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Heat distribution under microwave heating treatment

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ABSTRACT

This paper presents the process of microwave heating treatment to kill the rice weevil to improve the quality and quantity of rice for industrial storage purpose. Since many years ago, heat uniformity has been a major drawback of microwave heating application. The heat distribution in rice after undergoing four treatments with a microwave frequency of 2.4 GHz at the different power level of 540 and 900W with different time treatment of 50 and 80 seconds are shown in this paper. The samples are placed inside a square container, 8.5 cm x 8.5 cm x 2 cm. Each sample contains 15 adults of rice weevil of Sitophilus Oryzae placed randomly in the container and the mortality of the rice weevil for adult stages from each treatment are observed and interpreted in Analysis of Variance (ANOVA) technique.

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1. INTRODUCTION

Malaysia is one of the countries which has high potential to become one of the largest rice paddies in the world. However, one of the obstacles is most of the produced paddy is damaged by the threatening insects, Sitophilus Oryzae or it is well known as bubuk beras among locals. This damage has cause shortage of paddy supply and forces the government to receive supply from other countries which most of it is imported from Thailand.

There are methods used to control the damaged grain and commodities caused by insect pests which are the physical method, biological method, chemical method, and electrical method. The first three methods had resulted in the least favorable results. In the physical method, it is a process which needs skills and physical environment information to kill the insects and it takes a long time period to give an effective result to control the damage. By using the biological method, it involves many types of insects to be used as natural enemies to kill the insect pest that causes the grain destruction [1]. Chemical method is proven not effective when the contact insecticide which are malathion, chlorpyrifos-methyl, and pirimiphos-methyl when the insects develop their body resistant and become immune to the gas [2]. Also, the chemical substance only can kill the adult rice weevil but not the living eggs inside the rice kernel [3]. Our earth planet is threatened as the ozone layer has been eroded by fumigant gas methyl bromide (MeBr) and phosphine that are freed to our environment when they are sprayed onto the commodities during the treatment process [4]. Hence, the chemical method has been slowly exterminated in many countries [5]. In the electrical method, conventional heating has been introduced such as hot air and hot water heating but it gives less satisfaction result in term of treatment time and the quality of grain and commodities after the treatment [6-7]. Figure 1 shows rice weevil.

Figure 1. Rice weevil

In microwave heating treatment, it is supposed to shorten the treatment time to control the insect. With the accurate treatment time, temperature and power, it can maintain the quality of the product. It also can disrupt the ability of the adult's insect to reproduce and also can kill the eggs inside the commodities. The wave can penetrate through the commodities as microwave energy is able to heat the product volumetrically which mean that the product placed under the radiation will directly absorb the energy and transform it to heat as their particles collide vigorously with one another [8]. This advantage also will help to reduce the number of the insect within the storage and by the time the product reaches the customer, the product can be used and stored for a longer time.

However, microwave heating treatment has some complication in heat distribution as it does not heat the commodities uniformly [9]. Physically, it can be seen through thermal image by the existence of a hot spot and cold spot. This non-uniformity heating can allow the adult insect to escape from the hot spot to the cold spot to avoid being killed by the treatment [10]. Uniform heat distribution is important to ensure the product receive optimum treatment and at once, increase the effectiveness of this method to achieve its main aim which is to control the rice insect in for storage purpose.

Heat distribution has been holding back the full potential of microwave heating to be applied in the industry. The temperature distribution varies from one product to another as every material has different electrical properties such as the composition, moisture content and the applied frequency during the treatment [11]. The density of the material also is one of the notable factors because the different amount of mass has a different response to the electromagnetic field. Uneven heating is observed by the appearance of the hot spot and cold spot which can be visualized to human's eye by using a thermal camera. The temperature difference can be obtained by using a thermocouple.

The influence of cavity mode in microwave heating was investigated by Thomas Ohlsson in 1992 [12]. There are two polarizations in microwave field which are transversal electrical and transversal magnetic. They were discussed as a factor of overheating effect in food's shape as it was found that strong center heating in food with the spherical and cylindrical geometry. This later was agreed by Juming Tang is in his study of quarantine treatment of cherries using 915 MHz [13]. Also, the study of the overheating at the edge and the corner of the sample in wedge-shape food. It was concluded that TM should dominate the oven as with minimum reflection, high angle of incidences can lead to optimum power utilization and improve the possibilities of uniform heating.

In 2006, Manickavasagan found the non-uniform of in grains under microwave treatment [14]. The treatment was using microwave dyer with the frequency of 2450 MHz involving barley, canola, and wheat. The average temperature within the surface was found highest in barley which was 72.5 to 117.5°C, followed by wheat and canola which were 73.4 to 108.8°C and 65.9 to 97.5°C respectively. It is crossed with Vadivambal’s result that recorded temperature difference between the hot spot and cold spot of 70°C for barley.

In 2013, Ameziane et al developed a model of heat transfer to control insects specifically focus on larva and egg stage in date [15]. The treatment was analyzed for conventional heating, microwave heating of 915 MHz and both combined. The temperature measurement was taken on the surface and inside of the date to increase the reliability of result considering limiting phenomena such as the heterogeneity of temperature in the material, coupling process between heat transfer and mortality of insects and the optimization of various treatment condition. It was suggested that hot air circulation must be provided as the larva heating was reduced due to heat transfer and eggs stage insect did not reach a sufficient temperature to be killed.

In 2014, Fuji et al have conducted an evaluation of insect expulsion by using wheat sample under microwave treatment for disinfestation purpose [16]. Two type of 3-D treatment was studied which were the continuous treatment (3DCT) and intermittently treatment (3DIT). The difference between this two methods was the sample was kept inside the microwave oven for 5 minutes after the first treatment before continued with next treatment time. 3DCT was preferred over 3DIT as it 3DCT generate more uniform distribution as the treatment did not significantly reduce the moisture content of wheat. It was concluded as so based on the theory of, under the same treatment time, high moisture content reduced the temperature difference which with low temperature difference, high chance of uniform heating can be achieved.

This paper presents the heat distribution within rice in a square shape since it may vary according to its shape, height or the ability of the sample itself to couple well with the heating of the microwave. The center and each corner of the sample need to be observed and their temperature needs to be recorded to note whether it afford to kill the rice weevil at their points.

2. METHODOLOGY

In this experiment, microwave heating experiment in rice is using domestic Sharp Microwave Oven model R352ZS with the frequency of 2.4 GHz and output power of 900W. FLIR EX-Series Infrared Camera is used to see the thermal image to evaluate the hot spot and cold spot occurred in the sample. The room temperature and humidity are monitored by using DHT22 to ensure the environment condition is constant while the experiment is conducted. The samples are local Malaysian rice paddy and 15 adult rice weevil specifically from Sitophilus Oryzae species.

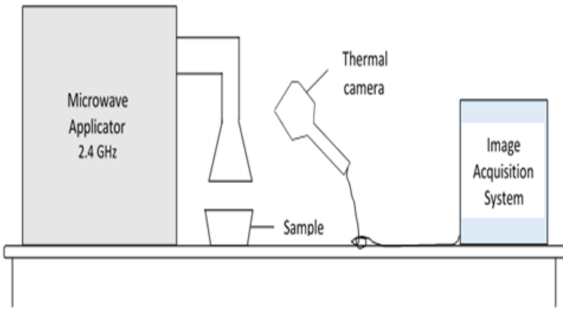

Figure 2. Measurement setup

2.1. Preparation of sample

The rice paddy is put inside a square plastic container with a height of 2 cm. The rice is already infested by female adult rice weevil for at least a month. With that period, it can be assumed that half of the rice sample contain eggs or even larvae. After the treatment is done, these samples are kept and observed for how many adult rice weevil will emerge from the treated sample. This will determine the mortality of the egg stage. The adult's rice weevil used in the experiment are cultured properly since the beginning and aged 2 weeks old. 15 of them are buried randomly within the rice paddy.

2.2. Microwave heating treatment

The experiment is carried out by placing the container samples into the microwave oven. Each treatment is matched to the treatment time and different power level starting at 50 and 80 second and 900 to 540 W. Maximum temperature range for each power level microwave oven can be seen in Table 1. Output power at different power level is calculated as the ratio of percentage power level to the output power of the microwave applicator.

Once the treatment time is up, the sample will be taken out and the image will be captured immediately by using the thermal camera. By this image, the cold spot and hot spot can be evaluated. After one minute, the insects will be checked to see whether they survive treatment or not by soft brushing on their body. The rice sample will be kept safe to evaluate the mortality of the egg stage.

Table 1. The temperature corresponding to the output power

Power Level/P	Output Power/W	Maximum Temperature/°C
60	540	65
100	900	95

3. RESULTS AND DISCUSSION

The treatments are running with the treatment time of 50 seconds with the power of 540W(treatment A) and 900W (treatment B) and treatment time of 80 seconds with the power of 540W (treatment C) and 900W (treatment D). Every treatment is repeated with 10 samples.

3.1. Hot spot

The hot spot and cold spot are captured by using FLIR EX Series thermal camera. It shows that the hot spots are focused in the center and cover most of the sample with the size of the container as shown as in Figure 3. With the well-distributed heat, the highest temperature represented by red color in the thermal image that causes high mortality is 82.5°C. At the edge and the corner of the container, the temperature recorded is medium with the range of 35 to 43°C.

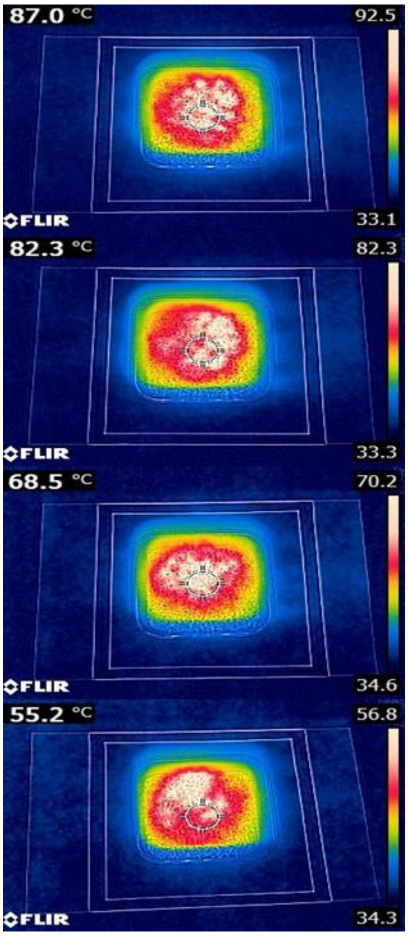

Figure 3. Thermal image of the sample

3.2. Mortality of rice weevil

The number of dead adult rice weevil from each sample are calculated and the mortality is shown in Table 2. The number of dead rice weevil was killed by the microwave energy are compared between the same treatment time with different power by using the ANOVA test. By the criteria, the difference in each pair of treatments are statistically significant at the 95% confidence level ($p<0.05$) and tabulated in Table 3. These values show that the treatments design does affect the mortality of adult rice weevil. High power with high treatment time cause high mortality when compared to low power with high treatment time only cause low mortality but the quality of the rice needs to be considered to maintain its nutrition.

Table 2. Mortality of adult rice weevil

Treatment	Mortality of Adult Rice Weevil/%	Temperature/°C
A	32	51.3
B	87	73.2
C	41	56.4
D	93	82.5

Table 3. ANOVA t-Test results of microwave heating treatment

ANOVA t-Test	Treatment			
	A	B	C	D
Mean	4.8	6.1	13.1	13.9
Standard Deviation	0.63	0.99	1.37	0.74
Standard Error Mean	0.20	0.31	0.43	0.23

4. CONCLUSION

From this experiment, the microwave heat distribution can be seen to conquer the center of the sample. The minimum temperature as seen as the yellow color through the thermal camera was observed at the edge of the square container. Also, it can be concluded that the treatment with high power and high treatment time achieve high mortality of rice weevil. Nevertheless, the rice paddy needs to be tested to ensure its quality is maintained. The occurrence of hot spot is found covering most of the sample surface with this specific size of the container. The highest mortality rate is 93% achieved at treatment of 80 seconds with 900W of output power with temperature at 82.5°C, followed by 87% in treatment of time 50 seconds and 900W at 73.2°C, 41% in treatment with time 80 seconds and 540W at 56.4°C and 32% in treatment of time 50 seconds and 540W at 51.3°C. High output power can cause high mortality and maintain the quality of rice paddy if it is matched with suitable treatment time. This experiment shows that microwave heating treatment has future in disinfestation of insect.

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