Donahaye, E.J., Navarro, S. and Varnava, A. [Eds.] (1997) Proc. Int. Conf. Controlled Atmosphere and Fumigation in Stored Products, 21–26 April 1996, Printco Ltd., Nicosia, Cyprus, pp. 425–434

DEVELOPMENT OF A DECISION SUPPORT SYSTEM FOR THE FUMIGATION OF MILLED-RICE BAG-STACKS IN THE TROPICS

R.J. HODGES, M. SMITH, A. MADDEN,
D. RUSSELL, I. GUDRUPS[1] AND H. HALID[2]
[1]*Natural Resources Institute, Chatham Maritime, Kent, ME4 4TB, UK*
[2]*BULOG, Jl. Gatot Subroto 49, Jakarta, Indonesia*

ABSTRACT

A Fumigation Decision Support System (FDSS) is described that enables pest-control operatives in milled-rice bag-stores both to predict when future fumigations will be required and to determine whether previous fumigations were successful. The FDSS consists of an insect monitoring technique, an insect growth model and a pragmatic pest-control threshold. The last two elements are contained in a computer program. The growth model, which is central to the system, is specific to *Tribolium castaneum*, and it is valid only for use in the humid tropics.

The FDSS was tested in rice stores in Indonesia, and a logistic model of insect population growth was found to perform best. The predicted time to fumigation deviated on average by only about 1 week from the actual time to fumigation. The FDSS was also tested, after suitable training, by unsupervised pest- and quality-control staff, at two godown sites in Java, who found the system easy to use. Their performance was evaluated. The predictions were again reliable. The FDSS is now ready for operational use.

INTRODUCTION

Insect pest infestation of stored foods is a major problem faced by store managers in developing countries. To prevent insect damage's resulting in excessive loss of both food quantity and quality, stores are often fumigated and sprayed with insecticide. Long experience has shown that the application of such control measures is frequently poorly timed. Thus expensive pest-control procedures may be used when they are not necessary or even after the damage has already been done. In either case, losses are incurred. A further problem is that pest-control treatments may not be properly applied, making it necessary to repeat treatment sooner than planned.

Previously, no practical system had been developed to establish the optimal timing of pest-control operations in tropical stores. The research described in this report was undertaken to develop a practical package of measures, called the Fumigation Decision Support

System (FDSS), to enable pest-control operatives in milled-rice bag-stores in Indonesia to predict the ideal timing for the application of fumigation, according to their own criteria, and to determine whether or not the most recent fumigation treatment was successful.

The FDSS consists of a trapping method for monitoring the number of pests in milled-rice stores, a population growth model using the trap data to predict future insect numbers, and a pest-control threshold that, when reached, indicates the need for the application of pest control. The growth model and the pest-control threshold are included in a computer program designed to be used by pest-control staff. The program, written in Turbo Pascal, version 7.0, has screens in both English and Indonesian.

To validate the FDSS, two trials were undertaken. The first, a 2-month long 'experimental trial' in West Javanese stores, observed how well the predictions of the time needed to reach the fumigation threshold, made approximately 6 weeks after fumigation, matched the actual time to threshold. This was followed by an 'operational study' in West and Central Javanese storage sites designed both to investigate whether godown staff were able to use the FDSS and to provide further evidence of the reliability of the population-growth predictions.

DESCRIPTION OF THE FDSS

Insect trapping system

Insect populations in milled-rice stores were monitored using bait-bag traps, consisting of 10 × 20-cm plastic net bags with 19 2-mm apertures per cm^2, filled with 100 g of brown rice (Hodges *et al.*, 1985). These traps can give reliable estimates of the insect population present in bag-stacks of milled rice, and Haines *et al.* (1991) established a calibration curve enabling the catches in the traps to be converted into the more familiar units of spear sampling (numbers/kg). For the operation of the FDSS, only adult *Tribolium castaneum* (Herbst) caught in the traps are used for fumigation predictions. In Indonesia, *T. castaneum* is considered the best indicator of stack infestation because it is both the most common species and, almost invariably, the first to arrive after the initial fumigation of new stock. Other important pest species, such as *Sitophilus* sp. or *Rhyzopertha dominica,* may sometimes be found at the start of storage, but they do not generally become re-established if they are killed at the initial fumigation (Haines and Rees, 1988).

A minimum of 20 bait-bag samples from stacks in the range of 175–300 t is required in order to get a good prediction. The number of bait-bags may be reduced or increased pro-rata according to tonnage (Haines and Rees, 1988). Users of the FDSS are advised not to monitor on either very small stacks or fractions of remaining stacks.

The minimum insect catch needed to predict insect population growth with the FDSS is a mean of 1.0/bait-bag. If the mean value is below this, a further sample should be taken at a later date. Earlier experience indicated that after successful fumigations the population will not rise to this level until more than 9 weeks following the fumigation date. However, to allow for exceptionally rapid reinfestation and possible fumigation failures, a sample should be taken at around 6 weeks. If the insect catch is sufficiently large, it can be used, together with the period of time since the last fumigation, to predict when the pest-control threshold will be reached. This is the time at which another fumigation is recommended.

Insect growth model

Initially, a simple exponential curve was used to predict growth; however, following tests of the program, better results were found to be obtainable from a logistic growth curve. This was fitted to data obtained from trials in East Java (Hodges *et al.*, 1992) in which the development of *T. castaneum* populations was monitored in a total of 6 stores and 12 bag-stacks, using both bait-bag traps and spear sampling (Fig. 1). The logistic curve took the standard form:

$$N = \frac{im}{[i + (m - i)\, e^{-rt}]} \qquad (1)$$

where N is population at time t, i is the initial population (after fumigation), m is the maximum population the stack can support, e^r is the rate of population expansion and t is time in weeks since fumigation.

The growth model was applied with no attempt to correct for variations in grain temperature, moisture content (m.c.) or degree of rice milling. Conditions for all these variables were considered to be sufficiently constant to make such corrections unnecessary. The inside-store temperature close to the equator shows little annual variation. Both the m.c. and milling-degree ranges are subject to regulation; although variable, they are controlled within relatively narrow limits. Thus the FDSS is only valid for the lowland humid tropics where rice is stored in jute bags and is of quality similar to that used in the study (e.g. m.c. 13.0–14.5%, milling degree 85–90%, broken grains 25–30%).

The growth model also does not take into account insects that migrate into a store after fumigation. During the initial phase of reinfestation, the influx of insects is a major component of population growth. However, experience has shown that the number of insects migrating into the store soon becomes insignificant compared with that generated by a breeding population still existing in the rice.

Pest-control threshold

The pest-control threshold used in the program is pragmatic. It is important that pest control be implemented before the live insects in the stores and before both live and dead insects in the rice itself have had a serious detrimental effect on either the cleanliness of the store or the marketability of the rice. Therefore, it was decided to set a threshold ensuring that fumigation was undertaken well before the rate of population growth reached its maximum. Examination of the model showed that this occurred when there were around 150 insects per bait-bag. At 40 *T. castaneum* per bait-bag, population expansion is approximately half the maximum (Fig. 1). This level of infestation was selected as the most convenient pest-control threshold because it allows a reasonable

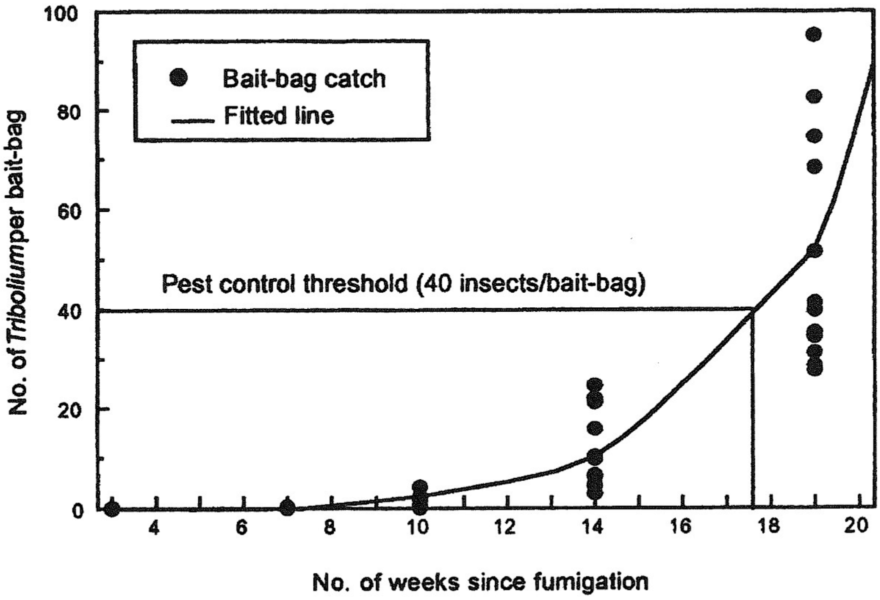

Fig. 1. The logistic growth curve fitted to trial data ($i = 0.03$, $m = 300$, $r = 0.42$).

lead-time to fumigation. The FDSS user can change this threshold to whatever level is convenient and/or appropriate to his system.

Such a threshold has a clear logical basis, but it does not address the issue of such cumulative effects of insect infestation as the contamination and weight loss that occur after successive fumigations. One potentially serious contaminant is quinone secretions from the thoracic and abdominal glands of adult *T. castaneum*. Quinones are mutagenic chemicals, and the possibility of their accumulation in milled rice was investigated; however, no significant build-up could be detected (Hodges *et al.*, 1996). The computer program enables store managers to predict what weight losses might occur in milled rice as a result of insect feeding in the period between the last fumigation and the recommended time of the next fumigation. These predictions are based on weight-loss estimates made by Halid (1988). However, no attempt has been made to compare the financial value of potential rice-weight losses to the cost of fumigation as a means of deciding whether or not pest control should be implemented. This is because high insect numbers will have become unacceptable before there are measurable weight losses. The facility for weight-loss calculation is, however, provided to demonstrate how small weight losses are when compared with the cost of fumigation and how relatively massive is rice contamination with insects and hence quality decline.

The pest-control recommendation

The program displays a table for each stack sampled stating in weeks the time between taking the insect sample and the next necessary fumigation. A recommendation, based on the stack with the greatest insect population, is then presented for the fumigation of the whole store. A graph can be displayed showing the predicted development of the insect population in each rice stack and the predicted growth for the entire store population, the mean of the sampled stacks.

Success or failure of last fumigation

Fumigation is considered successful if the average bait-bag count for a stack 6 weeks after the last fumigation is estimated to be equal to, or less than, two insects. If the population estimate was made more than 6 weeks after the last fumigation, it is compared with the predicted size of a population that, at 6 weeks, was two insects. This is derived from the recurrence relationship (Equation 2, legends as for Equation 1) based on the bait-bag population each week.

$$N_{t+1} = \frac{1}{\dfrac{300 - N_t}{300N_t \times 1.525} + \dfrac{1}{300}} \qquad (2)$$

The choice of an average of two insects/bait-bag is based on the results of trial work in East Java (Hodges *et al.*, 1992) where, after a good fumigation, less than one insect/bait-bag was observed 6 weeks after treatment. The somewhat higher figure of two insects/bait-bag has been adopted as the decision threshold in order to reduce any likelihood of claims that fumigations were failures when they may have been successful. The FDSS user can change the two insects/bait bag default value if this is required.

VALIDATION OF THE FDSS

Experimental trial

The trial was undertaken with 23 bag-stacks of milled rice, distributed among five stores at Cibitung in West Java. The stores had 3000 t capacity; 284–364 t bag stacks were constructed with 100-kg jute bags. The stocks in each store had been fumigated with methyl bromide about 6 weeks prior to the start of the test.

To obtain an initial measure of the insect population, 20 bait-bags were deployed for 1 week on each stack. Seven bags were placed on each long side and three bags on each short side. The bags were placed in suitable crevices in sacks between the third and seventh layer from the floor. To obtain final population estimates, bait-bag monitoring was repeated at a convenient time (around 2–4 weeks after sampling or 7–10 weeks after fumigation). This period was rather shorter than planned because the initial insect infestations were heavier than anticipated.

To test the growth model's ability to predict future fumigation requirements, the time between the initial fumigation and the second insect population assessment was taken as the actual fumigation interval. This was compared with the predicted fumigation interval obtained by entering the first population estimate in the FDSS and setting the pest-control threshold at the value of the second population estimate.

The accuracy of the model's predictions was first tested on the data from all 23 stacks. The stacks were then grouped according to whether their initial bait-bag values were relatively low (13–28 insects/bag) or high (35–57 insects/bag). The program was originally tested using three different exponential growth models and the logistic model mentioned above.

Depending on the growth rate and model, predictions of the fumigation interval had an absolute mean deviation varying from 1.5 to 0.7 weeks (Table 1). When the stacks with low initial bait-bag results are considered separately, there is a similar, but slightly narrower, range (1.1 to 0.8). Where initial bait-bag values are high, the deviation between the predicted and actual fumigation interval was considerably larger. As FDSS predictions will normally be based only on low bait-bag values, the most interesting tests were those carried out on the stacks with low initial values. Here, the exponential ($r = 0.39$) and the logistic growth models, with 33% of the predictions completely accurate, performed better than did the alternative models. However, the absolute mean deviation for the logistic model was smaller (0.8 compared to 1.1 weeks), making it the preferred choice for use in the model; the exponential model ($r = 0.39$) would also be expected to perform well.

This trial was not an ideal test of the program because the insect population in the stacks just 6 weeks after fumigation was much greater than would normally be expected,

TABLE 1

Comparison of actual and predicted fumigation intervals for stacks in the experimental trial

	T. castaneum growth model			
	Exponential			Logistic
Models	$r = 0.48$	$r = 0.40$	$r = 0.39$	$r = 0.42$
Absolute mean deviation (weeks)				
All initial bait-bag values	1.5	1.0	0.9	0.9
Low initial bait-bag values (13–28)	1.0	1.0	1.1	0.8
High initial bait-bag values (35–37)	1.8	1.7	0.7	1.2
Late, early and accurate predictions (%)				
All bait-bag values				
Late	5	17	22	5
Early	87	78	43	69
Accurate	8	5	35	26
Low bait-bag values				
Late	11	44	55	12
Early	67	44	12	55
Accurate	22	12	33	33
High bait-bag values				
Late	0	0	0	0
Early	100	100	64	79
Accurate	0	0	36	21

indicating that the initial fumigations were failures. Consequently, the predictions were based on relatively high bait-bag values, the lowest being 13–28 insects/bag instead of the 1–2 insects/bag required for a good advance warning of the need for fumigation. However, the trial has shown that, at least over short time-spans, the system can predict the rate of insect growth with a useful degree of accuracy.

Operational study

The trial was undertaken at two godown complexes, one in Central Java (Semarang) and the other in West Java (Bandung), using the FDSS with logistic growth model. Both complexes had small-scale laboratory facilities. The trial used four godowns at Semarang and two at Bandung, each containing 284–364 t bag-stacks built with 100-kg bags of milled rice in jute sacks. Four Pest and Quality Control (PQC) staff at each site were given 2 d training in the use of the bait-bag insect monitoring technique, the FDSS and the computer.

Not more than six stacks were monitored in any godown. These were chosen to be as far apart as possible. This is because two or three stacks are confined under the same gastight sheets at the time of fumigation, and such stacks represent a single fumigation that will have either succeeded or failed. Choosing stacks as far apart as possible meant that a greater number of these groups was sampled. Twenty bait-bags were placed on each stack being monitored, seven on the long sides and three on the short sides.

PQC staff began the insect monitoring 6 weeks after the initial fumigation. At Bandung, two population estimates of the same stacks were made, the second 2 or 3 weeks after the first, to confirm the reliability of the initial estimate. Owing to a general shortage of stock, the study was confined to only one fumigation period; thereafter, stocks moved too quickly to warrant pest control. The performance of the pest-control staff was evaluated at the middle and end of the study period.

Staff at both Semarang and Bandung were receptive to training and, by the time the 2-d course had ended, showed competence in using both the computer program and the bait-bag monitoring system. Although initial insect numbers recorded at Semarang were so high, due to earlier fumigation failure, that they could not be counted in full, the staff reported no difficulties in actually using the technique. At Bandung, insect numbers at the first estimate were within the 'normal' post-fumigation range. The second population estimate at Bandung, 2 or 3 weeks after the first, deviated by only 14 and 17% from the values predicted by the first estimate in the two godowns (Table 2); this means that the fumigation interval predicted from the two estimates differed by less than 1 week.

CONCLUSIONS

The FDSS can be used to give reasonably accurate predictions of the optimum timing for future fumigation in milled-rice bag-stores as well as to indicate failures in earlier fumigations. Although the system has the advantage of being simple and effective, it is limited because it is currently configured only for use in stores using jute bags in the humid lowland

TABLE 2

FDSS predictions of *T. castaneum* and population growth and fumigation intervals for two godowns in Bandung

Godown 4	Week 6	Week 8			Predicted fumigation intervals		
Stack no.	Mean no./ bait-bag	Mean no./ bait-bag	Predicted no./ bait-bag*	% deviation actual–predicted no./bait bag	Week 6	Week 8	Difference
1	2.0	8.3	4.7	−43	13	10	−3
2	2.6	6.7	6.0	−10	12	12	0
3	3.0	7.4	7.1	−14	12	12	0
4	2.7	6.7	6.2	−7	12	12	0
5	3.1	7.6	7.1	−6	12	12	0
6	2.5	4.6	5.7	+23	12	13	+1
		Absolute mean deviation 17%			Absolute mean deviation 0.66 weeks		
Godown 3	Week 7	Week 11			Predicted fumigation intervals		
Stack no.	Mean no./ bait-bag	Mean no./ bait-bag	Predicted no./ bait-bag*	% deviation actual–predicted no./bait bag	Week 7	Week 11	Difference
1	4.0	23.5	20.7	−12	12	12	0
2	3.2	15.3	16.3	+6	13	13	0
3	4.8	26.4	24.0	−9	12	12	0
4	3.3	25.6	17.0	−33	12	12	0
5	3.3	16.1	17.0	−6	12	13	+1
6	3.4	14.8	17.5	+18	12	13	+1
		Absolute mean deviation 14%			Absolute mean deviation 0.33 weeks		

*Calculated from first population estimate using growth model.

tropics. In addition, the rice stored must be what is generally regarded as medium grade (m.c. of 13.0–14.5%, 20–35% broken grains and a milling degree of 85–90%). Use of the FDSS under other conditions will require both confirmation of the population growth rate and, if polypropylene bags are used instead of jute bags, confirmation of the relationship between bait-bag catch and the numbers of insects actually present in the rice.

The FDSS uses a simple pragmatic pest-control threshold, easily understood by pest-control operatives, which can be altered to suit local conditions if necessary. Economic aspects are touched on by mentioning actual rice weight losses associated with the predicted insect population, but this is included largely as a matter of information in order to demonstrate that weight losses are small in relation to the costs of pest control, whereas both store and rice insect-contamination is relatively massive. One aspect of the cumulative effects of insect infestation, the accumulation of quinones, has been investigated and found to be insignificant (Hodges *et al.*, 1996). However, a further aspect, the actual accumulation of dead bodies, remains an area for further study. Very few, if any, rice-storage systems in the tropics pay attention to the numbers of dead bodies present in marketed rice even if in theory a threshold does exist. If further versions of the FDSS could be made to take this factor into account, however, it would increase awareness of quality deterioration and, even if the facility was not used immediately for storage operations, it might have an important training function. To take dead-body accumulation into account would require knowing how long a stock would remain in store, the current dead-body contamination rate, the rate at which stocks become reinfested after fumigation and the rate at which dead bodies disintegrate and become, in effect, undetectable. The FDSS could be modified to accept these data and recalculate the pest-control threshold to ensure that dead-body contamination would be below critical level at the stacks' expected discharge time.

The FDSS is one of a very few decision support systems available for use in tropical stores. Another is Ceranyl, developed in West Africa by the German aid agency (GTZ), which assesses the quality of stocks destined for national food security programmes and advises on storage potential. Most other systems are relatively large and complex 'grain store advisors', used principally for training purposes (Wilkin and Mumford, 1994). The FDSS is not currently in operational use although it is being considered in Indonesia. As part of a training 'workbench' developed by the Australian Centre for International Agricultural Research (ACIAR) and the Indonesian National Logistics Agency (BULOG), the system is being prepared in WINDOWS® format with the intention of making it available as both a training tool and an operational system. Copies of the TurboPascal version of the FDSS can be obtained on request from the Food Security Department of the Natural Resources Institute.

REFERENCES

Haines, C.P. and Rees, D.P. (1988). *Monitoring of Insect Pests in Milled Rice Stores by the Use of Brown-Rice Bait Bags: Final Report on a Calibration Trial with BULOG, Indonesia.* Project A1457. NRI Report R1539. 74 pp.

Haines, C.P., Rees, D.P., Ryder, K., Sistyanto, S. and Cahyana, Y. (1991). Brown-rice bait bags for monitoring insect pest populations in bag stacks of milled rice as an aid to pest control decision-making. In: *Proc. 5th Int. Working Conf. on Stored-Product Protection* (Edited by Fleurat-Lessard, F. and Ducom, P.), Bordeaux, France, 9–14 September 1990, **2,** 1351–1358.

Halid, H. (1988) Interactions between stored products insects in relation to their management in Indonesian milled rice. PhD Thesis, University of London (Imperial College). 211 pp.

Hodges, R.J., Halid, H., Rees, D.P., Meik, J. and Sarjono, J. (1985) Insect traps tested as an aid to pest management in milled rice stores. *J. Stored Prod. Res.* **21** (4), 215–229.

Hodges, R.J., Robinson, R. and Hall, D.R. (1996) Quinone contamination of dehusked rice by *Tribolium castaneum* (Herbst) (Coleoptera:Tenebrionidae). *J. Stored Prod. Res.* **32,** 31–37.

Hodges, R.J., Sidik, M., Halid, H. and Conway, J.A. (1992). Cost efficiency of respraying store surfaces with insecticide to protect bagged milled rice from insect attack. *Tropical Pest Man.* **38** (4), 391–397.

Wilkin, R. and Mumford, J. (1994). Decision support systems for integrated management of stored commodities. In: *Proc. 6th Int. Working Conf. on Stored-Product Protection* (Edited by Highley, E., Wright, E.J., Banks, H.J. and Champ, B.R.), Canberra, Australia, 17–23 April 1994, CAB International, Wallingford, Oxon, UK, **2,** 879–883.