

RESEARCH ARTICLE

Control of insect pests under ware-house conditions using smoke generated from partial combustion of rice (paddy) husk

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Abstract: Adult *Sitophilus oryzae* and *Rhyzopertha dominica*, two major devastating insect pests of stored paddy in Sri Lanka, included in cloth sacks with rice medium inside were placed at three locations of the poly sack stacks containing paddy viz. outside, just inside and centremost. They were then exposed to smoke generated from partial combustion of paddy husk for 2 1/2-3 hours {where carbon monoxide (CO) concentration was higher than 5000ppm} and sealed for 18, 36, 54 and 72 hours in the first step and repeated for a similar time period with a subsequent smoking in between as against the control.

Results revealed that increasing CO₂ concentrations in smoke caused no significant mortality on the target insects. Smoke generated by partial combustion of paddy husk where CO concentration was above 5000ppm was directly responsible for insect mortality. Insect mortality was increased with the increase in the sealed period up to 72 hours irrespective of both the location of insect (outside, just inside and centermost) and species. However, a significant difference in the mortality levels of insects was observed among the above 3 locations, outside the poly sack bag recording the highest mortality. This indicates that the poly propylene membrane acts as a physical barrier for the penetration of smoke into the poly sacks.

Experiments under ware-house conditions also revealed that there was no significant difference among the treatments smoked once a week, once in two weeks and once a month in terms of percentage weight loss due to insect attack which all differed significantly with the control stack which was not smoked.

This study shows the possibility of using smoke generated from partial combustion of paddy husk for the control of stored product insect pests as an alternative to the chemical insecticides.

Keywords: Insect Pests, Paddy-husk, *Rhyzopertha dominica*, *Sitophilus oryzae*

INTRODUCTION

Serious losses occur in grains during post harvest storage due to insect attack. Recent studies have revealed that in Sri Lanka, like in other tropical countries, the loss of grains during storage under normal ware-house conditions due to various agents of grain deterioration is 4-6% and 80% of this loss is due to insect attack¹.

There are several insecticides recommended for control of stored product insect pests. However, the widespread use of synthetic insecticides has affected human health and environment. Besides, most of them are expensive and consequently the farmers and medium scale traders are unable to afford them. Furthermore, the use of these expensive chemicals has led to an appreciable escalation of cost of the production of rice and other grains. Resistance development in stored product insect pests to chemical insecticides has aggravated this condition. Therefore, there is an urgent need to develop safer, cost effective and environmentally friendly pest control methods.

Insecticides of gaseous nature hold their place in controlling insects during grain storage because of their ability to penetrate through bulks of stored goods and cause lethal effect on insects.

A traditional method of controlling insects in grains stored at house hold level in Sri Lanka is to expose the grains to smoke generated from biomass combustion, by

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storing the grains in sacks above the kitchen fire place (“*Dum Messa*”). However, application of this traditional technology to commercial level storage has not yet been scientifically established.

Paddy husk is a by-product of the rice milling industry and it is freely available at almost no cost to the farmers in rice growing areas. Laboratory level experiments revealed that smoke generated from paddy husk combustion caused lethal effects on major insect pests of stored paddy². It was found that CO concentration of greater than 5000 ppm was responsible for the said insect mortality³. Hence, this study was aimed at determining the suitability of using smoke generated from paddy husk combustion for control of insect pests during storage of paddy under normal ware-house conditions, as an alternative method for chemical pesticides.

METHODS AND MATERIALS

Establishment and maintenance of insect cultures: Cultures of Rice Weevil *Sitophilus oryzae* L. (Coleoptera: Curculionidae) and Lesser Grain Borer *Rhyzopertha dominica* F. (Coleoptera: Bostrichidae) were prepared and maintained as described by Heinrichs *et al.*⁴. Non parboiled (raw) paddy of popular variety BG 350 with long slender grain type and red pericarp, was used as the medium for insect cultures. Paddy was milled and later polished in such a manner that part of the bran layer was retained in the seeds (8% bran removal). Rice obtained using the above procedure was heated at 60°C for 48 h and used as the culture medium for the insects. In order to maintain the nutritional composition required to meet the insect population growth, milled legume seeds (25% by weight as that of rice medium) were also incorporated as a protein source.

The insects were reared in the insectarium at the Institute of Post Harvest Technology (IPHT), Anuradhapura under ambient temperature (30-33°C). In order to maintain the relative humidity of the insectarium around 70%, the jute sacks were hung around the walls of the insectarium on to which water was sprayed periodically at 3-4 h intervals. Freshly emerged 1 wk old adults were used in the experiments.

The experiments were conducted under normal ware-house conditions to determine the efficacy and toxicity of the smoke generated from paddy husk combustion on *S. oryzae* and *R. dominica* in paddy stored in poly sack bags and the frequency of application of smoke required to control the damage incurred to the stored paddy. All experiments were conducted during evening hours (after 4 p.m.) when the activity of the stored product insects is maximum.

Determination of the efficacy and toxicity of the smoke generated from paddy husk combustion on S. oryzae and R. dominica in paddy stored in poly sack bags:

- a) *experimental design:* This experiment was designed in the Randomized Complete Block Design (RCBD) with 3 replicates for each treatment
- b) *paddy:* 50 kg of paddy stored in poly sacks (polypropylene bags) was used in the experiments. These paddy bags were made into a stack of 9 bags in 3 layers.
- c) *test insects:* *S. oryzae* and *R. dominica* were reared in the insectarium at the IPHT as described above and were used in the experiments.

Insect adults were counted into cloth sacks made from thin material to which a small amount of rice medium was added, and these bags containing insects were placed at different positions; outside, just inside and at the center of the poly sack stacks. Ten adults from each species were included in each cloth sack placed at one position of the above places. Thus, this experimental design included 30 insects from one species for one paddy bag, accordingly 90 in a replicate (3 paddy bags) and 270 in a treatment. Similar number of 270 insect adults was included in the respective control stacks. Thereby, altogether 540 insect adults were used from one species in one experiment. Similar number of 540 adults were also used from the other species in the experiment. Both species were included in the same cloth sacks for one particular position.

Sealing the stack: The stack containing paddy bags were sealed to prevent gas leakage. Tarpaulin sheets were used to cover the stack and sand bags were placed outside the tarpaulin sheets.

d) *smoke:* Paddy husk was burnt in a stove made from iron sheets (Figure 1). Paddy husk was pressed well inside the stove to minimize the air (O₂) availability. Thus, the conditions were set for the partial combustion of paddy husk and to generate more CO in the stove. The CO concentration was maintained above 5000 ppm. The gas concentration was measured using the Ecoline® Gas Analyzer and the temperature of smoke by a thermometer. The temperature of the smoke was maintained at 30-33°C.

The spread of smoke throughout the stack was facilitated by opening the stack, at the beginning of the combustion process, at the opposite end to the stove in which the smoke was generated. Thus, spread of smoke throughout the stack was facilitated by simple diffusion.

e) *stove*: The husk stove consists of the following components.

- Flame tube (a)
- Inner cylinder (b)
- Outer cylinder (c)
- Bottom plate (d)

The flame tube and the inner cylinder are made of metallic wire mesh which has 6 perforations per square inch. The outer cylinder, bottom plate and the top cover are fabricated by gauge 10 sheet metal of thickness 1.2 mm. The top cover is conical in shape in order to facilitate better air movement. Air for the combustion is supplied from the small openings made around the bottom of the outer cover metal sheet.

f) *operational features*: The paddy husk was filled into the space between the inner wire mesh cylinder and the middle flame tube. Flame was generated by initiating a small fire inside the flame tube, in the middle, using newspaper scraps or piece of cloth soaked in kerosene. The air required for the combustion moves into the burning chamber (flame tube) by natural convection (Figure 2). The combustible volatile gases from the paddy husk bed were carried into the flame tube by air moving through the wall of the wire mesh cylinder.

The smoke generated from the partial combustion of paddy husk was applied continuously for about 3 h till the CO concentration inside the entire sealed structure was above 5000 ppm and then the structure was sealed.

g) *sealed period*: The smoked treatments and the respective controls were sealed for a similar period as follows until the insect mortality was increased gradually. The sealed period for the treatment stacks were begun with 18 h based on the results of the laboratory level experiments where the highest insect mortality was

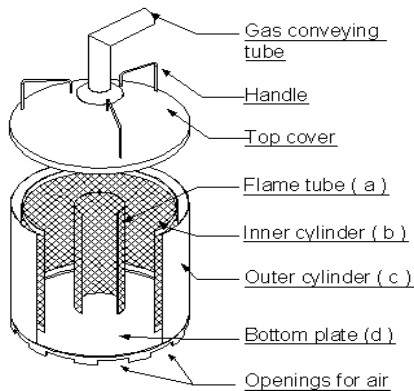


Figure 1: Stove fabricated to generate smoke from partial combustion of paddy husk

achieved in 18 h^{3,5}. Sealed periods used in the experiment were 18 h, 36 h, 54 h and 72 h.

As the insect mortality received for the sealed period of 72 h was low as 40% and 53.3 % for *S. oryzae* and *R. dominica* respectively, the application of smoke was repeated at the end of the sealed period and allowed to follow a similar period of second sealing as stated below.

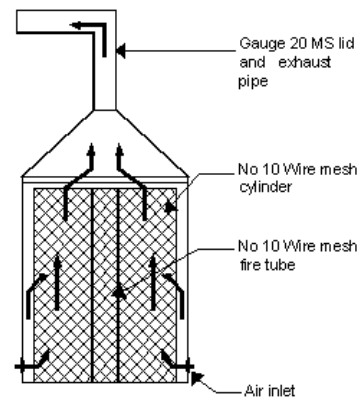


Figure 2: Air flow pattern through the stove

- Sealed periods: 18 h + smoking + 18 h
- 36 h + smoking + 36 h
- 54 h + smoking + 54 h
- 72 h + smoking + 72 h

The data were analysed by ANOVA procedure of SAS system; means separated by DMRT.

Determination of the frequency of application of smoke required to meet the substantial reduction of damage incurred to the stored paddy:

a) *paddy*: Freshly harvested paddy (variety long red) was used. Prior in the experiment, they were dried well under direct sun light (about 55°C) for a few hours to remove moisture, if any, and thereby to minimize the favourable conditions for insect growth.

b) *poly sacks*: The poly sacks used were the already used ones. They were dried well under direct sun light, after being unfolded, for a few hours to eliminate the insect adult and immature stages supposed to be present in the poly sacks, resulting from previous use.

c) *stacks*: Using the paddy stored in poly sacks in the manner mentioned above, stacks were made on wooden dunnage. The dunnage used was also dried well under direct sun light for a few hours to eliminate presence of insect life stages.

Thus, the procedures generally followed by the farmers during their normal storage practices were aimed to be met. Four stacks were made each with 3 replicates. For 1 replicate, 3 bags of paddy of 50 kg were used.

d) *sealing*: The stacks were covered by tarpaulin sheets available at the retail outlets. The tarpaulin sheet was guage 544 (thickness 0.14 mm). The stacks were sealed by placing sand bags around the stack, outside the tarpaulin sheet. The sand bags were placed in such a manner that a third sand bag is at the rendezvous of another two placed already.

- e) *treatments* : There were 3 treatments.
 treatment 1 : Smoked once a week
 treatment 2 : Smoked fortnightly
 treatment 3 : Smoked once a month
 control stack : Not smoked

For one particular stack, smoke was applied continuously for 3 h and was eventually sealed. This practice was done in 3 consecutive days. Subsequent smoking was to avoid the practical obstacle of the smoke leakage from the sealed stack to the outside environment. After applying smoke on the third day, the stack was kept sealed for another 48 h to leave a sufficient period of time for the smoke to retain in the enclosed stack. After the removal of the tarpaulin sheets from a particular stack, it was kept open for a period of 1 wk, 2 wks and 4 wks for the treatments 1, 2 and 3 respectively before applying smoke again.

f) *control stack*: Another stack of fresh paddy, stored in poly sacks was sealed with the same tarpaulin material and kept for a similar period sealed as for the relevant treatment stack without any smoke being applied. The above treatments were applied throughout a period of 6 months.

g) *smoke*: Smoke was applied as described in the earlier step. After the stack was covered by tarpaulin sheets, the spread of smoke throughout the stack was facilitated by opening the stack, at the beginning, at the opposite end to the stove. The spread of smoke throughout the stack was facilitated by simple diffusion.

h) *sampling*: Samples were drawn at the end of every month of the 6 month storage period from all the replicate paddy bags of a particular treatment stack and the control stack to determine the following parameters.

- a) moisture percentage
- b) weight loss due to insect damage

Destructive sampling was done. Samples were drawn by a grain tier. As soon as the samples were drawn, the

moisture percentage was determined by the SATAKE moisture meter. Sampling was done in such a manner that it represented the whole batch of grains in the poly sack bag. Accordingly, 9 samples were drawn. Samples were drawn from one bag as shown in Figure 4.

All the samples taken from one replicate (27 from 3 bags) were mixed together to make a composite sample which was subsequently divided using the 'Divider', to obtain a "small sample (working sample)" which was easy to handle.

i) *determination of moisture*: Three random samples were taken from the sample obtained from the paddy bags as described above and the moisture percentages were determined (m_1 , m_2 and m_3) by using the 'SATAKE' grain moisture meter. Percentage moisture data obtained were fed to the following equation to determine the final moisture level.

$$\% \text{ moisture} = \frac{m_1 + m_2 + m_3}{3}$$

Readings from different treatment stacks were analysed by ANOVA procedure of SAS system. Means separated by Least Significant Difference (LSD).



Figure 3: Smoke generated from paddy husk combustion within the stove conveyed to the stack



Figure 4: Sampling Procedure

Determination of the weight loss due to insect attack: Paddy seeds in the working sample obtained from the composite sample were evaluated for the following parameters to determine the weight loss due to insect attack.

- i) Number of insect damaged grains (Nd)
- ii) Weight of insect damaged grains (D)
- ii) Number of undamaged grains (Nu)
- iv) Weight of undamaged grains (U)

Insect damaged grains were identified by the presence of tiny hole that represents the emergence of insects to outside after completing the life cycle within the grain.

These data were fed to the following equation⁶

$$\% \text{ Weight loss due to insect attack} = \frac{UNd-DNu}{U(Nd+Nu)} \times 100\%$$

Readings from different treatment stacks were analysed by the ANOVA of SAS system. Means separated by Least Significant Difference (LSD).

RESULTS

Determination of the efficacy and toxicity of the smoke generated from paddy husk combustion on *S. oryzae* and *R. dominica* in paddy stored in poly sack bags.

Results of the storage level experiments reconfirmed the findings obtained under laboratory conditions with regard to the lethal effect of the smoke on selected storage insects. Always insect mortality was brought about with the presence of CO monoxide concentrations greater than 5000 ppm. Insect mortality was observed to have increased with the increase in the sealed period (Tables 1 and 2) regardless of both the location of the paddy bag (outside, just inside and center most) and the insect species (*S. oryzae* and *R. dominica*). For a given location and an exposure period, the mortality level of *R. dominica* was always found to be higher than that of *S. oryzae*. On the contrary, *S. oryzae* has extended higher level of tolerance over *R. dominica* as declared by the laboratory level experiments.

For both *S. oryzae* and *R. dominica*, when the insects were placed outside the poly sack (when the insects were directly exposed to the flue gas), always a significant

Table 1: Change of mortality in *S. oryzae* with the exposure (sealed) period to the smoke (under normal ware-house conditions)

Status	Period of exposure (h)	% Mean mortality of <i>S. oryzae</i>		
		Outside	Just inside	Centremost
T	18	23.33 ^{c,d,e}	10 ^e	3.33 ^c
C	18	3.33 ^f	3.33 ^e	3.33 ^c
T	36	30 ^c	13.33 ^e	6.67 ^{b,c}
C	36	3.33 ^f	3.33 ^e	6.67 ^{b,c}
T	54	36.67 ^{b,c}	26.67 ^{c,d}	10 ^{a,b,c}
C	54	3.33 ^f	6.67 ^e	10 ^{a,b,c}
T	72	40 ^{b,c}	33.33 ^c	10 ^{a,b,c}
C	72	6.67 ^{e,f}	10 ^e	10 ^{a,b,c}
T	18+18	26.67 ^{c,d}	23.33 ^d	10 ^{a,b,c}
C	18+18	3.33 ^f	3.33 ^e	10 ^{a,b,c}
T	36+36	40 ^{b,c}	33.33 ^c	13.33 ^{a,b}
C	36+36	6.67 ^{e,f}	6.67 ^e	13.33 ^{a,b}
T	54+54	56.67	43.33 ^b	16.67 ^a
C	54+54	6.67 ^{e,f}	6.67 ^e	16.67 ^a
T	72+72	76.67 ^a	3.33 ^a	16.67 ^a
C	72+72	10 ^{d,e,f}	10 ^e	16.67 ^a

Letters T and C denotes Treatment and Control stacks respectively
 Means followed by the same letter in vertical columns do not differ significantly (p≥0.05) according to ANOVA procedure of SAS system; means separated by DMRT

Table 2: Change of mortality in *R. dominica* with the exposure (sealed) period to the smoke (under normal ware-house conditions)

Status	Period of exposure (h)	% Mean mortality of <i>R. dominica</i>		
		Outside	Just inside	Centremost
T	18	30 ^d	16.67 ^{f,g}	6.67 ^c
C	18	3.33 ^e	6.67 ^h	6.67 ^c
T	36	33.33 ^d	20 ^{e,f}	13.33 ^{b,a,c}
C	36	3.33 ^e	6.67 ^h	10 ^{b,c}
T	54	36.67 ^d	26.67 ^{d,e}	16.67 ^{b,a}
C	54	6.67 ^e	10 ^{g,h}	16.67 ^{b,a}
T	72	53.33 ^{b,c}	40 ^{b,c}	20 ^a
C	72	10 ^e	16.67 ^{f,g}	20 ^a
T	18+18	36.67 ^d	26.67 ^{d,e}	10 ^{b,c}
C	18+18	3.33 ^e	6.67 ^h	10 ^{b,c}
T	36+36	46.67 ^c	33.33 ^{c,d}	13.33 ^{b,a,c}
C	36+36	6.67 ^e	6.67 ^h	13.33 ^{b,a,c}
T	54+54	60 ^b	46.67 ^b	16.67 ^{b,a}
C	54+54	10 ^e	33.33 ^{c,d}	16.67 ^{b,a,c}
T	72+72	80 ^a	56.67 ^a	20 ^a
C	72+72	13.33 ^e	16.67 ^{f,g}	20 ^a

Letters T and C denotes Treatment and Control respectively

Means followed by the same letter in vertical columns do not differ significantly ($p \geq 0.05$) according to ANOVA procedure of SAS system; means separated by DMRT

difference in mortality was exhibited between treated and control samples for every sealed period). This trend is observed in the 'just inside' location at exposure (sealed) periods higher than 36 h for *S. oryzae* and for each exposure period (starting from 18 h minimum) in case of *R. dominica*. However, the highest mortality achieved at a 'just inside location' (53.33% for *S. oryzae* and 56.67% for *R. dominica* at the exposure period 72+72 h) is fairly lower compared to the highest recorded in the 'outside' location (76.67% for *S. oryzae* and 80% in *R. dominica* at the exposure period 72+72 h). So it is clear that the polypropylene membrane acts as a physical barrier for the penetration of the smoke into the poly sack and the subsequent dispersal of the smoke throughout the grain mass. More importantly, the insect mortality recorded at the centremost location showed no significant difference between the treatment and the control samples. So it is clear that the required gas concentration for the mortality effect of the insects has not reached the centre of the poly sack. This again proves the poor dispersal of the smoke throughout the grain mass in a poly sack.

The above results gave an indication that a sealed period of 72 h confer better insect mortality compared

to the other sealed periods lower than that. Repetition of the sealed period became a requirement to make up for the loss due to gas leakage which is a natural process attributed to the dynamic property of the gas.

The results in Figure 5 & 6 provided evidence for the inability low efficiency to use the smoke generated from partial combustion of paddy husk to eliminate the insects already infested in the stored paddy. Therefore based on this preliminary result, it was decided to conduct the storage level experiments using the freshly harvested paddy stored in poly sacks.

Determination of the frequency of application of smoke required to meet a substantial reduction of damage incurred to the stored paddy

According to Figure 8 the best moisture content during storage period has been obtained in the stack smoked once a month. The trend line drawn for that treatment shows the lowest rate of increase in the moisture content. Considering the moisture content during the storage period, smoking once a month appears to be the best treatment.

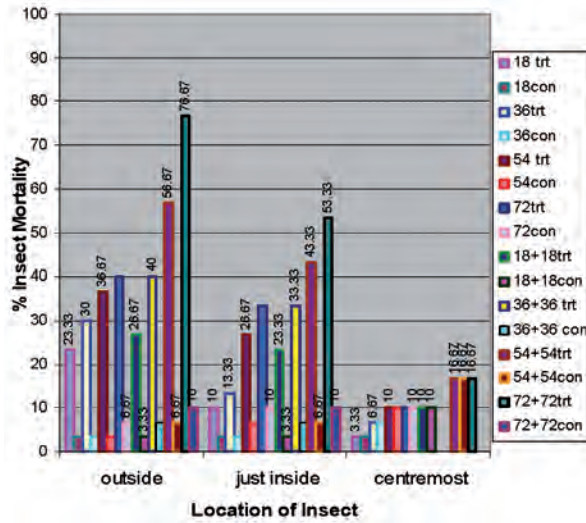


Figure 5: Change of insect mortality with the location of the insect in paddy bag-S. oryzae

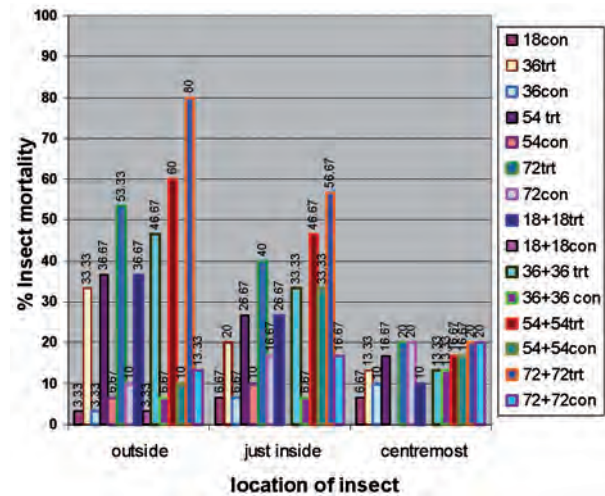


Figure 6: Change of insect mortality with the location of the insect in paddy bag-R. dominica

Determination of weight loss due to insect attack

$y = 0.8579\text{Ln}(x) + 0.3779$ control
 $y = 0.3578\text{Ln}(x) + 0.1295$ once a week
 $y = 0.3719\text{Ln}(x) + 0.2602$ once a month
 $y = 0.2548\text{Ln}(x) + 0.2337$ once in two weeks

In general;
 $y = A.\text{Ln}(x) + B$,
 where A and B are constants for a particular period of smoking

According to the relationships in Figure 10 (considering the dotted trend lines), the weight loss due to insect attack is lowest in the treatment smoked fortnightly. However, the statistical analysis showed that there is no significant difference (at $p=0.05$) among the 3 treatments; smoked once a wk, smoked fortnightly and smoked once a month. Furthermore, all the above 3 treatments exhibited a significant difference with the percentage weight loss occurred in the control stack which was not smoked (Table 3). Therefore, from the point of view of the weight loss due to insect attack is concerned, once a month smoke is recommended.

DISCUSSION

Smoke generated from rice husk combustion contains carbon dioxide (CO₂), carbon monoxide (CO), Hydrocarbons and Non Methane Volatile Organic compounds (NMVOC). Specially CO and NMVOC are

reported under incomplete combustion conditions^{7,8}. Also CO₂ and CO are considered respiratory toxic causing the death of insects. Furthermore, it is reported that the use of gas mixtures confer increased toxicity, against paddy insects⁹. As the CO concentration was increased during the experiment, the insect mortality achieved upon the exposure to the smoke generated from paddy husk combustion may be attributed to the accumulation of CO concentration inside the bottle thus affecting insect respiratory system. In alternation, experiments conducted in Australia and Brazil, highlight the use of CO₂, applied as dry ice, for the control of stored product insect pests^{10,11}.

This study shows the possibility of using smoke generated from paddy husk combustion for the control of stored product insect pests as an alternative to the chemical insecticides. Certain unavoidable practical issues, such as the poor penetration of the smoke into the bag through the poly propylene membrane, suggest that this technology can be applied for freshly harvested paddy where the initial insect infestation is minimum. Paddy husk which is a by-product in rice production confers remarkable advantages such as free availability, extremely low cost, environmentally sound nature and non-toxic compared to the commercially available fumigants. Specially when compared to the use of hazardous chemicals and their consequent deleterious effects both in the short-long term and acute-chronic nature and the low cost compared to the use of synthetic chemicals, the limitations stipulated above would be negligible from both the scientific and practical points of view.

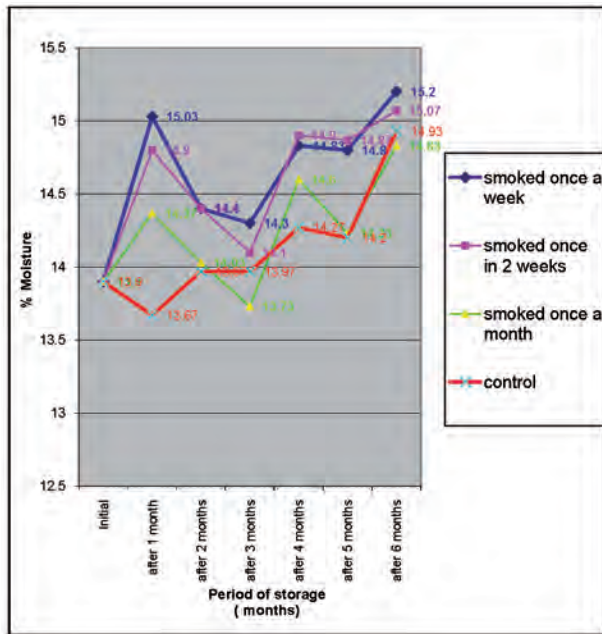


Figure 7: Change of moisture during storage period

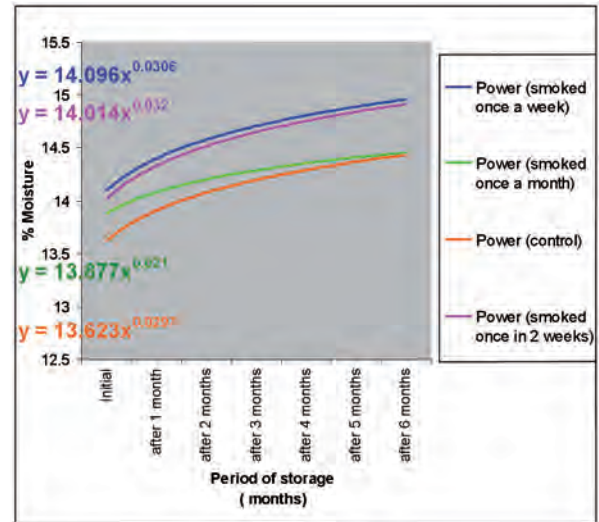


Figure 8: Change of moisture during storage period-Trend lines $y=A.x^n$

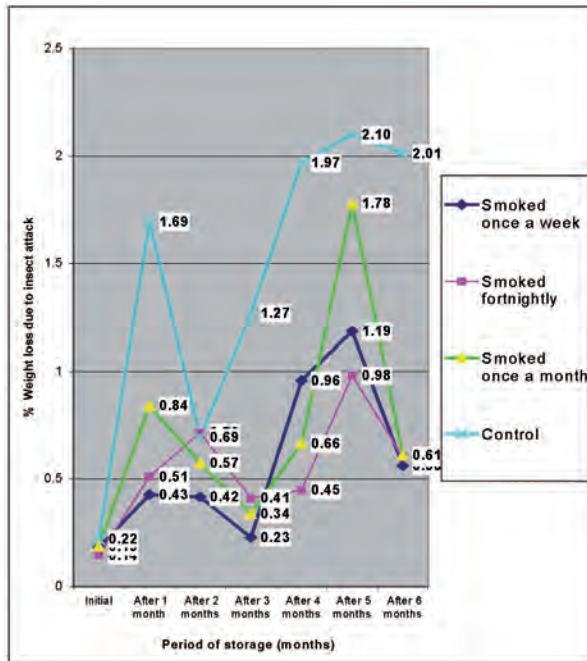


Figure 9: Weight loss due to insect attack

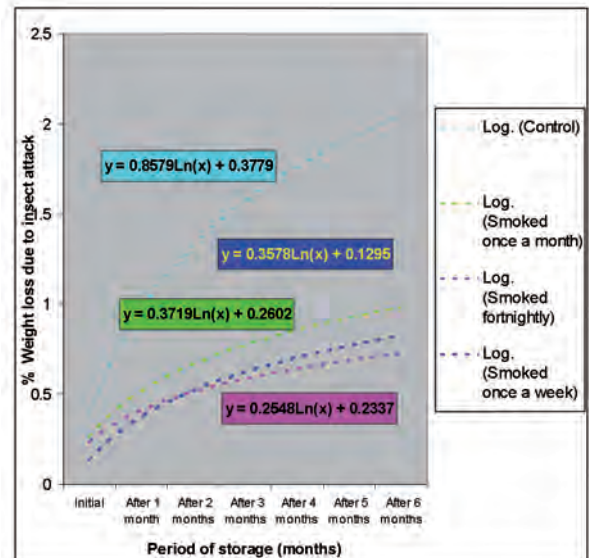


Figure 10: Weight loss due to insect attack- trend lines

Table 3: Variation in percentage of moisture during the storage period

	Initial	After 01 month	After 02 months	After 03 months	After 04 months	After 05 months	After 06 months
smoked once a week	13.9a	15.03a	14.4a	14.3a	14.83a	14.8a,b	15.2a
smoked once in 2 weeks	13.9a	14.8a	14.4a	14.1a,b	14.9a	14.87a	15.07a,b
smoked once a month	13.9a	14.37b	14.03a	13.73b	14.6a,b	14.23b	14.83b
control	13.9a	13.67c	13.97a	13.97a,b	14.27b	14.2b	14.93a,b

Means followed by the same letter in vertical columns do not differ significantly ($p \geq 0.05$) according to ANOVA procedure of SAS system. Means separated by Least Significant Difference (LSD)

Table 4: Percentage weight loss due to insect attack

	Smoked once a week	Smoked once in two weeks	Smoked once a month	Control- not smoked
Initial	0.18193371a	0.197978a	0.1858403a	0.18584a
After 01 month	0.42679884 b	0.509988b	0.840301b	1.694587a
After 2 months	0.41654032b	0.7153555b	0.5746099b	0.694282a
After 3 months	0.22737969b	0.410174b	0.3371726b	1.268497a
After 4 months	0.95787421b	0.4479087b	0.6645465b	1.968501a
After 5 months	1.18511924b	0.9802139b	1.7799654b	2.09934a
After 6 months	0.56110189b	0.60113b	0.609439b	2.012612a

Means followed by the same letter in horizontal rows do not differ significantly ($p \geq 0.05$) according to ANOVA of SAS system. Means separated by Least Significant Difference (LSD)

Insect pest control using the smoke generated from paddy husk combustion, has never been scientifically documented or recommended to use in Sri Lanka. The promising results obtained during this study, indicates the possibility of using it as an insect pest management strategy during freshly harvested paddy storage.

Considering all these, this novel technology of using smoke generated from paddy husk combustion for the control of insect pests during storage of freshly harvested paddy would play a remarkable role in the future.

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