ANNUAL REPORT
COMPREHENSIVE RESEARCH ON RICE
January 1, 2005 - December 31, 2005

PROJECT TITLE: RICE UTILIZATION AND PRODUCT DEVELOPMENT
- Developing Alternative Non-chemical Disinfestation Methods

STATUS OF PROPOSAL: _____/New __X__/Continuing

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LEVEL OF 2005 FUNDING: $30,000

OBJECTIVES AND EXPERIMENTS CONDUCTED BY LOCATION TO ACCOMPLISH OBJECTIVES:

Objectives:

This research was a continuation of the previously funded project with the goal of developing rapid, non-chemical, safe alternative methods to eliminate insect pests from rough rice. The research results obtained in the previous year have shown that both infrared and radio frequency heating treatments were effective in disinfestation of dried (storage) rough rice. The research for the current year specifically addressed the following objectives:

1. Optimize the design and operating conditions of infrared and radio frequency treatments for disinfestation of storage rough rice with high rice milling quality.
2. Investigate the effectiveness of simultaneous drying and disinfestation treatment of freshly harvested rough rice using infrared heating.
3. Study the milling quality of rice treated with infrared and radio frequency heating treatments.

Experimental Procedures

Rough Rice and Infestation Methods

For storage rough rice, medium grain rice, M202, with moisture content of 11.0% was used for this study. The rice sample was obtained from Pacific International Rice Mills, Inc. (Woodland, CA). The moisture contents of all rice samples used for this study were determined by using an oven method at 130°C for 24 h. The infestation methods of storage rice samples were different for infrared and radio frequency treatments. For infrared treatment, each 250 g rice sample was infested with 100 adult lesser grain borers (beetles), *Rhizopertha dominica*, and 50 adult angoumois grain moths, *Sitotroga cerealella,* at 18 and 6 days before the thermal treatment to produce larvae and eggs of the insects in the sample. At the 18 days before the infrared treatment, the adult insects were mixed with the rice samples and kept for 2 days and then manually removed by sifting and hand picking. It was expected that the eggs laid by the adult insects during the two days would become larvae at the time of thermal treatment. At the 6 days before the treatment, the same numbers of adult insects were put into the infested rice samples and kept until the infrared treatment. The eggs from the adult insects should be produced and adult insects were remained in the samples. For radio frequency treatment, a large sample of storage rough rice was infested by mixing both adult beetles and moths at about a month before the disinfestation treatment. The infested rice was kept in an incubator at 28-30 ºC and 35-40 % relative humidity to emerge more insects. When it was used for the radio frequency disinfestation treatment, the rice contained a large numbers of insects in all stages. Each 100 g rice sample contained several moths and 30-40 beetles.

For conducting simultaneous infrared drying and disinfestation treatment, freshly harvested medium grain rice, M202, was obtained from Farmer's Rice Cooperative (Sacramento, CA). The moisture content of the rough rice was 25.0%. Part of the rice was gradually dried to 20.6% on the floor in the Food Processing Laboratory in the Department of Biological and Agricultural Engineering, UC Davis. The rice samples (250 g each) with the two different moisture contents (25% and 20.6%) were infested with both adult beetles and moths for four days before the infrared drying. The same numbers of insects were used as the storage rice samples. The rice samples should contain both adult insects and their eggs at the time of infrared treatment.

Infrared Treatment

In the previous year, the storage rice was heated as bulk with mixing during infrared heating. It lost about 1.5% moisture, which was not desirable. In order to reduce the moisture loss during disinfestation treatment, in the current research the infested storage rice samples were heated as single-layer using a catalytic infrared emitter with the radiation intensity of 5300 W/m^2 and five exposure times from 10 to 30 s (Fig. 1). The rice loading-rate was 2 kg/m^2. To reduce the heating time, the drying bed was preheated to the temperatures closed to targeted rice temperatures before the rice sample was placed. The final temperatures of heated rice were in the range of 46°C to 67°C, which was measured using an infrared temperature sensor after the heating. After the heating treatments, the samples were held at the heated temperature for various times, up to 3 h, and then cooled gradually in a closed container to the room temperature, about 23°C. The detailed experimental design is shown in Table 1. The moisture losses of the rice samples caused by the heating were calculated based on the weight losses during the treatment and original moisture content. Based on the disinfestation results, only uninfested rice samples with temperatures of 46°C, 53°C and 60°C were separately produced for milling quality evaluation.

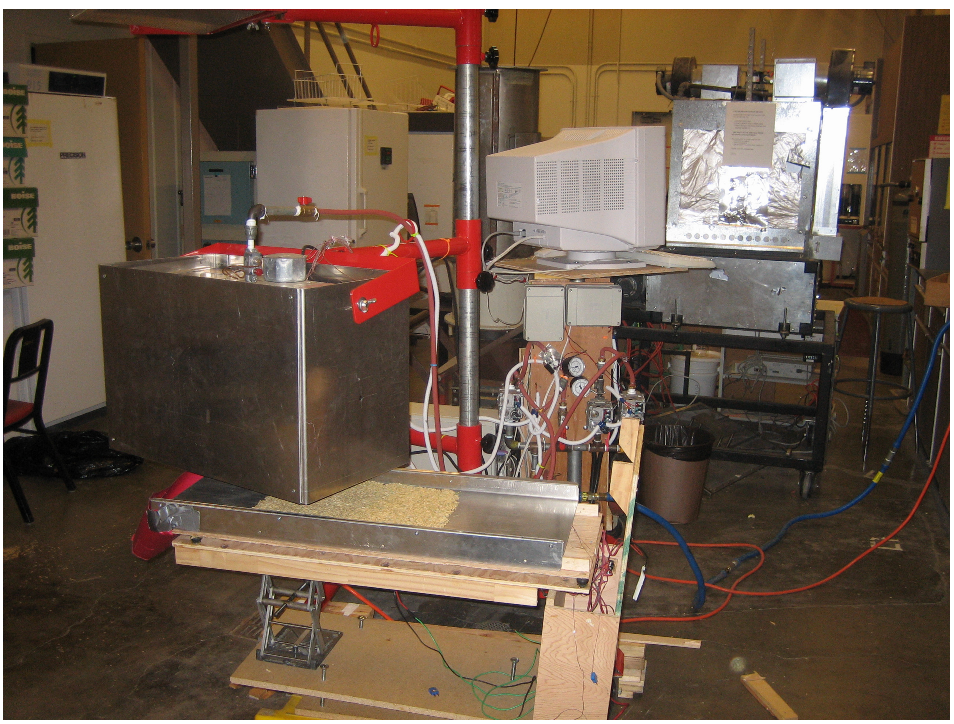

Figure 1. Infrared treatment set-up

Table 1. Experimental design of infrared heating treatment for storage rice

Heating time (s)	Rice temperature (°C)	Holding time (min)
10	46	0, 5, 20, 60,180
15	53	0, 5, 20, 60,180
20	60	0, 5, 20, 60,180
25	62	0, 5, 20
30	67	0

For the simultaneous drying and disinfestation, rice samples with 20.6% and 25.0% moistures were also dried as single-layer. The heating times were from 15 to 90 s with initial drying bed temperature of 36°C. The final rice temperatures were in the range of 49°C to 68°C. In order to study the effects of tempering on drying, disinfestation, and milling quality, both tempered and non-tempered samples were prepared. The tempering was conducted by keeping rice samples in an incubator with the same temperature of heated rice for 4 hours following the heating. The heated rice samples with and without tempering were cooled as a thin layer (about 0.5 inch thick) with natural cooling in room temperature and then further dried to 13.3% moisture using room air before milling. The weight changes after heating and cooling were recorded and used to calculate the moisture losses at the stages of heating and cooling.

Radio Frequency Treatment

A well-insulated rough rice sample holder (polyethylene and styrofoam) was designed and constructed to contain about 100 g rough rice. The holder's 4-π insulation allowed maintaining a homogeneous rice temperature (± 1^{o}C) in the sample during the heating process. The sample holder design allowed high energy efficiency and an adequate heating rate (about 10^{o}C/min) of the radio frequency heating. During the radio frequency heating (16.6 MHz, 150 W), the rice sample was placed in the closed sample holder to minimize the moisture loss caused by the heat. Fiber optic temperature sensors were used to measure rice temperature on-line during radio frequency treatment. When each selected final temperature was reached, the rice container was rapidly transferred into an incubator preset at the same temperature of the heated rice. The samples were then held for a various times (Table 2) before the samples were cooled in the holder to the room temperature.

Table 2. Experimental design of radio frequency heating treatment for storage rice

Rice temperature (°C)	Holding time
45	2 h, 4 h
50	1 h, 2 h
55	5 min, 30 min, 1 h
60	5 min, 30 min, 1 h, 2h

Evaluation of the Effectiveness of Disinfestation Treatments

After infrared and radio frequency treatments, all cooled, infested rice samples were transferred to plastic containers or glass jars with screen on lids to maintain sample moisture and oxygen supply to allow for surviving insects, larvae or eggs to grow. All these containers were kept inside incubators at 28°C with 60% relative humidity (RH) for infrared treated samples and 35-43% RH for radio frequency treated samples. The different RHs were used due to availability of the related facilities. The populations of the live adult insects were visually examined every several days for up to 35 days which covered more than one life cycle of the insects. All adult insects were removed from the rice samples after each examination. Two or three samples were produced with each thermal treatment condition. The average numbers of live adult insects at different storage times were reported.

Milling Quality Evaluation

The rice samples used for milling quality evaluation were not infested and separately produced using the same heating conditions as disinfestation treatments. The control samples of storage rough rice were not treated with infrared or radio frequency heating treatment. The treated storage rice samples were milled at the moisture contents after the treatments. For the simultaneous infrared drying and disinfestation samples, the moisture contents were controlled at 13.3% when the samples were milled. The control samples for simultaneous infrared drying and disinfestation treatments were dried using room air without additional heat.

Yamamoto rice mill was used to produce milled rice samples for the milling quality evaluation. The rice samples were milled three times. For the first two times, the settings of throughput and whitening were 1 and 4. For the third time, the settings were 1 and 5. The final degree of milling of milled rice samples in this research was very similar to the commercial products. The evaluated milling quality indicators included total rice yield (TRY), head rice yield (HRY), and Whiteness Index (WI). The WI was used to evaluate the whiteness (degree of milling) of milled rice determined with the Whiteness Tester, C-300, (Kett Electronic Laboratory, Tokyo, Japan). High index number indicates whiter milled rice. All quality evaluations were conducted at Pacific International Rice Mills, Inc. (Woodland, CA) and Farmer's Rice Cooperative (Sacramento, CA).

SUMMARY OF 2005 RESEARCH (MAJOR ACCOMPLISHMENTS) BY OBJECTIVES

Effectiveness of Infrared Disinfestation Treatment and Milling Quality of Storage Rice

Since the single-layer heating was used, the required heating time to reach certain temperature was significantly reduced compared to the results from previous year. It took only 20 s to reach 60°C, which meant that the heating rate was very high. Due to the reduced heating time, the moisture loss was also significantly reduced compared the results from pervious year. For example, the moisture loss was only 0.53% when the rice sample was heated to the temperature of 60°C. In the tested temperature range, 46°-67°C, the moisture losses were in the range of 0.28% to 0.76%. The results meant that single-layer heating was better method for reducing the moisture loss caused by infrared disinfestation treatment compared with the bulk heating used in the previous year.

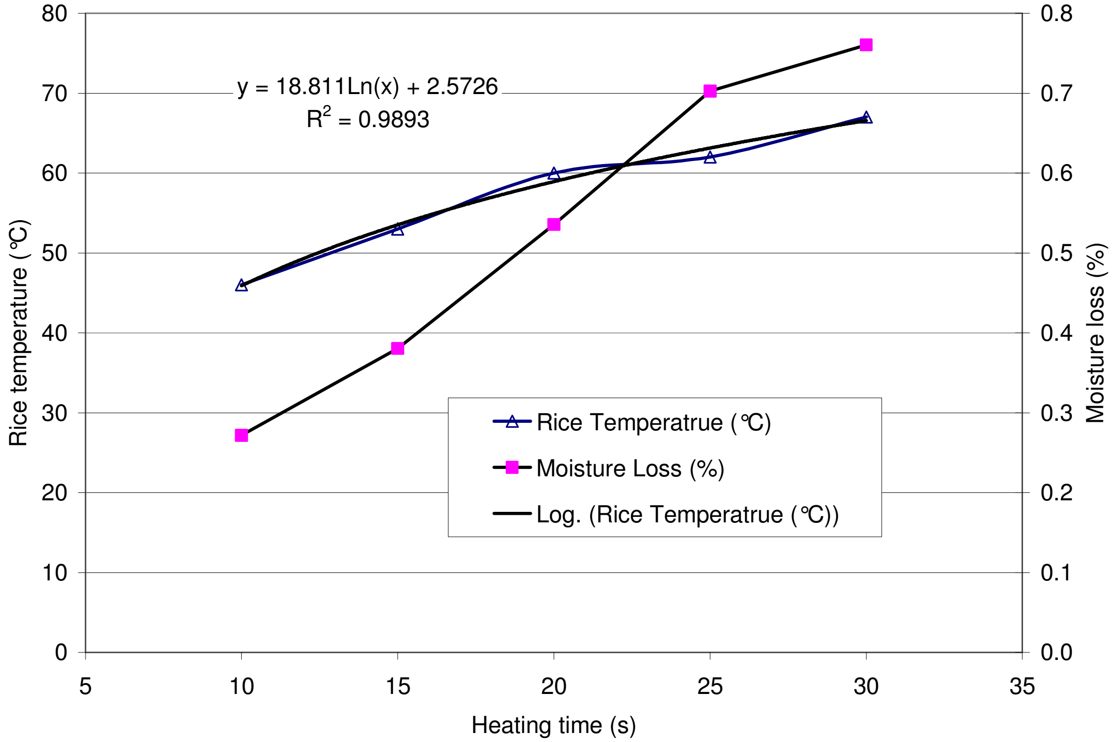

Figure 2. Storage rice temperature and moisture loss after infrared heating treatment.

The disinfestation results of storage rice are shown in Tables 3 and 4. No live adult moths were found in all treated samples during the first 14 days. For storage time of 21 days or longer, live moths appeared for all treatments with 46°C and 53°C with no holding and 5 min holding, which may indicate that some insect eggs survived the thermal treatments at those conditions. For beetles, it was clear that treatment temperatures at 53°C or below could not completely kill the adult beetles. It seems that 60°C treatment was effective even though the treatment of 60°C with 5 min holding had two unhealthy live beetles in the three samples were recovered following the thermal treatment. Very few live beetles from the 46°C treated samples were recovered during incubation. Such results may indicate that adult beetles were more heat resistant than the insect in other forms, such as eggs and larvae, which was different from the moths. The disinfestation results also showed that the beetles were more heat resistant than the moths, which has also been observed during the tests.

The milling qualities of rice samples treated with the temperatures from 46°C to 60°C without holding and 3 h holding are shown in Figures 3 to 5. The infrared treatments reduced the total rice yield from 0.2 to 1.0 percentage points, but the head rice yields slightly increased except for the treatment of 60°C without holding. Since the WI of treated rice samples were 0.5-0.7 unit higher than the control, the total rice yields of treated samples and control could be very similar if the samples were milled to the similar whiteness. Therefore, it is reasonable to believe that the infrared disinfestation treatments did not significantly affect the rice milling quality except for the treatment of 60°C without holding. For high temperature treatment of 60°C, the holding was necessary to reduce the quality loss caused by the disinfestation treatment.

Table 3. Numbers of live moths in rice samples treated with infrared heating*

Rice temperature (℃)	Holding time (min)	Days of storage after treatment					
		1**	14	21	27	31	35
67	0	0	0	0	0	0	0
62	0	0	0	0	0	0	0
62	5	0	0	0	0	0	0
62	20	0	0	0	0	0	0
60	0	0	0	0	0	0	0
60	5	0	0	0	0	0	0
60	20	0	0	0	0	0	0
60	60	0	0	0	0	0	0
60	180	0	0	0	0	0	0
53	0	0	0	0	0	0.3	0
53	5	0	0	0	0	0.3	0
53	20	0	0	0	0	0	0
53	60	0	0	0	0	0	0
53	180	0	0	0	0	0	0
46	0	0	0	0.3	0	1.3	13.0
46	5	0	0	0.0	0.3	8.0	9.3
46	20	0	0	0.7	4.3	4.3	2.7
46	60	0	0	2.0	6.7	4.7	4.3
46	180	0	0	0.3	3.0	1.7	1.0

*Numbers are the average numbers of insects recovered from three samples at each treatment condition
** Numbers of insects that survived the thermal treatment

Table 4. Numbers of live beetles in rice samples treated with infrared heating*

Rice temperature (℃)	Holding time (min)	Days of storage after treatment					
		1**	14	21	27	31	35
67	0	0	0.3	0	0	0	0
62	0	0	0	0	0	0	0.3
62	5	0	0	0	0	0	0
62	20	0	0	0	0	0	0
60	0	0	0	0	0	0	0
60	5	0.7	0	0	0	0	0
60	20	0	0	0	0	0	0
60	60	0	0	0	0	0	0
60	180	0	0	0	0	0	0
53	0	2.3	0	0	0	0.3	0
53	5	2	0	0	0	0	0
53	20	3.7	0	0	0	0	0
53	60	0	0.7	0	0	0	0
53	180	2	0	0	0	0	0
46	0	67.0	0.7	0.3	0	0.0	0.0
46	5	64.7	1.3	2.0	0.3	0.0	0.0
46	20	52.7	2.0	1.0	0.0	0.7	0.7
46	60	60.0	3.7	1.7	0.3	0.3	0.0
46	180	69.3	4.0	0.0	0	0.0	0.7

*Numbers are the average numbers of insects recovered from three samples at each treatment condition
** Numbers of insects that survived the thermal treatment

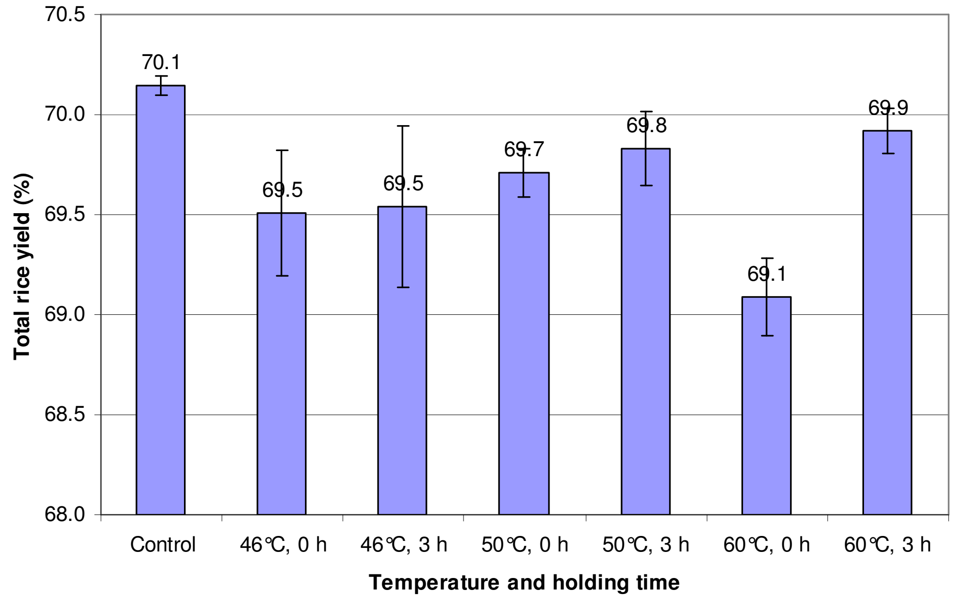

Figure 3. Total rice yields of the rice treated at different temperatures with and without holding

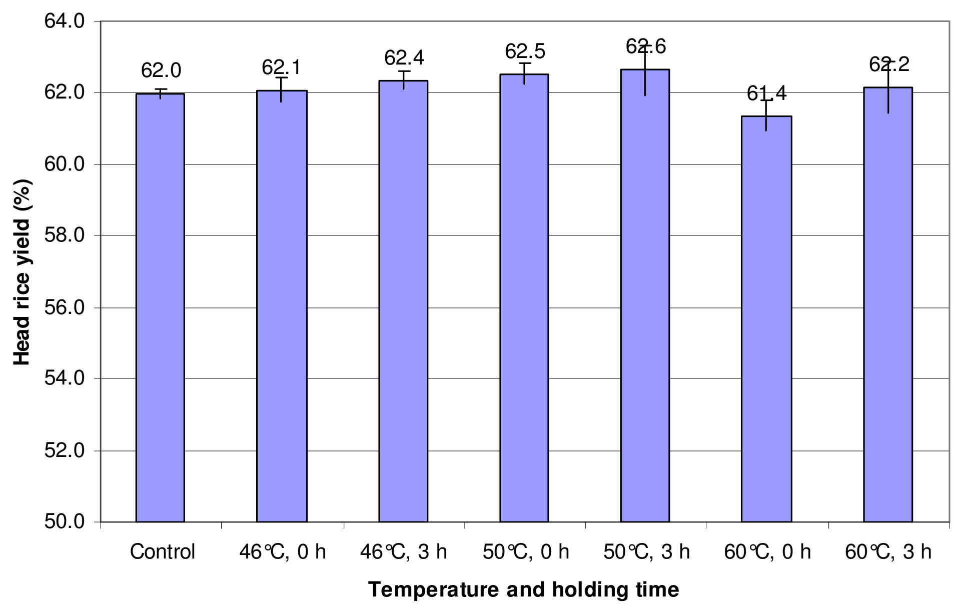

Figure 4. Head rice yields of the rice treated at different temperatures with and without holding

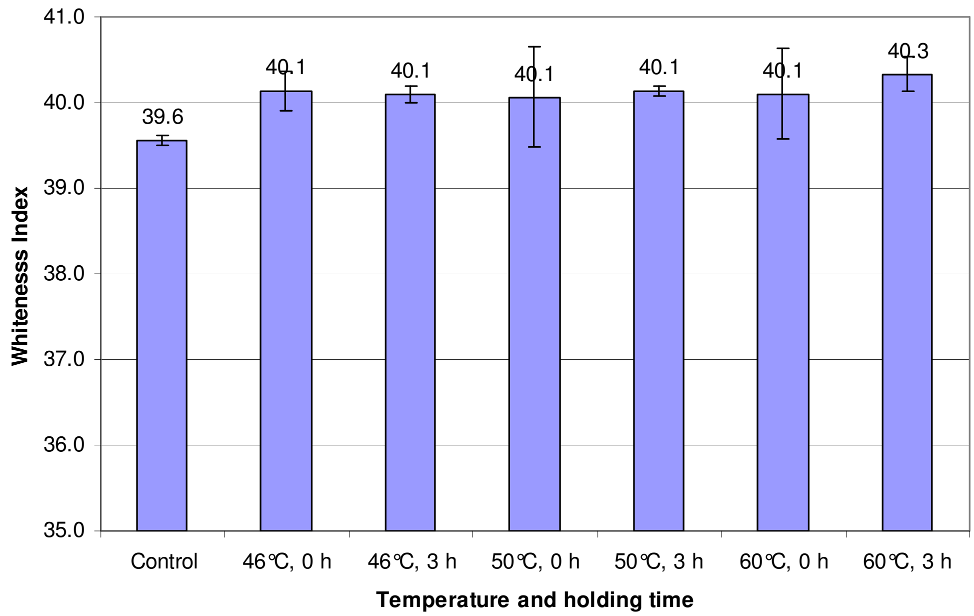

Figure 5. Whiteness index of the rice treated at different temperatures with and without holding

Effectiveness of Simultaneous Infrared Drying and Disinfestation and Milling Quality of Freshly Harvested Rice

The disinfestation results of freshly harvested rice were similar to the storage rice. The beetles were more heat resistant than the moths. Very few moth eggs, many adult beetles survived from the treatments of 55°C and 49°C. Therefore, the minimum required temperature was above 55°C. For disinfesting beetles, the recommended minimum required temperature was 58°C even though a couple of unhealthy beetles were recovery during incubation from the 68°C treatment with unknown reason.

The moisture removal data of rice sample heated to 58°C are shown in Table 7. A significant amount of moisture, 1.7-1.8%, was removed during the 60 s heating. This moisture removal rate was very high compared to current hot air drying which may take 20 to 30 min to remove 2% moisture. In order to develop high throughput infrared dryer in the future, the required heating time to achieve desired rice temperature can be further reduced by preheating the drying bed as shown in the storage rice disinfestation tests. Additional 0.6-0.9% moisture for non-tempering samples and 1.0-1.4% moisture for tempered samples were removed with natural cooling. The tempering significantly increased the moisture removal during cooling. The moisture removal during cooling can also be further improved by using forced air cooling, which has been observed in the experiment. The total moisture removals were 2.7% to 3.2% when the 60 heating followed by a 4 hour tempering. Such results are very important for the development of high throughput and energy efficient infrared dryers.

The rice samples dried with heating to 58°C and followed with 4 h tempering had similar or higher total and head rice yields, but lower whiteness compared with the control sample dried with ambient air. If the rice samples were milled to the same degree of whines, the total and head rice yields of infrared dried rice samples could be similar to that of ambient air dried rice. Therefore, the overall results showed that using infrared for simultaneous drying and disinfestation should be a viable approach to achieve high drying rate and kill insects.

Table 5. Numbers of live moths in the rice samples with different drying treatments*

Harvest MC (%)	Heating time (s)	Rice temperature (℃)	Tempering	Days of storage after treatment						
				1**	5	8	15	27	32	34
20.6%	90	68	Yes	0	0	0	0	0	0	0
	90	68	No	0	0	0	0	0	0	0
	60	58	Yes	0	0	0	0	0	0	0
	60	58	No	0	0	0	0	0	0	0
	40	55	Yes	0	0	0	0	0	8	2.5
	40	55	No	0.5	0	0	0	0	0	0
	15	49	Yes	0	0	0	0	0.5	17.5	3.5
	15	49	No	0	0	0	0	0	0.5	0
25.0%	90	68	Yes	0	0	0	0	0	0	0
	90	68	No	0	0	0	0	0	0	0
	60	58	Yes	0	0	0	0	0	0	0
	60	58	No	0	0	0	0	0	0	0
	40	55	Yes	0.5	0.5	0	0	0	0	0
	40	55	No	0	0	0	0	0	0	0
	15	49	Yes	1	1	0	0	0	0	0
	15	49	No	0	0	0	0	0	0	0

*Numbers are the average numbers of insects recovered from three samples at each treatment condition
** Numbers of insects that survived the thermal treatment

Table 6. Numbers of live beetles in rice samples with different drying treatments*

Harvest MC (%)	Heating time (s)	Rice temperature (℃)	Tempering	Days of storage after treatment						
				1**	5	8	15	27	32	34
20.6%	90	68	Yes	0	0	0.5	0	0.5	0	0
	90	68	No	0	1	0	0	0	0	0
	60	58	Yes	0	0	0	0	0	0	0
	60	58	No	0	0.5	0	0	0	0	0
	40	55	Yes	26	51	1	1	0	0.5	0
	40	55	No	0.5	0	0	0	0	0	0
	15	49	Yes	33	54.5	3.5	1.5	0.5	0	0
	15	49	No	33.3	44.5	2	0.5	0.5	0	0
25.0%	90	68	Yes	0	0	0	0	0	0	0
	90	68	No	0	0	0	0	0	0	0
	60	58	Yes	0	0	0	0	0	0	0
	60	58	No	2	4.5	0.5	0	0	0	0
	40	55	Yes	26	51	1	1.5	0	0.5	0
	40	55	No	0	0	0	0	0	0	0
	15	49	Yes	58.5	67.5	2.5	1.5	2	0	0
	15	49	No	29.5	48.5	0.5	1	1	0	1

*Numbers are the average numbers of insects recovered from three samples at each treatment condition
** Numbers of insects that survived the thermal treatment

Table 7. Moisture removal of rice heated to 60C

Rice MC	MC removal during heating	No tempering		Tempering (4h)	
		Natural cooling	Total	Natural cooling	Total
20.6	1.7	0.6	2.3	1.0	2.7
25.0	1.8	0.9	2.7	1.4	3.2

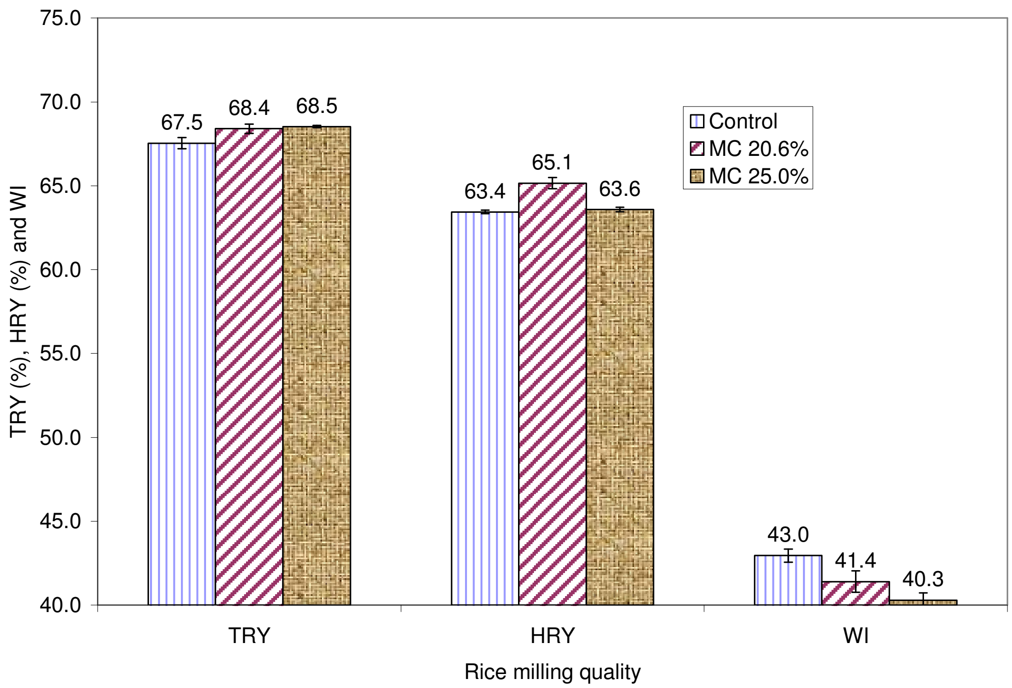

Figure 6. Comparison of milling qualities of control sample and rice samples dried with infrared heating (58°C and 4 h tempering)

Effectiveness of Radio Frequency Treatment in Disinfestation and Milling Quality

The disinfestation results of radio frequency treatment are summarized in Table 8 and 9. The required holding time after heating increased with the decrease of rice temperature. The minimum required treatments for killing all forms of moths were 50ºC and 2 h holding, 55ºC and 1 h holding, or 60ºC and 30 min holding. Similarly, the minimum required treatments for killing all forms of beetles were 60ºC and 1 h holding.

The milling quality results showed that the rice samples treated with radio frequency heating had similar total rice yields, higher head rice yields, and whiter color compared to the control samples, which was desirable (Fig. 7). Also, because the treatment was conducted with a closed container, no significant moisture loss was observed during the treatment.

Table 8. Numbers of live moths in rice samples treated with radio frequency*

Rice temperature (°C)	Holding time (min)	Days of storage after treatment								
		1**	4	7	11	13	18	21	25	28
60	5	0	5	3	2	0	0	1	4	3
60	30	0	0	0	0	0	0	0	0	0
60	60	0	0	0	0	0	0	0	0	0
60	120	0	0	0	0	0	0	0	0	0
55	5	0	5	2	0	0	2	2	3	5
55	30	0	3	1	0	0	4	0	1	1
55	60	0	0	0	0	0	0	0	0	0
50	60	1	5	2	6	0	2	2	5	8
50	120	0	0	0	0	0	0	0	0	0
45	120	1	15	3	5	1	2	0	10	12
45	240	0	7	9	1	2	2	3	2	4
Control		2	17	5	4	0	3	4	16	15

*Numbers are the sum of insects recovered from three samples at each treatment condition
** Numbers of insects that survived the thermal treatment

Table 9. Numbers of live beetles in rice samples treated with radio frequency*

Rice temperature (°C)	Holding time (min)	Days of storage after treatment								
		1**	4	7	11	13	18	21	25	28
60	5	0	7	14	25	28	43	51	76	59
60	30	0	0	3	5	6	15	14	32	25
60	60	0	0	0	0	0	0	0	0	0
60	120	0	0	0	0	0	0	0	0	0
55	5	3	9	20	51	27	69	71	85	76
55	30	0	2	9	19	19	52	71	72	71
55	60	0	0	0	0	0	0	0	3	3
50	60	19	17	23	63	58	141	116	139	118
50	120	0	7	17	21	16	47	51	78	81
45	120	26	19	27	57	58	149	124	154	129
45	240	22	16	34	52	51	164	128	138	106
Control		39	38	55	99	95	244	179	131	136

*Numbers are the sum of insects recovered from three samples at each treatment condition
** Numbers of insects that survived the thermal treatment

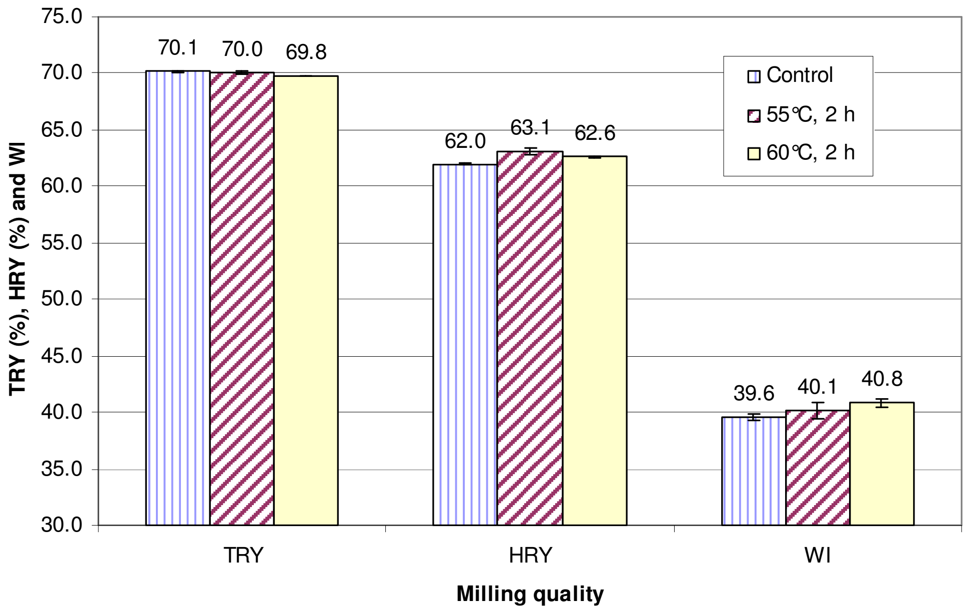

Figure 7. Comparison of milling qualities of control sample and rice samples treated with radio frequency heating

Conclusions

The research results indicated that both infrared and radio frequency could be used to disinfest rough rice. For infrared disinfestation of storage rough rice, the minimum required treatments were 53°C with 20 min holding for moths and 60°C with 20 min holding for beetles. The similar conditions can also be used for disinfestation of freshly harvested rough rice. For the storage rice, the infrared disinfestation could cause about 0.53% moisture loss. The 60°C temperature of single-layer storage rice can be achieved with 20 s heating when the drying bed was pre-heated to the targeted temperature. If the drying bed was only pre-heated to 36°C, it took 60 s to reach 58°C for the freshly harvested rice samples with moisture content of 20.6% and 25.0%. The moisture removals of the freshly harvested rice were 1.7%-1.8% during heating alone. When the rice samples were tempered for 4 h following the heating, additional 1.0% to 1.4% moistures were removed by natural cooling and thus the total moisture removals were 1.7% to 3.2%. Both infrared dried rice and treated storage rice had similar milling qualities compared with the corresponding control samples. Since the infrared can remove rice moisture and kill insects without lowering the milling quality of freshly harvested rice, it is concluded that the infrared heating can be used for simultaneous drying and disinfestation. For radio frequency disinfestation, the required treatments for killing all forms of moths were 50ºC and 2 h holding, 55ºC and 1 h holding, or 60ºC and 30 min holding. Similarly, the minimum required treatments for killing all forms of beetles were 60ºC and 1 h holding. Since the disinfestation was done in closed container, no moisture loss was observed. The rice samples treated with the radio frequency had superior milling quality compared with the untreated samples.

PUBLICATIONS OR REPORTS

N/A

CONCISE GENERAL SUMMARY OF CURRENT YEAR'S RESULTS

The research for the current year specifically addressed three objectives: (1) optimize the design and operational conditions of infrared and radio frequency treatments for disinfestation of storage rough rice; (2) investigate the effectiveness of simultaneous drying and disinfestation treatment of freshly harvested rough rice using infrared heating; and (3) study the milling quality of rice treated with infrared and radio frequency heating treatments.

For storage rice disinfestation, medium grain rice, M202, with moisture content of 11.0% was used for this study. Before the disinfestation treatment, the rice samples were infested with lesser grain borers (beetles), *Rhizopertha dominica*, and angoumois grain moths, *Sitotroga cerealella*. After the thermal treatments of using infrared and radio frequency, the survived insects in different forms were examined by counting the survived and emerged adult insects during storage after the treatments. In order to reduce the moisture loss during infrared disinfestation treatment, the drying bed was pre-heated and rice was heated as single-layer. The new heating method resulted in rapid heating of the rice with reduced moisture loss. For example, it took only 20 s to heat the rice sample to 60°C with 0.53% moisture loss compared to about 1.5% loss obtained in the previous year. The infrared heating did not cause any significant changes in rice milling quality. The minimum required disinfestation conditions were 53°C with 20 min holding for moths and 60°C with 20 min holding for beetles.

For radio frequency disinfestation of storage rice, the required treatment conditions for killing all forms of moths were 50ºC and 2 h holding, 55ºC and 1 h holding, or 60ºC and 30 min holding. Similarly, the minimum required treatments for killing all forms of beetles were 60ºC and 1 h holding. Since the disinfestation was done in closed container, no moisture loss was observed. The rice treated with the radio frequency had superior milling quality compared with the untreated samples.

The similar disinfestation conditions used for storage rice can also be used for disinfestation of freshly harvested rough rice. When the drying bed was pre-heated to 36°C, it took 60 s to reach 58°C temperature for the freshly harvested rice samples with moisture content of 20.6% and 25.0% with satisfactory disinfestation. The moisture removals were 1.7%-1.8% during heating alone. When the rice samples were tempered for 4 h following the heating, additional 1.0% to 1.4% moistures were removed by natural cooling and thus the total moisture removals were 1.7% to 3.2%. The infrared dried rice samples with 60°C had similar milling quality of the ambient air-dried samples.

In conclusion, both infrared and radio frequency treatment can be used for disinfestation of storage rice without lowering the milling quality, but radio frequency could cause about 0.53% moisture loss during heating. The infrared heating can also be used for simultaneous drying and disinfestation with high heating and drying rates.

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