

Adult insect species	Temperature (°C)	Frequency (GHz)							
		0.2		0.5		1.08		2.47	
		ε′	ε″	ε′	ε″	ε′	ε″	ε′	ε″
S. oryzae	10	54	40	49	20	45	14	42	13
	70	59	92	50	43	45	24	42	15
T. castaneum	10	59	43	54	22	50	16	46	15
	70	66	108	54	50	48	27	44	17
O. surinamensis	10	69	53	62	27	58	19	53	17
	70	81	125	67	59	59	34	53	22
R. dominica	10	59	41	54	22	50	16	45	15
	70	80	128	66	60	59	34	52	22

The dielectric properties of insect larvae were measured by Wang et al. (2003a) using an open ended coaxial probe method. The larvae of Indian meal moth, Plodia interpunctella (Hubner), Navel orange worm, *Amyelois transitella* (Walker), Codling moth, *Cydia pomenella (L.)* and Mexican fruit-fly, *Anastrepha ludens (Loew)* were made into slurry and the initial moisture content of insect slurry was about 74% w.b. The dielectric properties of the four insect larvae are shown in Table 1.3. Ikediala et al. (2000) has shown that dielectric constant and loss factor of compacted codling moth has no significant difference from that of live larvae.

Table 1.3: Dielectric properties of four types of insect larvae at different frequencies (Wang et al. 2003a).

Insect species	Temperature (°C)	Frequency (MHz)					
		40		915		1800	
		ε′	ε″	ε′	ε″	ε′	ε″
C. pomonella	20	65 ± 0.9	163 ± 0.4	48 ± 0.2	12 ± 0.1	45 ± 0.1	12 ± 0.2
	40	72 ± 2.9	349±18.3	45 ± 2.4	19 ± 1	42 ± 2.2	14 ± 0.7
P. interpunctella	20	69 ± 0.9	149 ± 3.7	40 ± 0.4	13 ± 1.4	38 ± 0.5	11 ± 0.6
	40	90 ± 2.2	281 ±37.9	38 ± 1.6	20 ± 2.8	36 ± 1.7	13 ± 1.7
A. ludens	20	71 ± 0.3	231 ± 5.9	49 ± 3.4	18 ± 2.0	47 ± 0.7	13 ± 1.7
	40	112± 22	415 ± 31.7	45 ± 2	29 ± 5.9	43 ± 1.6	17 ± 2.7
A. transitella	20	69 ± 0.4	213 ± 3.1	45 ± 1.3	16 ± 0.1	42 ± 1.4	13 ± 0
	40	80 ± 0	387 ± 2.2	42 ± 0.1	24 ± 0.1	40 ± 0	16 ± 0

Dielectric properties of insects are affected by the frequency and temperature. The dielectric constant decreases with increasing frequency and generally increases with increasing temperature. The loss factor of insects decreases rapidly as frequency increases from 200 MHz to about 2 to 3 GHz and then they change little up to 20 GHz. Loss factors are highly dependent on temperature at the lower frequencies, but show little dependence above 2 or 3 GHz (Nelson et al. 1998).

2.3.4 Dielectric properties of grains

The dielectric properties of grain became very important as there was an increase in the interest for using microwave energy for grain drying, insect control, seed treatment to improve germination and moisture measurement (Chugh et al. 1973; Nelson 1992). At radio and microwave frequencies, dielectric properties of moist granular materials (grain) depend on frequency, moisture content, bulk density and temperature (Nelson 1981; Chugh et al. 1973).

Various methods have been developed and utilized for measurement of dielectric properties of grains. The three most popular methods for measuring dielectric properties of foods are: open ended coaxial probe, transmission line and resonant cavity method (Ohlsson, 1980).

The probe method is based on a coaxial line ending abruptly at the tip which is in contact with the test material. The probe method is the easiest to use because it does not require a particular sample shape or special containers. The transmission line method involves placing a sample inside an enclosed transmission line. This is more accurate than the probe method but it is difficult to use and is time consuming. The resonant cavity method uses a single-mode cavity. A sample of known geometry is placed in the cavity and the changes in the reflected power of the cavity and the frequency of resonance are used to determine the dielectric property of the sample (Wang et al. 2003a). The dielectric constant for wheat varies between (2.7 - 2.98) and dielectric loss factor between (0.25 - 0.59) for frequencies 5 - 17 MHz and moisture content varying between 10.2-17.8% (Trabelsi and Nelson 2003).

The dielectric constant and loss factor of grain types at 24ºC are listed in Table 1.4. The moisture content has the greatest influence on the dielectric properties of grain at any frequency. The dielectric constant increases with increasing moisture content at any given frequency and the dielectric constant decreases with increasing frequency. The dielectric loss factor is less predictable than the dielectric constant and may either increase or decrease with frequency or with moisture content, depending upon the particular range of frequency or moisture content (Nelson 1981). Grain bulk density is the next important factor, followed by temperature. Other factors such as chemical composition may also have smaller influence on the dielectric properties of grain (Nelson 1981).

Table 1.4: Dielectric constant and loss factor of grains at 24°C and different moisture contents (w.b).

Grain	MC (%)	Frequency (GHz)					
		10		40		1	
		ε′	ε″	ε′	ε″	ε′	ε″
Barley, spring	12.9	3.2	0.25	3.0	.038		
Rye, winter	12.7	-	-	4.0	0.52		
Oats, spring	10.7	2.8	0.2	-	-	2.2	0.18
Sorghum	11.4	4.2	0.38	-	-	2.9	0.29
Wheat	12.5	-	-	-	-	2.89	0.35
Oats	10.7	-	-	-	-	2.12	0.16
Sorghum	11.4	-	-	-	-	2.81	0.34

There has been a lot of research on microwave disinfestation of cereals and of some other food materials.

In this research, the heating process must be implemented with the condition that the temperature is less than 70^{o}C to avoid damage to the rice. The rice is exposed to the microwave energy for about three minutes by maintaining the temperature less than 70^{o}C. These are the optimum parameters to ensure the quality of rice and mortality of insects (Faiza sdn. Bhd.).

The next chapter will discuss the proposed method in terms of design, block diagram and circuitry construction.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter attempts to discuss the development of the project in detail and the overview of the procedures and methods that being used in the project. The project involved the modification of remained equipment and the development of hardware and software to come out with a system to achieve the project goals. The project was carried out on three main sections as follows:

a) The modification of domestic oven for the purpose of the project
b) The development of the controller module with software.
c) The development of the relay switching circuit.

3.2 The project scope

The main objective of this project is to study the mortality of adult insect and the ability to eliminate the insect eggs inside and outside the rice kernel. To achieve the objective a microwave system is developed by associating a domestic microwave oven, temperature sensor module with Arduino microcontroller and a relay circuit. Figure 3.1 show the block diagram of the system.

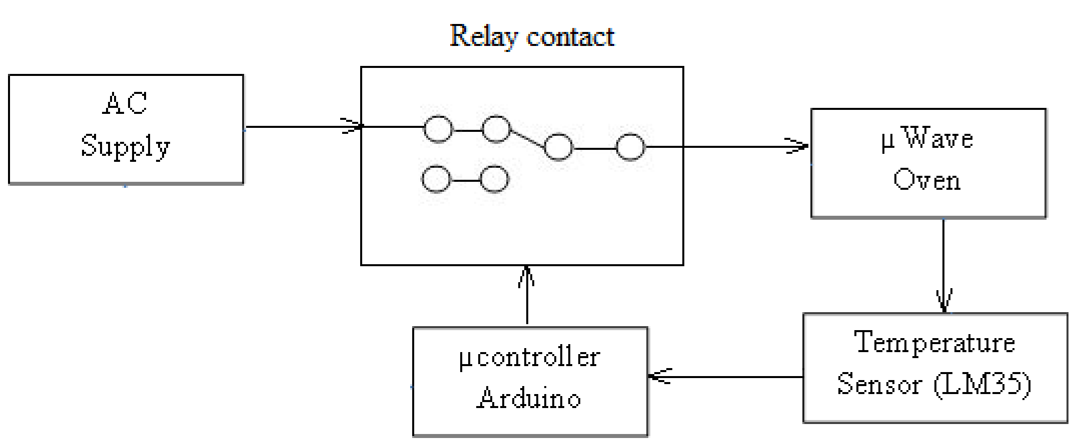


Figure 3.1: Microwave system block diagram for rice treatment

3.3 The Modification of Microwave oven.

In this project, a Samsung M1600N model microwave oven has been modified to make it appropriate for this project. This oven operates at 2450 Hz operating frequency magnetron. The controller time on the oven is removed and instead two supply wires are connected to the relay circuit as shown in figure 3.2(a). Figure 3.2(b) shows that the turn-table is removed and a tray with embedded temperature sensor is located at the center of oven cavity. The three wires are connected from LM35 sensor to Arduino board.

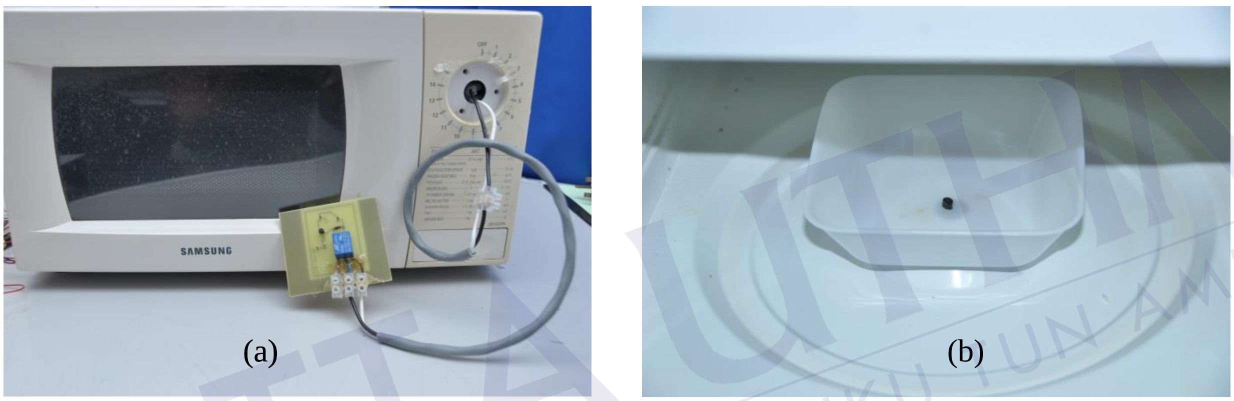


Figure 3.2: Setup for microwave oven. (a) Relay circuit replaced the oven timing switch, (b) Tray with temperature sensor on oven cavity.

3.4 The Development of Controller Module and Software.

The controller module consists of a microcontroller, an LCD display and a temperature sensor. An LCD display used is a type of 16x2 with Hitachi driver HD44780 and temperature sensor used is type of plastic package LM35.

In this project, a microcontroller is used to control a relay circuit for the power supply to the microwave oven system. A PIC microcontroller from microchip is a very common used but this type of system needs to decide which is the board, language, compiler to the language, hardware programmer etc. However, an Arduino is an open source development board from Atmel with a full software development that can be easily downloaded from the internet. In this project, Arduino UNO is selected to be used.

3.4.1 Arduino UNO Microcontroller

The Arduino Uno is a microcontroller board based on the ATmega328. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz ceramic resonator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller, simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started.

The Uno differs from all preceding boards in that it does not use the FTDI USB-to-serial driver chip. Instead, it features the Atmega16U2 (Atmega8U2 up to version R2) programmed as a USB-to-serial converter. Arduino also have another types of board namely Duemilanove, Romeo, Mega, Leonardo etc. Figure 3.3 below shows the Uno development board which utilizes an Atmega328 microcontroller chip designed by Atmel as shown in figure 3.4.

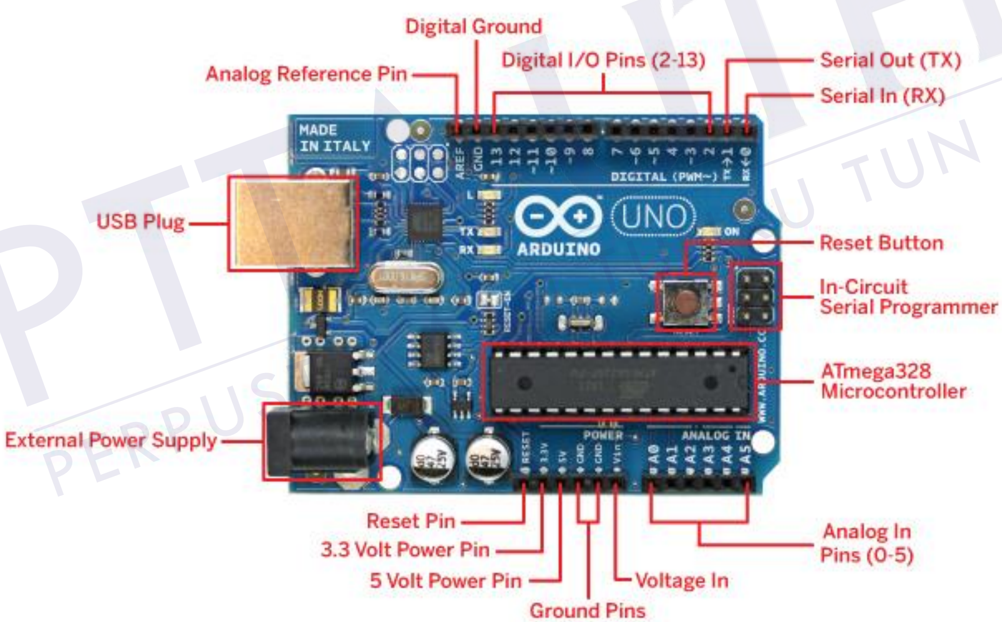


Figure 3.3: Arduino UNO development board configuration (http://arduinoarts.com/2011/08/thearduino-uno-anatomy/arduino-callouts1/)

An ATmega328 in DIP package, pre-loaded with the Arduino Optiboot (Uno 16MHz) Bootloader. This will allow you to use Arduino code in your custom embedded project without having to use an actual Arduino board. Atmel's ATMega328 8-Bit Processor in 28 pin DIP package. It's like the ATmega168, with double the flash space, 32K of program space, 23 I/O

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